MODERN REFRACTORY PRACTICE

Modern Refractory Practice: 3rd Edition (1950)
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625 MARKET STREET
SAN FRANCISCO 5, CALIF.

GENERAL OFFICES
PITTSBURGH, PA.

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MODERN REFRACTORY PRACTICE



THIRD EDITION

WITH SPECIAL REFERENCE TO THE PRODUCTS OF

HARBISON-WALKER REFRACTORIES COMPANY

PITTSBURGH, PENNSYLVANIA

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ACKNOWLEDGMENTS

In this, the third edition of Modern Refractory Practice, the text has been completely rewritten, and much new material has been added. In its preparation, special effort has been made to include such engineering and technological data as will be most useful to those interested in refractories and their applications.

Many individuals — both members and friends of the Harbison-Walker organization — have helped in the preparation of this volume, with information, advice and constructive criticism of manuscript and drawings. Without such assistance and cooperation much of the material given herein could not have been presented. To all those who have helped, we are most grateful.

Much of the credit for the development of Modern Refractory Practice through the three editions of 1929, 1937 and 1950 is due to two members of the Harbison-Walker organization — J. Spotts McDowell and W. F. Rochow. For all editions, Mr. McDowell has been the editor and has written the larger portion of the text, and Mr. Rochow has supplied most of the information and background experience for that part of the text dealing with the applications of refractories.

Harbison-Walker Refractories Company

E. A. Barber

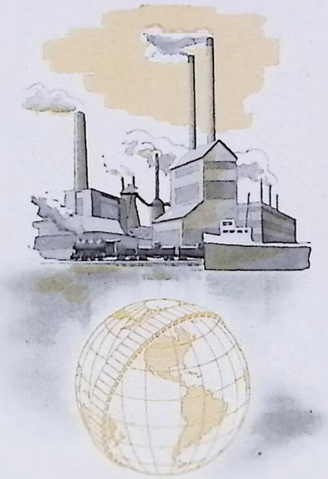
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RESEARCH *Pittsburgh, Pennsylvania* CONTROL *Various Works*

PRODUCTS

FIRECLAY REFRACTORIES	BASIC REFRACTORIES	ELECTRICAL PORCELAIN
HIGH-ALUMINA REFRACTORIES	INSULATING FIRE BRICK	KILN FURNITURE
SILICA REFRACTORIES	ACID-PROOF BRICK	POROUS REFRACTORIES

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F O R E W O R D

IN 1865, with the construction of a small plant in Pittsburgh for the manufacture of fireclay refractories, there came into being an organization which ultimately developed into the Harbison-Walker Refractories Company. Those responsible for the early growth of the organization set about building a reputation for integrity, quality of product and service to the user. Not only did they maintain high standards of quality and workmanship, but they constantly endeavored to improve those standards, to develop types of refractories better adapted to service conditions, and to anticipate future needs by acquiring extensive reserves of raw materials.

The policies responsible for the early growth of Harbison-Walker still govern its organization. A continuous program of prospecting insures the development and maintenance of reserves of raw materials of the highest quality. An extensive program of construction and modernization has provided facilities for the production of refractories of many kinds and in any quantity, in model manufacturing units. In the processes of manufacture the company has taken prompt advantage of improvements in machine design and production methods, and has itself initiated many advances in the art. An adequate staff of testing engineers and supervisors

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maintains standards of quality at every step in the manufacture, from the time the raw material leaves the mine or quarry until the finished product is shipped. An alert research organization constantly strives to improve existing refractories, and to develop modifications or new types to meet the ever changing demands of industry.

The facilities of the company and its subsidiaries include mining and manufacturing operations in fourteen states, covering all of the principal producing districts. The manufacturing plants are most advantageously situated with respect to the transportation of both raw materials and finished products.

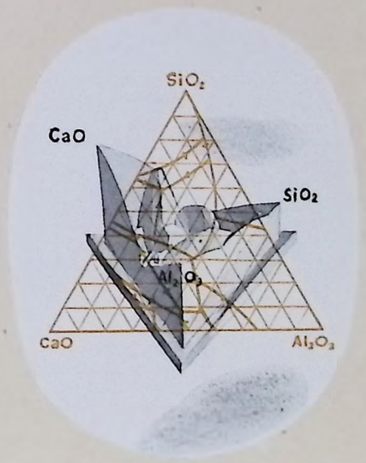
Service has been an important factor in the steady growth of Harbison-Walker. It takes many consumers to absorb the company's output. The needs of every user of refractories are given the same careful attention, whether the requirements are large or small. To assist in the solution of problems connected with the use of refractories, Harbison-Walker's engineering and technical staffs and research facilities are at the service of all clients.

To summarize: extensive reserves of raw materials which insure uniformity of quality far into the future years, products of highest quality, technical assistance that is helpful in the selection of refractories, equal service to all — these are the reasons for the steady growth of Harbison-Walker. They are likewise the basis on which the world's largest producer of refractories solicits your patronage.

HARBISON-WALKER REFRACTORIES COMPANY

HARBISON-WALKER

RESEARCH



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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HARBISON-WALKER

RESEARCH

THE importance of experimentation in the development of refractories and of control testing in their manufacture was early recognized by the founders of Harbison-Walker. The thousands of chemical analyses recorded between 1877 and 1910 give evidence of the great interest taken in chemical composition. The first recorded analysis of STAR silica brick, dated June 18, 1888, showed 1.87 per cent lime, which differs very little from the amount used in STAR today.

It soon became clear that the heat-resisting quality of a refractory could not be estimated from its chemical analysis alone. Therefore in 1890 Harbison and Walker, as the firm was then known, developed a high-temperature reheat test to determine the ability of brick to withstand extremely high temperatures. The test was used to evaluate raw materials and to control the quality of finished products.

During the closing years of the nineteenth century and the early years of the twentieth, many hundreds of experimental mixes were made and tested for the purpose of developing and improving products.

In 1909, a central laboratory for research and control was built at Hays, Pennsylvania. The history of the Research Department since then has been one of steady and continuing growth. The central laboratory has become one of the most completely equipped laboratories in the world for testing and research in refractories. The equipment includes a wide variety of instruments and furnaces which are continually supplemented by improved apparatus as ceramic science and art progress. Everything in the field of refractories is of interest to Harbison-Walker. Its research staff is alert to anticipate the needs of industry for new and improved refractories with specialized combinations of properties.

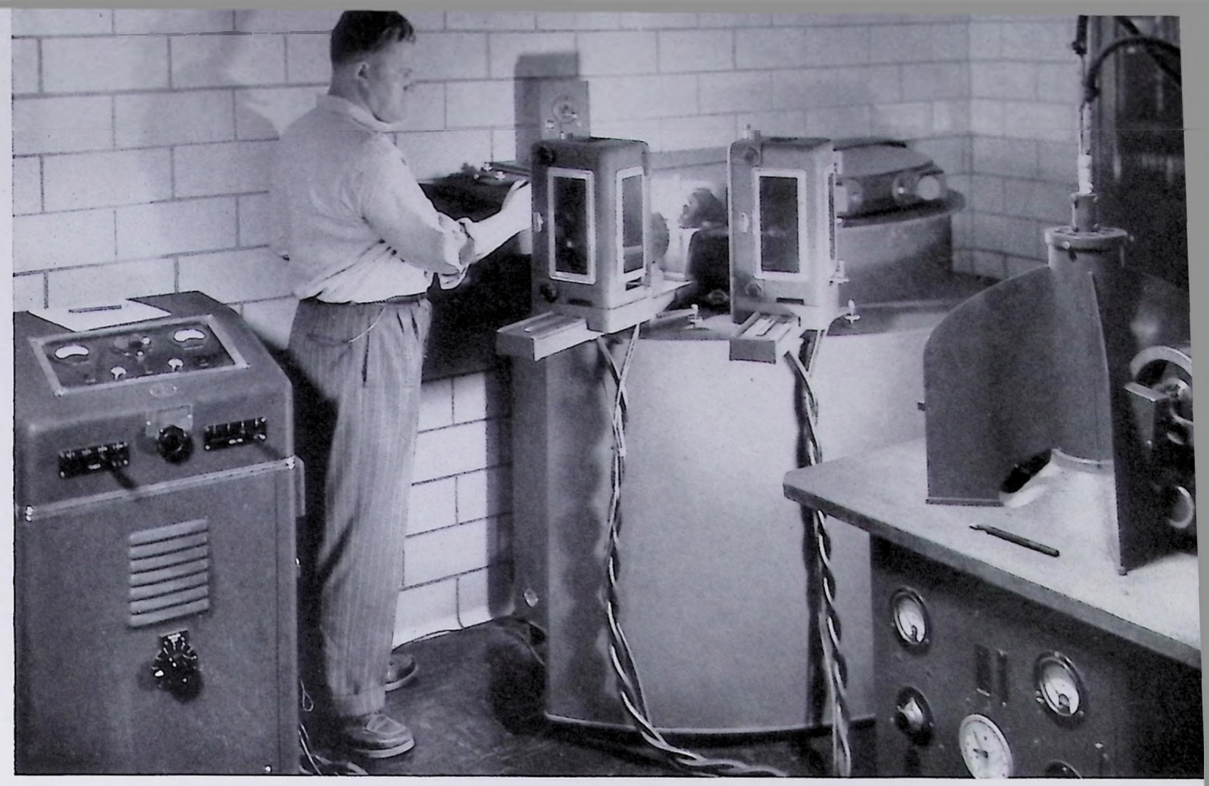
A modern chemical laboratory, X-ray diffraction and thermal analysis equipment, and binocular and polarizing microscopes serve for the study of the chemical composition and mineral constitution of raw materials, of finished products, and of refractories which have been in service. The latest addition to the laboratory was erected for the housing of new facilities, including complete equipment for spectrographic analysis. This equipment has uses both for research and for control of quality.

Research in refractories includes problems of many types. Beneficiation of raw materials

← *Forming of Experimental Brick by Hydraulic Pressing in Pilot Plant, at Hays Laboratory*

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View Showing Spectroscope and X-Ray Equipment

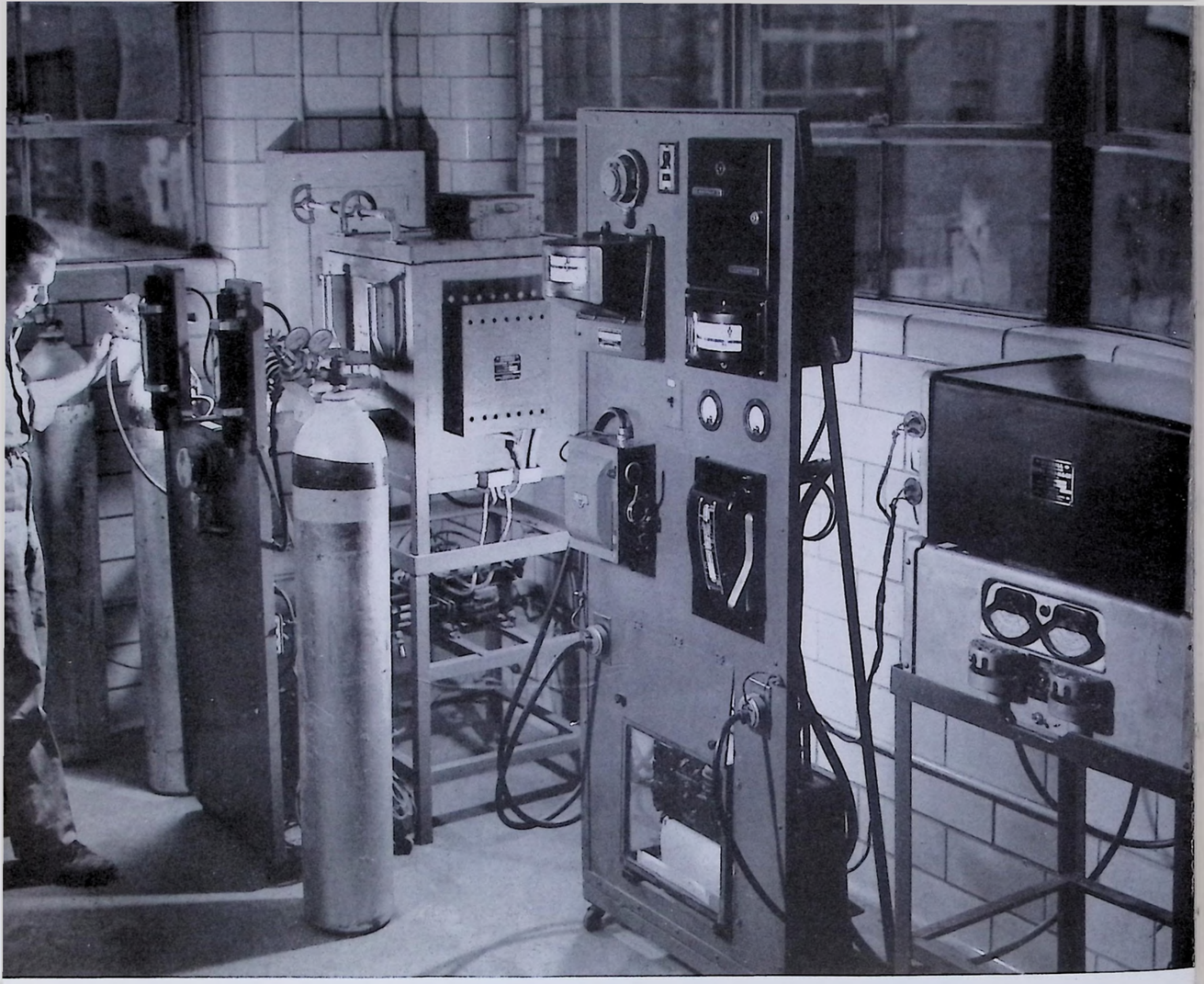
Crushing Flint Fire Clay, Preliminary to Further Processing in Pilot Plant, at Hays Laboratory

is often necessary, and will become more important in the future. The laboratory is therefore provided with complete ore dressing equipment suitable for studies on either a small scale or on a pilot plant scale. Study of the processes of manufacture of refractories will continue to occupy a prominent place in the research program, since the physical properties, workmanship and cost of refractories are dependent to a large degree upon the methods used in their manufacture. The laboratory contains a complete pilot plant for the manufacture of experimental refractories in the form of brick and in other forms. The facilities include equipment for crushing, grinding, blending and mixing the raw materials, and for the preparation of test brick both by experimental methods and by processes that are used commercially.

Each raw material used in the company's plants and each product in regular manufacture is the subject of a program of control testing to maintain its quality. Well equipped laboratories for this purpose are maintained in each producing district at points of easy access to the various mining operations and manufacturing plants. The tests conducted in these laboratories furnish quick results to the mine and plant operators, as a check both on the raw materials and the manufacturing procedures. This program of control locally is supplemented by a more complete program at the central laboratory, where samples of all products made by the company are tested periodically. In addition to the equipment provided for making standard or routine tests, facilities are available for making many special tests, such as thermal expansion of refractories, their permeability, and the effects of carbon monoxide and other gases upon them.

The Harbison-Walker Research Department is staffed by research engineers and scientists trained in ceramic and chemical engineering,

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Partial View of Electric Furnace Room, at Hays Research Laboratory

in physics, chemistry, physical chemistry, mineralogy, petrography and ore dressing. The department has cooperated actively with Committee C8 of the American Society for Testing Materials in the development of tests for evaluating the properties of refractories. The new and improved products that have been introduced by Harbison-Walker and the numerous contributions to the technical literature by members of its staff are evidences of the activities of the department.

Industrial processes are continually changing, operating temperatures of furnaces always tend to become higher, and the conditions to which refractories are exposed are becoming increasingly severe. The Harbison-Walker research staff is ever on the alert for scientific advances which may point the way to new and improved refractory products. The company today supplies products which are superior to those available even a decade ago, and the diligence of research can be depended upon to provide refractories suitable for the more exacting requirements of the future.

INDUSTRIAL REFRACTORIES



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INDUSTRIAL REFRACTORIES

Refractories of many kinds find industrial application. However, those of greatest commercial importance can be classified on the basis of composition or properties into a few main groups. These are known as alumina-silica, silica, basic and insulating refractories. In each of these groups there are a number of classes. In addition, there are various special refractories, including silicon carbide, carbon, zircon, zirconia, and several others.

Alumina-silica refractories have two main divisions: fireclay and high-alumina. The alumina content of the former covers the range from 47.5% down to about 18%, and the silica content from 50% up to 80%. More fireclay refractories are used than all others combined. The alumina content of high-alumina refractories ranges from about 99% down to 47.5%, and the silica content from about 0.5% to 50%.

Silica refractories of the different classes contain 94% to 97% silica, with an alumina content ranging from 2.5% down to about 0.25%. Basic refractories include magnesite, chrome spinel, other refractory spinels, and forsterite.

Refractory materials are supplied mainly as pre-formed shapes. Other products include dead-burned grain magnesite, crude and calcined fire clays, ground silica ganister, bonding mortars and high temperature cements, ramming mixtures, plastic fire brick, and castables.

FIRECLAY REFRACTORIES

Fire Clay: The essential components of fire clay are hydrated aluminum silicates. The general type formula is $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, corresponding to 39.5% alumina, 46.5% silica, and 14.0% water. Kaolinite is the most common member of this group. At high temperatures the water is driven off, and the resulting product theoretically consists of 45.9% alumina, 54.1% silica. However, even the purest of clays as mined contain small amounts of other constituents such as compounds of iron, calcium, magnesium, titanium, sodium, potassium, and lithium, and usually some free silica.

The clays of greatest importance as refractories are flint and semi-flint fire clays, semi-plastic and plastic fire clays, and kaolins.

Flint clays, known also as hard clays, are hard, dense, and resistant to weathering. Most of such clays break with a conchoidal or shell-like fracture. Their plasticities and drying shrinkages, after they have been ground and mixed with water, are very low; their firing shrinkages are moderately high and somewhat variable. The best clays of this type are low in impurities and are highly refractory, having a Pyrometric Cone Equivalent (P.C.E.) of Cone 33 to 34-35. Deposits of flint and semi-flint clays occur in rather limited areas in Pennsylvania, Maryland, Kentucky, Ohio, Missouri, and several other states.

Semi-plastic and plastic refractory clays, often called "soft clays", vary considerably in refractoriness, plasticity and bonding strength. Drying and firing shrinkages are usually fairly high. The P.C.E. of clays of this type ranges from Cone 30 to Cone 33 for the most refractory varieties, and from Cone 26 to Cone 30 for many clays of high plasticity and excellent bonding power. Certain clays with a P.C.E. which is even lower are widely used for special purposes. Important deposits of semi-plastic and plastic refractory clays occur in Pennsylvania, Ohio, Kentucky, West Virginia, Maryland, Alabama, and in various other states.

CHARACTERISTIC PROPERTIES OF REFRACTORY BRICK

Type	Class	Characteristics
High-Alumina	99% Alumina 90% Alumina 80% Alumina 70% Alumina 60% Alumina 50% Alumina	High refractoriness, which increases with increasing alumina content. High mechanical strength at high temperatures. Excellent to fair resistance to spalling. Greater resistance than fireclay brick to corrosion by most basic slags and fluxes.
Fireclay	Super-Duty	Stability of volume and high mechanical strength at high temperatures. Excellent resistance to thermal spalling. Fair resistance to highly acid slags; lower resistance to basic slags.
Fireclay	High Duty Intermediate Duty Low Duty	The chemical and physical properties of fire clays vary between wide limits; hence, fireclay brick with widely varying combinations of properties are available. This fact accounts for their suitability for service under widely different operating conditions. Most fireclay brick have relatively good spalling resistance and thermal insulation value. Fair resistance to acid slags and fluxes, lower resistance to basic slags and fluxes.
Silica	Super-Duty Conventional	High refractoriness and resistance to abrasion. High mechanical strength at high temperatures. Thermal conductivity at high temperatures about 25% greater than that of fireclay brick. High resistance to corrosion by acid slags. Fair resistance to attack by oxides of lime, magnesia and iron. Readily attacked by basic slags and fluorine. Not subject to thermal spalling at temperatures above 1200° F.; poor resistance to thermal spalling at low temperatures.
Magnesite	Fired 85–90% Magnesia More than 90% Magnesia Chemically Bonded, Metal Encased	Extremely high refractoriness and high thermal conductivity. Great resistance to corrosion by basic slags; poor resistance to slags containing high percentages of silica. The chemically bonded and metal encased brick have marked resistance to spalling.*
Chrome	Fired	High resistance to corrosion by basic and moderately acid slags and fluxes. In general, basic slags do not adhere to chrome brick. Under certain unusual conditions, iron oxide is absorbed and causes a damaging expansion. Thermal conductivity lower than that of magnesite brick but higher than that of fireclay brick.
Magnesite-Chrome	Chemically Bonded Chemically Bonded, Metal Encased Fired	Mechanical strength and stability of volume at high temperatures. Excellent resistance to spalling.* High resistance to corrosion by basic slags.
Chrome-Magnesite	Chemically Bonded Fired	Mechanical strength and stability of volume at high temperatures. Excellent to good resistance to spalling.* High resistance to corrosion by basic slags.
Forsterite	Fired	High refractoriness. Excellent strength at high temperatures. Marked resistance to corrosion by alkali compounds. Fair resistance to most basic slags; attacked by acid slags.

* See last paragraph on page 329.

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Pure kaolins are usually moderately plastic and have extremely high drying and firing shrinkages; siliceous kaolins have much lower shrinkages. The most refractory kaolins have a P.C.E. of Cone 33 to 35; less pure varieties with a P.C.E. of Cone 28 to 32 are fairly common. Among the largest deposits of refractory kaolin are those which occur in Georgia.

Fireclay Refractories: Fireclay brick are sometimes made of a single clay, but more commonly of a blend of clays. Flint clays and high-grade kaolins impart high refractoriness; plastic clays facilitate forming and impart bonding strength; calcined clays are used to control the drying and firing shrinkages. The relative proportions of these in a blend will depend upon the character and quality of the ware to be made.

Fireclay brick are fired either in periodic kilns or in continuous tunnel kilns at temperatures which are dependent upon the maturing temperatures of the clays used, upon the class of refractories being produced, and often upon particular properties desired. Four classes of fireclay brick are produced, known as super-duty, high duty, intermediate duty and low duty. The raw material used in the manufacture of super-duty and high duty brick consists predominantly of flint clay or kaolin; that for intermediate and low duty brick consists largely of semi-plastic or plastic clay.

Various special clays, both raw and calcined, find widespread industrial application as refractories. Ground refractory clays serve as mortar materials for laying refractory brick.

HIGH-ALUMINA REFRACTORIES

Refractory products which belong to the alumina-silica group of refractories, and which contain 47.5% alumina or more, are known as "high-alumina" refractories. The materials used in their manufacture include the following:

Diaspore ($Al_2O_3 \cdot H_2O$). Gibbsite ($Al_2O_3 \cdot 3H_2O$).
Bauxite (Probably $Al_2O_3 \cdot H_2O + Al_2O_3 \cdot 3H_2O$).
Diaspore Clay (Diaspore crystals or nodules in a groundmass of refractory fireclay).
Andalusite ($Al_2O_3 \cdot SiO_2$). Kyanite ($Al_2O_3 \cdot SiO_2$).
Sillimanite ($Al_2O_3 \cdot SiO_2$).
Fused Alumina (Al_2O_3).

Most high-alumina refractories are made from diaspore clay, either alone or blended with flint or plastic clay according to the properties and alumina content desired in the finished product. On account of the high firing shrinkage of diaspore clay, a large proportion is pre-calcined before being used in the manufacture of refractory ware.

Various grades of high-alumina brick are available, containing approximately 50, 60, 70, 80, 90 and 99% alumina. Brick made essentially from diaspore clay are available in the 50, 60 and 70% alumina classes.

SILICA REFRACTORIES

The raw material most widely used for the manufacture of silica refractories is a hard, dense, fine-grained quartzite rock, commonly known as ganister. The deposits of greatest commercial importance occur in the Tuscarora formation of Pennsylvania, the Baraboo formation of Wisconsin, and the Weisner formation of Alabama. Rock from the Sharon Conglomerate formation in eastern Ohio is used in several plants for making silica brick. Quartzite for the manufacture of refractories is quarried in several other states, including North Dakota, Montana, Colorado, Utah and California.

Relatively small quantities of silica brick are made from hard, fine-grained sandstone — notably Homewood Sandstone from restricted areas in Pennsylvania, where the rock is of a sufficient degree of purity. The product is known as "sand-rock" silica brick.

Silica brick are bonded by firing in periodic or in continuous tunnel kilns. The firing not only makes the brick strong and hard, but also causes the mineral quartz of the quartzite rock to transform into other minerals which are stable at the high temperatures of furnace operation. The transformation is accompanied by an appreciable increase in volume. Larger quantities of silica brick are used than of any other type of refractory except fireclay.

Ground silica ganister is extensively used for the construction of the hearths or bottoms of certain types of furnaces.

Three types of silica brick are available:

(1) "Super-duty" brick, containing not more than 0.50% alumina, titania and alkalies.
(2) Brick of the conventional type, containing a total of about 0.8% to 1.4% alumina, titania and alkalies.
(3) "Sand-rock" brick, containing about 1.4% to 2.5% alumina, titania and alkalies, and fired at a somewhat lower temperature than the other types of silica brick.

BASIC REFRACTORIES

Until recent years, a relatively sharp distinction was made between basic and neutral refractories. On account of their chemical characteristics, magnesite refractories were classified as basic and chrome refractories as neutral. However, as a result of the development and increasing application of refractory compositions containing both magnesite and chrome ore, a precise distinction between the two can no longer be made and the term "neutral refractories" has fallen into disuse. The classification "basic refractories" as now used is understood to include magnesite, chrome spinel, other refractory spinels, and forsterite.

MAGNESITE REFRACTORIES

Refractories composed mainly of magnesia are known commercially as "magnesite" products. This name is carried over from the period during which such products were derived entirely from naturally occurring magnesite. This raw material is a rock composed essentially of the mineral also called magnesite, which in theoretical purity would contain 47.6% magnesia and 52.4% carbon dioxide. An important proportion of magnesite refractories is now made from magnesia produced from magnesium hydroxide, which theoretically consists of 69.0% magnesia, 31.0% water.

Natural magnesium hydroxide occurs in the form of the mineral brucite. Deposits of commercial size are rare, consequently this mineral has been used only to a limited extent in the manufacture of refractories. Within recent years, magnesium hydroxide prepared chemically has come to be used commercially in relatively large quantities. It is produced by precipitation from natural magnesium-bearing solutions, such as sea water or brine from wells. The precipitating agent is calcium hydroxide; it is added in the form of slaked high-calcium lime or of slaked calcined dolomite.

The largest magnesite operations in the United States are those of the Northwest Magnesite Company, which utilizes natural magnesite in the plant near Chewelah, Washington, and chemically prepared magnesium hydroxide, recovered from sea water and calcined dolomite,

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in the plant located at Cape May, New Jersey.

An essential step in the manufacture of magnesite refractories is the dead-burning of the crude material. This process consists of heating the raw rock or the magnesium hydroxide in a rotary kiln to a temperature sufficiently high not only to drive off the carbon dioxide or the water of combination, but also to form a dense sintered product. In this product the magnesia is in such condition that its tendency to combine chemically at ordinary temperatures with the moisture or carbon dioxide of the atmosphere is practically negligible. Sometimes a small percentage of iron oxide or of iron pyrite is added to the charge fed to the rotary kiln to promote sintering.

Dead-burned magnesite as ordinarily produced consists of rounded agglomerates varying greatly in size. For commercial use, it is either crushed or ground and is marketed under the trade classifications of "dead-burned grain magnesite", and "fine-ground furnace magnesite". Carefully controlled sizings of this type, with added air-setting bonding agents, are now widely used for rammed hearths.

Brick made from dead-burned magnesite are known as "magnesite brick". They are usually bonded by firing, and are supplied in two major modifications, one containing about 85% to 90% magnesia with 2% to 4% iron oxide, and the other containing more than 90% magnesia, with 0.5% to 3% iron oxide.

CHROME REFRACTORIES

The raw material used in the manufacture of chrome brick is an ore consisting mainly of chrome spinel. Practically all of the chrome brick made in the United States have been manufactured from imported ores. The greater part of the ore is now imported from the Philippine Islands and from Cuba.

Refractory chrome ores are composed of about 30% to 50% chromic oxide (Cr_2O_3), 12% to 16% ferrous oxide (FeO), 14% to 20% magnesia (MgO), 13% to 30% alumina (Al_2O_3), 3% to 6% silica (SiO_2) and up to 1% lime (CaO). The Philippine and Cuban chrome ores are noted for their high contents of alumina.

In ores used as refractories the sum of the chromic oxide (Cr_2O_3) and alumina (Al_2O_3) in general is not less than 60%. Some of the ores of highest quality contain only 32% to 35% Cr_2O_3, with 28% to 30% Al_2O_3; other excellent ores contain 42% Cr_2O_3 or more, with correspondingly lower amounts of Al_2O_3. Silica in minor quantities functions as a bond.

The term "chrome brick" refers to refractory ware made essentially from chrome ore without the addition of magnesia, and bonded by firing at a relatively high temperature.

MAGNESITE-CHROME AND CHROME-MAGNESITE REFRACTORIES

Within recent years there has been a great increase in the use of basic brick containing both dead-burned magnesite and chrome ore. Compositions in which the amount of magnesite exceeds the amount of chrome ore are called "magnesite-chrome"; those in which the amount of chrome ore predominates are termed "chrome-magnesite".

A large proportion of these brick is bonded chemically, with omission of the firing procedure. In service, the portions of chemically bonded brick exposed to high temperatures undergo the same changes as those which would have occurred in firing. The omission of firing is possible because properly chosen combinations of chrome ore and dead-burned magnesite, formed into brick at high pressures with the addition of chemical bonding agents, become strong and hard, and undergo only negligible permanent volume change when subjected to high temperatures. In service under the influence of heat, the brick lose the chemical bond while an adequate ceramic bond is developed through the sintering together of adjoining particles.

Chrome-magnesite and magnesite-chrome brick of special compositions are bonded by firing at very high temperatures, approximately 3000° Fahrenheit.

The characteristics of magnesite-chrome and chrome-magnesite brick which have led to their wide adoption are their resistance to spalling, their high refractoriness and their mechanical strength at high temperatures. These properties are especially well developed in certain high-fired chrome-magnesite brick.

METAL-ENCASED BASIC BRICK

Metal-encased basic brick consist of basic refractory material, partially enclosed in containers of soft steel. In general, their cross-section is either rectangular or round. The rectangular casings are applied either to fired magnesite brick or to chemically bonded magnesite-chrome or chrome-magnesite brick. The steel casing usually covers three or four faces of a brick, but not the ends. The round brick are made by packing and bonding dead-burned magnesite, with added bonding ingredients, solidly into steel tubes of standard lengths.

FORSTERITE REFRACTORIES

Forsterite refractories consist mainly of the mineral forsterite, a silicate of magnesium having the theoretical composition 2 $MgO \cdot SiO_2$, corresponding to 57.3% magnesia (MgO), 42.7% silica (SiO_2). The melting point of pure forsterite is 3461° F. (1905° C.). In nature, forsterite usually occurs in intimate association with the iron silicate mineral fayalite ($2FeO \cdot SiO_2$). The mineral composed of forsterite and fayalite is known as "olivine".

Forsterite brick are made from olivine-bearing rock, obtained mainly from deposits in the western part of North Carolina. Smaller quantities have been obtained from the western part of Washington.

Brick consisting mainly of forsterite are available in several different grades. They are bonded by firing at high temperatures.

INSULATING FIRE BRICK

One of the most important functions of insulating fire brick is to retard the flow of heat through furnace walls, thereby diminishing heat losses and increasing thermal efficiency. Since the capacity of insulating fire brick for storing heat is low, their use in place of the heavier fireclay brick diminishes the amount of heat which is stored in the linings on heating and lost when the brickwork is cooled.

Insulating fire brick are made from expanded vermiculite, crude or calcined diatomaceous earth, fire clay, diaspore clay and other high-alumina materials, and quartzite. During manufacture, the ground base material is generally mixed with a combustible material such as coke, sawdust or cork. This burns out during

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the firing process, with the formation of small voids or pores. It is these pores which impart high insulating value.

Insulating fire brick are classified by the American Society for Testing Materials as Groups 16, 20, 23, 26 and 28. The group identification number multiplied by 100 gives the ultimate temperature in degrees Fahrenheit to which the brick may be exposed in service. Lightweight insulating fireclay and silica brick, other than those included in the A.S.T.M. classification, are now available commercially.

REFRACTORY MORTARS

For their ultimate bonding strength hot-setting bonding mortars depend upon a ceramic bond formed at high temperature. Such mortars generally consist of finely ground crude and calcined refractory materials, similar in composition and properties to the brick with which they are to be used. The temperature range of maximum bonding strength usually is somewhere between 2200° and 2600° F.

Air-setting bonding mortars contain chemical bonding agents which impart a rigid set merely upon drying. Upon firing, the initial bond decreases, while a ceramic bond develops which adds strength. Air-setting bonding mortars form mechanically strong, dense joints, highly resistant to abrasion and to penetration by slags. Among the various air-setting bonding mortars available commercially, there is a wide range in chemical composition and in refractoriness. Some types are of extremely high refractoriness.

The mortar material selected for any particular service must be one which will react chemically only slightly or not at all with the brick with which it is to be used. Combinations to be avoided are aluminous fireclay mortar with silica brick, fireclay mortar of any type with magnesite brick, and magnesite mortar with fireclay or silica brick.

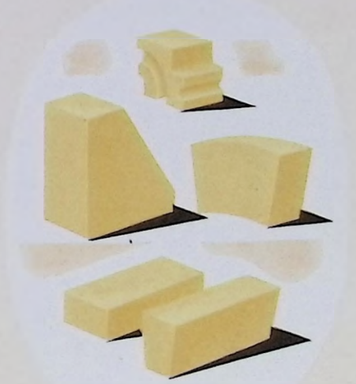
RAMMING MIXTURES, PLASTIC FIRE BRICK, AND CASTABLES

Ramming mixtures consist essentially of ground refractory materials, carefully graded as to relative proportions of different particle sizes, and with minor amounts of other materials added to make the mixtures workable and self-bonding. Various of these compositions have a magnesite or a chrome base. Some ramming mixtures are supplied in plastic form ready to apply; others are supplied in dry form, and are prepared for use by adding the proper amount of water and mixing. When rammed into place, the material sets merely upon drying to form a dense, well-bonded, monolithic refractory.

Plastic fire brick, which is shipped in stiffly plastic condition, consists of mixtures of refractory fire clays. For use, it is rammed into place to form furnace linings without joints.

Castables consist of ground refractory materials containing a suitable percentage of added bonding agents. Castables are supplied in dry form. For use they are mixed with water and cast in place. They develop a strong hydraulic set at room temperatures and a ceramic bond at high temperatures. Castables are available both with a refractory clay base and with a chrome base. The former are supplied in three grades: standard castables for use up to 2400° F., super-castables for use up to 2700° F., and lightweight castables for use up to 2200° F., in service where lightweight or low thermal conductivity is required. After having been cast in place, standard castables and super-castables are referred to as refractory concrete, and lightweight castables as insulating concrete.

STANDARD SIZES AND MODIFIED SHAPES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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GUARANTEES — *Harbison-Walker makes every effort to supply only products which meet high standards of quality, and which in its judgment are best suited for the purposes for which they are intended.*

The user will find it advantageous to exercise care and discretion in the selection, handling, installation, and use of refractory materials.

In the sale of refractories, no performance guarantees are made, since the manufacturer has no control over the conditions to which his products are subjected in service.

ALLOWABLE VARIATIONS FROM SPECIFIED DIMENSIONS — *Allowable variations of standard 9-inch brick from the intended or specified dimensions are plus 2 per cent to minus 2 per cent, when measured as described in A.S.T.M. Designation C134. The allowable variations of rectangular tile and modified shapes from the intended or specified dimensions are plus 2 per cent to minus 2 per cent on dimensions of 4 inches or over, and plus 3 per cent to minus 3 per cent on dimensions less than 4 inches.*

ALLOWABLE WARPAGE — *Ninety-five per cent of the tile or shapes shall not show a warpage greater than 1 per cent of the diagonal used in making the measurement, when tested in accordance with A.S.T.M. Designation C154.*

OVERSHIPMENTS — *Overages in accordance with the following table shall be allowable on all shipments of shapes that are not standard.*

QUANTITY SPECIFIED	OVERAGES	QUANTITY SPECIFIED	OVERAGES
1 – 100	10%*	5,001 – 10,000	2%
101 – 1,000	7%	Over 10,000	1%
1,001 – 5,000	3%		

* Not less than one shape. If in sets, one complete set.

SIZES AND SHAPES

CLASSIFICATION

REFRACTORY brick are classified on the basis of their form as Standard Sizes, Rectangular Tile or Modified Shapes.

1. STANDARD SIZES are brick of certain definite sizes and of relatively simple design which are marketed in sufficient amounts to permit quantity production. Wherever furnace construction and operating conditions permit, standard sizes are to be preferred. They cost less than larger and more intricate shapes, and the sizes in most common use are generally carried in stock by the manufacturer.

2. RECTANGULAR TILE are solid brick shapes which have six plane rectangular faces, with all opposite faces parallel and with all adjacent faces at right angles to each other.

3. MODIFIED SHAPES are shapes of special design, and of either simple or intricate form. Non-standard rectangular tile and modified shapes are not included in the list of standard sizes. Modified shapes for which there is a continuing demand of substantial quantity are carried in stock; those used infrequently or in relatively small quantities are manufactured only on order. Drawings showing complete details of the individual shapes as well as their assembly in the furnace should be included with orders for modified shapes.

Modified shapes are generally referred to as "special shapes".

TABLES AND ILLUSTRATIONS

Standard Sizes: The standard sizes of refractory brick include rectangular sizes (such as straights, soaps and splits); radial sizes having only plane surfaces (arch, wedge and key brick); neck, skew, feather edge and jamb brick; and radial sizes having two curved surfaces (circle brick, cupola blocks and rotary kiln blocks).

Disregarding circle brick, cupola blocks and rotary kiln blocks, standard sizes are classified on the basis of their thickness as 2½ inch sizes and 3 inch sizes. Further groupings are made on the basis of length and width.

The most widely used single group of standards is that known as "9 x 4½ x 2½ inch series of sizes", listed on page 30 and illustrated on page 31. These sizes are standard in all types of refractory brick, as well as in most insulating fire brick and acid-proof brick.

The 9 x 4½ x 3 inch series of sizes is standard in all types of refractory brick and in acid-proof brick, but not in all brands of insulating fire brick. The sizes are listed and illustrated on pages 32 and 33.

Complete lists of the sizes which are standard in the various types of refractories will be found on pages 34 to 38, 41 to 43, 45, 46 and 48.

Sizes and Shapes other than Standard: A number of sizes and shapes which are not classified as standard, but which are widely used, are listed on pages 39, 40, 44 and 47.

Typical Shapes for Special Service: It is beyond the scope of Modern Refractory Practice to list the many shapes commonly used in all types of industrial furnaces. Typical shapes for a few specific applications are illustrated on pages 49 to 56.

Skewbacks: Proper design of skewbacks is important in the construction of all the numerous types of furnaces having sprung arches. Special attention is therefore called to the illustrations of skewbacks shown on pages 57 and 58.

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STANDARD 9 x 4½ x 2½ INCH SIZES

STANDARD IN ALL TYPES OF REFRACTORIES, INSULATING FIRE BRICK* AND ACID-PROOF BRICK

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ Straight—2½″ Series	9″ x 4½″ x 2½″	...	.....	.....
Small 9″ Brick—2½″ Series	9″ x 3½″ x 2½″	...	.....	.....
9″ Soap—2½″ Series	9″ x 2½″ x 2¼″	...	.....	.....
1¼″ Split Brick—2½″ Series	9″ x 4½″ x 1¼″	...	.....	.....
2″ Split Brick—2½″ Series	9″ x 4½″ x 2″	...	.....	.....
9″ No. 1 Arch—2½″ Series	9″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
9″ No. 2 Arch—2½″ Series	9″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
9″ No. 3 Arch—2½″ Series	9″ x 4½″ x (2½″–1″)	19	0′- 6″	1′- 3″
9″ No. 1-X Wedge—2½″ Series	9″ x 4½″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
9″ No. 1 Wedge—2½″ Series	9″ x 4½″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ No. 2 Wedge—2½″ Series	9″ x 4½″ x (2½″–1½″)	57	2′- 3″	3′- 9″
9″ No. 1 Key—2½″ Series	9″ x (4½″–4″) x 2½″	113	12′- 0″	13′- 6″
9″ No. 2 Key—2½″ Series	9″ x (4½″–3½″) x 2½″	57	5′- 3″	6′- 9″
9″ No. 3 Key—2½″ Series	9″ x (4½″–3″) x 2½″	38	3′- 0″	4′- 6″
9″ No. 4 Key—2½″ Series	9″ x (4½″–2¼″) x 2½″	26	1′- 6″	3′- 0″
9″ Neck Brick—2½″ Series	9″ x 4½″ x (2½″–⅝″)	...	.....	.....
9″ Edge Skew—2½″ Series	9″ x (4½″–1½″) x 2½″	...	.....	.....
9″—60° End Skew—2½″ Series	(9″–7 9/16″) x 4½″ x 2½″	...	.....	.....
9″—48° End Skew—2½″ Series	(9″–6¾″) x 4½″ x 2½″	...	.....	.....
9″—60° Side Skew—2½″ Series	9″ x (4½″–3 1/16″) x 2½″	...	.....	.....
9″—48° Side Skew—2½″ Series	9″ x (4½″–2¼″) x 2½″	...	.....	.....
9″ Feather Edge—2½″ Series	9″ x 4½″ x (2½″–⅛″)	...	.....	.....
9″ Jamb Brick—2½″ Series	9″ x 4½″ x 2½″	...	.....	.....

** Except H-W 16 and H-W 444.* *(See page 48.)*

STANDARD 9 x 4½ x 2½ INCH SIZES



9″ Straight
9″ x 4½″ x 2½″



Small 9″ Brick
9″ x 3½″ x 2½″



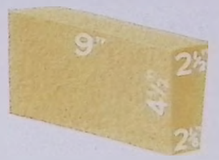
9″ Soap
9″ x 2½″ x 2¼″



1¼″ Split Brick
9″ x 4½″ x 1¼″



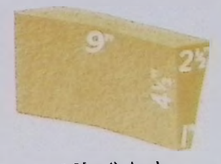
2″ Split Brick
9″ x 4½″ x 2″



9″ No. 1 Arch
9″ x 4½″ x (2½″—2⅛″)



9″ No. 2 Arch
9″ x 4½″ x (2½″—1¾″)



9″ No. 3 Arch
9″ x 4½″ x (2½″—1″)



9″ No. 1-X Wedge
9″ x 4½″ x (2½″—2¼″)



9″ No. 1 Wedge
9″ x 4½″ x (2½″—1⅞″)



9″ No. 2 Wedge
9″ x 4½″ x (2½″—1½″)



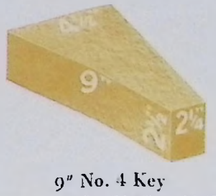
9″ No. 1 Key
9″ x (4½″—4″) x 2½″



9″ No. 2 Key
9″ x (4½″—3½″) x 2½″



9″ No. 3 Key
9″ x (4½″—3″) x 2½″



9″ No. 4 Key
9″ x (4½″—2¼″) x 2½″



9″—48° End Skew
(9″—6¾″) x 4½″ x 2½″



9″—48° Side Skew
9″ x (4½″—2¼″) x 2½″



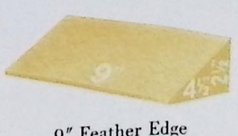
9″—60° End Skew
(9″—7 9/16″) x 4½″ x 2½″



9″—60° Side Skew
9″ x (4½″—3 1/16″) x 2½″



9″ Edge Skew
9″ x (4½″—1½″) x 2½″



9″ Feather Edge
9″ x 4½″ x (2½″—⅛″)



9″ Neck Brick
9″ x 4½″ x (2½″—⅝″)



9″ Jamb Brick
9″ x 4½″ x 2½″

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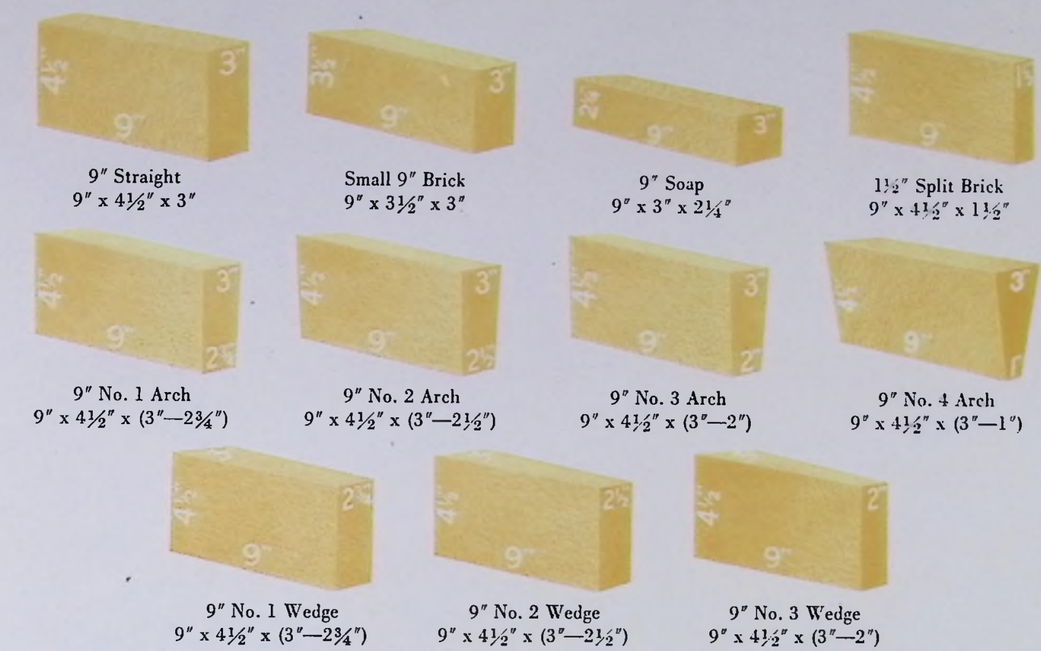
STANDARD 9 x 4½ x 3 INCH SIZES

STANDARD IN ALL TYPES OF REFRACTORIES, INSULATING FIRE BRICK* AND ACID-PROOF BRICK

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ Straight—3″ Series	9″ x 4½″ x 3″	...	.....	.....
Small 9″ Brick—3″ Series	9″ x 3½″ x 3″	...	.....	.....
9″ Soap—3″ Series	9″ x 3″ x 2¼″	...	.....	.....
1½″ Split Brick—3″ Series	9″ x 4½″ x 1½″	...	.....	.....
9″ No. 1 Arch—3″ Series	9″ x 4½″ x (3″–2¾″)	113	8′- 3″	9′- 0″
9″ No. 2 Arch—3″ Series	9″ x 4½″ x (3″–2½″)	57	3′- 9″	4′- 6″
9″ No. 3 Arch—3″ Series	9″ x 4½″ x (3″–2″)	29	1′- 6″	2′- 3″
9″ No. 4 Arch—3″ Series	9″ x 4½″ x (3″–1″)	15	0′- 4½″	1′- 1½″
9″ No. 1 Wedge—3″ Series	9″ x 4½″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ No. 2 Wedge—3″ Series	9″ x 4½″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ No. 3 Wedge—3″ Series	9″ x 4½″ x (3″–2″)	57	3′- 0″	4′- 6″
9″ No. 1 Key—3″ Series	9″ x (4½″–4″) x 3″	113	12′- 0″	13′- 6″
9″ No. 2 Key—3″ Series	9″ x (4½″–3½″) x 3″	57	5′- 3″	6′- 9″
9″ No. 3 Key—3″ Series	9″ x (4½″–3″) x 3″	38	3′- 0″	4′- 6″
9″ No. 4 Key—3″ Series	9″ x (4½″–2¼″) x 3″	26	1′- 6″	3′- 0″
9″ Neck Brick—3″ Series	9″ x 4½″ x (3″–⅝″)	...	.....	.....
9″ Edge Skew—3″ Series	9″ x (4½″–1½″) x 3″	...	.....	.....
9″—60° End Skew—3″ Series	(9″–7¼″) x 4½″ x 3″	...	.....	.....
9″—48° End Skew—3″ Series	(9″–6⅝″) x 4½″ x 3″	...	.....	.....
9″—60° Side Skew—3″ Series	9″ x (4½″–2¾″) x 3″	...	.....	.....
9″—48° Side Skew—3″ Series	9″ x (4½″–1 13/16″) x 3″	...	.....	.....
9″ Feather Edge—3″ Series	9″ x 4½″ x (3″–⅛″)	...	.....	.....
9″ Jamb Brick—3″ Series	9″ x 4½″ x 3″	...	.....	.....

* *Except H-W 16 and H-W 444.* (*See page 48.*)

STANDARD 9 x 4½ x 3 INCH SIZES



9″ Straight
9″ x 4½″ x 3″

Small 9″ Brick
9″ x 3½″ x 3″

9″ Soap
9″ x 3″ x 2¼″

1½″ Split Brick
9″ x 4½″ x 1½″

9″ No. 1 Arch
9″ x 4½″ x (3″—2¾″)

9″ No. 2 Arch
9″ x 4½″ x (3″—2½″)

9″ No. 3 Arch
9″ x 4½″ x (3″—2″)

9″ No. 4 Arch
9″ x 4½″ x (3″—1″)

9″ No. 1 Wedge
9″ x 4½″ x (3″—2¾″)

9″ No. 2 Wedge
9″ x 4½″ x (3″—2½″)

9″ No. 3 Wedge
9″ x 4½″ x (3″—2″)

9″ No. 1 Key
9″ x (4½″—4″) x 3″

9″ No. 2 Key
9″ x (4½″—3½″) x 3″

9″ No. 3 Key
9″ x (4½″—3″) x 3″

9″ No. 4 Key
9″ x (4½″—2¼″) x 3″

9″—48° End Skew
(9″—6⅝″) x 4½″ x 3″

9″—48° Side Skew
9″ x (4½″—1 13/16″) x 3″

9″—60° End Skew
(9″—7¼″) x 4½″ x 3″

9″—60° Side Skew
9″ x (4½″—2¾″) x 3″

9″ Edge Skew
9″ x (4½″—1½″) x 3″

9″ Feather Edge
9″ x 4½″ x (3″—⅛″)

9″ Neck Brick
9″ x 4½″ x (3″—⅝″)

9″ Jamb Brick
9″ x 4½″ x 3″

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STANDARD SIZES
IN FIRECLAY AND HIGH-ALUMINA REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE AND KEY BRICK



Straight *Arch* *Wedge* *Key*

STANDARD 9″ x 4½″ x 2½″ SIZES

The complete list of Standard 9″ x 4½″ x 2½″ sizes is given on Pages 30 and 31

STANDARD 9″ x 4½″ x 3″ SIZES

The complete list of Standard 9″ x 4½″ x 3″ sizes is given on Pages 32 and 33

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 6″ x 2½″ SIZES				
9″ x 6″ x 2½″ Straight	9″ x 6″ x 2½″	...	.....	.....
9″ x 6″ x 2½″ No. 1 Key	9″ x (6″–5⅜″) x 2½″.	91	13′- 0″	14′- 6″
9″ x 6″ x 2½″ No. 2 Key	9″ x (6″–4 13/16″) x 2½″	48	6′- 0″	7′- 6″
9″ x 6″ x 2½″ No. 3 Key	9″ x (6″–3″) x 2½″	19	1′- 6″	3′- 0″
STANDARD 9″ x 6″ FLAT BACK SIZES				
Flat Back Straight	9″ x 6″ x 2½″	...	.....	.....
Flat Back Split	9″ x 6″ x 1¼″	...	.....	.....
No. 1 Flat Back Arch	9″ x 6″ x (3½″–2½″)	38	2′- 6″	3′- 6″
No. 2 Flat Back Arch	9″ x 6″ x (3½″–2″)	26	1′- 4″	2′- 4″
STANDARD 9″ x 6″ x 3″ SIZES				
9″ x 6″ x 3″ Straight	9″ x 6″ x 3″	...	.....	.....
9″ x 6″ x 3″ No. 1 Key	9″ x (6″–5⅜″) x 3″	91	13′- 0″	14′- 6″
9″ x 6″ x 3″ No. 2 Key	9″ x (6″–4 13/16″) x 3″	48	6′- 0″	7′- 6″
9″ x 6″ x 3″ No. 3 Key	9″ x (6″–3″) x 3″	19	1′- 6″	3′- 0″

STANDARD SIZES
IN FIRECLAY AND HIGH-ALUMINA REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 6¾″ x 2½″ SIZES				
9″ x 6¾″ x 2½″ Straight	9″ x 6¾″ x 2½″	...	.....	.....
9″ x 6¾″ x 2½″ No. 1-X Wedge	9″ x 6¾″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
9″ x 6¾″ x 2½″ No. 1 Wedge	9″ x 6¾″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ x 6¾″ x 2½″ No. 2 Wedge	9″ x 6¾″ x (2½″–1½″)	57	2′- 3″	3′- 9″
STANDARD 9″ x 6¾″ x 3″ SIZES				
9″ x 6¾″ x 3″ Straight	9″ x 6¾″ x 3″	...	.....	.....
9″ x 6¾″ x 3″ No. 1 Wedge	9″ x 6¾″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6¾″ x 3″ No. 2 Wedge	9″ x 6¾″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6¾″ x 3″ No. 3 Wedge	9″ x 6¾″ x (3″–2″)	57	3′- 0″	4′- 6″
STANDARD 12″ x 6″ x 3″ SIZES				
12″ x 6″ x 3″ Straight	12″ x 6″ x 3″	...	.....	.....
12″ x 6″ x 3″ No. 1 Wedge	12″ x 6″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Wedge	12″ x 6″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 6″ x 3″ No. 3 Wedge	12″ x 6″ x (3″–2″)	76	4′- 0″	6′- 0″
STANDARD 13½″ x 6″ x 2½″ SIZES				
13½″ x 6″ x 2½″ Straight	13½″ x 6″ x 2½″	...	.....	.....
13½″ x 6″ x 2½″ No. 1 Key	13½″ x (6″–5″) x 2½″	85	11′- 3″	13′- 6″
13½″ x 6″ x 2½″ No. 2 Key	13½″ x (6″–4⅜″) x 2½″	52	6′- 0″	8′- 3″
13½″ x 6″ x 2½″ No. 3 Key	13½″ x (6″–3″) x 2½″	29	2′- 3″	4′- 6″
STANDARD 13½″ x 6″ x 3″ SIZES				
13½″ x 6″ x 3″ Straight	13½″ x 6″ x 3″	...	.....	.....
13½″ x 6″ x 3″ No. 1 Wedge	13½″ x 6″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 6″ x 3″ No. 2 Wedge	13½″ x 6″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 3 Wedge	13½″ x 6″ x (3″–2″)	85	4′- 6″	6′- 9″
13½″ x 6″ x 3″ No. 1 Key	13½″ x (6″–5″) x 3″	85	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 2 Key	13½″ x (6″–4⅜″) x 3″	52	6′- 0″	8′- 3″
13½″ x 6″ x 3″ No. 3 Key	13½″ x (6″–3″) x 3″	29	2′- 3″	4′- 6″
STANDARD MISCELLANEOUS STRAIGHTS				
10½″ x 4½″ x 3″ Straight	10½″ x 4½″ x 3″	...	.....	.....
10½″ x 4½″ x 4½″ Straight	10½″ x 4½″ x 4½″	...	.....	.....
13½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 3″	...	.....	.....
13½″ x 4½″ x 4½″ Straight	13½″ x 4½″ x 4½″	...	.....	.....
18″ Bottom Blocks	18″ x 9″ x 4½″	...	.....	.....

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STANDARD SIZES
IN FIRECLAY AND HIGH-ALUMINA REFRACTORIES

STANDARD 9″ x 4½″ x 2½″ CIRCLE BRICK



9″ Circle Brick

Name	Outside Chord	Inside Chord	Radial Dimension	Thickness	Diameter of Ring		Number Per Ring
					Inside	Outside	
24–33 Circle	9″	6 17/32″	4½″	2½″	24″	33″	12
36–45 Circle	9″	7 3/16″	4½″	2½″	36″	45″	16
48–57 Circle	9″	7 19/32″	4½″	2½″	48″	57″	20
60–69 Circle	9″	7 13/16″	4½″	2½″	60″	69″	24
72–81 Circle	9″	8″	4½″	2½″	72″	81″	29
84–93 Circle	9″	8 1/8″	4½″	2½″	84″	93″	33
96–105 Circle	9″	8 7/32″	4½″	2½″	96″	105″	37
108–117 Circle	9″	8 5/16″	4½″	2½″	108″	117″	41
120–129 Circle	9″	8 3/8″	4½″	2½″	120″	129″	45

9″ x 4½″ x 3″ Circle Brick are furnished also when desired. They are specified by including "3" in the name thus, 24-33-3 Circle.

STANDARD BUNG BRICK



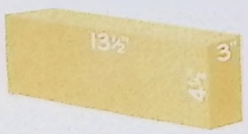
9″ Arch Bung



101 — 9″ Straight Bung



105 — 9″ Arch Bung



101 — 13½″ Straight Bung



103 — 13½″ Arch Bung



105 — 13½″ Arch Bung

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ Arch Bung	9″ x 4½″ x (2½″–2⅜″)	227	14′- 3″	15′- 0″
101–9″ Straight Bung	9″ x 4½″ x 3″	...	.....	.....
105–9″ Arch Bung	9″ x 4½″ x (3″–2⅞″)	227	17′- 3″	18′- 0″
101–13½″ Straight Bung	13½″ x 4½″ x 3″	...	.....	.....
103–13½″ Arch Bung	13½″ x 4½″ x (3″–2⅝″)	76	5′- 3″	6′- 0″
105–13½″ Arch Bung	13½″ x 4½″ x (3″–2⅞″)	227	17′- 3″	18′- 0″

STANDARD SIZES
IN FIRECLAY AND HIGH-ALUMINA REFRACTORIES

STANDARD CUPOLA AND ROTARY KILN BLOCKS

4½″ x 4″ Cupola Blocks



9″ x 4½″ x 4″

4½″ x 9″ Cupola Blocks



9″ x 4½″ x 9″

6″ Cupola and Rotary Kiln Blocks



9″ x 6″ x 4″

9″ Rotary Kiln Blocks



9″ x 9″ x 4″

Name	Outside Chord	Inside Chord	Radial Dimension	Thickness	Diameter of Ring		Number Per Ring
					Inside	Outside	
STANDARD 4½″ x 4″ CUPOLA BLOCKS 9″ x 4½″ x 4″							
27–36 Cupola	9″	6¾″	4½″	4″	27″	36″	13
32–41 Cupola	9″	7 1/32″	4½″	4″	32″	41″	15

Name	Outside Chord	Inside Chord	Radial Dimension	Length	Diameter of Ring		Number Per Ring
					Inside	Outside	
STANDARD 4½″ x 9″ CUPOLA BLOCKS 9″ x 4½″ x 9″							
A Cupola	9″	5 ¾″	4½″	9″	16″	25″	9
B Cupola	9″	6 5/16″	4½″	9″	21″	30″	11
C Cupola	9″	6 ¾″	4½″	9″	27″	36″	13
D Cupola	9″	6 15/16″	4½″	9″	30″	39″	14
E Cupola	9″	7 11/32″	4½″	9″	40″	49″	18
F Cupola	9″	7 21/32″	4½″	9″	51″	60″	21
G Cupola	9″	7 13/16″	4½″	9″	60″	69″	24
H Cupola	9″	8″	4½″	9″	73″	82″	29

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STANDARD SIZES
IN FIRECLAY AND HIGH-ALUMINA REFRACTORIES

Name	Outside Chord	Inside Chord	Radial Dimension	Thickness	Diameter of Ring		Number Per Ring
					Inside	Outside	
STANDARD 6″ CUPOLA AND ROTARY KILN BLOCKS 9″ x 6″ x 4″							
30–42 Cupola or RKB	9″	6 7/16″	6″	4″	30″	42″	15
36–48 Cupola or RKB	9″	6 3/4″	6″	4″	36″	48″	17
42–54 Cupola or RKB	9″	7″	6″	4″	42″	54″	19
48–60 Cupola or RKB	9″	7 3/16″	6″	4″	48″	60″	21
54–66 Cupola or RKB	9″	7 3/8″	6″	4″	54″	66″	23
60–72 Cupola or RKB	9″	7 1/2″	6″	4″	60″	72″	26
66–78 Cupola or RKB	9″	7 5/8″	6″	4″	66″	78″	28
72–84 Cupola or RKB	9″	7 23/32″	6″	4″	72″	84″	30
78–90 Cupola or RKB	9″	7 13/16″	6″	4″	78″	90″	32
84–96 Cupola or RKB	9″	7 7/8″	6″	4″	84″	96″	34
90–102 Cupola or RKB	9″	7 15/16″	6″	4″	90″	102″	36
96–108 Cupola or RKB	9″	8″	6″	4″	96″	108″	38
102–114 Cupola or RKB	9″	8 1/16″	6″	4″	102″	114″	40
108–120 Cupola or RKB	9″	8 3/32″	6″	4″	108″	120″	42
114–126 Cupola or RKB	9″	8 5/32″	6″	4″	114″	126″	44
120–132 Cupola or RKB	9″	8 3/16″	6″	4″	120″	132″	46
123–135 Cupola or RKB	9″	8 3/16″	6″	4″	123″	135″	48
126–138 Cupola or RKB	9″	8 7/32″	6″	4″	126″	138″	49
132–144 Cupola or RKB	9″	8 1/4″	6″	4″	132″	144″	51
138–150 Cupola or RKB	9″	8 9/32″	6″	4″	138″	150″	53
STANDARD 9″ ROTARY KILN BLOCKS 9″ x 9″ x 4″							
48–66 RKB	9″	6 17/32″	9″	4″	48″	66″	23
54–72 RKB	9″	6 3/4″	9″	4″	54″	72″	26
60–78 RKB	9″	6 15/16″	9″	4″	60″	78″	28
66–84 RKB	9″	7 1/16″	9″	4″	66″	84″	30
72–90 RKB	9″	7 3/16″	9″	4″	72″	90″	32
78–96 RKB	9″	7 5/16″	9″	4″	78″	96″	34
84–102 RKB	9″	7 13/32″	9″	4″	84″	102″	36
90–108 RKB	9″	7 1/2″	9″	4″	90″	108″	38
96–114 RKB	9″	7 19/32″	9″	4″	96″	114″	40
102–120 RKB	9″	7 21/32″	9″	4″	102″	120″	42
108–126 RKB	9″	7 23/32″	9″	4″	108″	126″	44
114–132 RKB	9″	7 25/32″	9″	4″	114″	132″	46
117–135 RKB	9″	7 13/16″	9″	4″	117″	135″	48
120–138 RKB	9″	7 13/16″	9″	4″	120″	138″	49
123–141 RKB	9″	7 27/32″	9″	4″	123″	141″	50
126–144 RKB	9″	7 7/8″	9″	4″	126″	144″	51
132–150 RKB	9″	7 29/32″	9″	4″	132″	150″	53
138–156 RKB	9″	7 31/32″	9″	4″	138″	156″	55
144–162 RKB	9″	8″	9″	4″	144″	162″	57
150–168 RKB	9″	8 1/32″	9″	4″	150″	168″	59

SIZES OTHER THAN STANDARD
IN FIRECLAY AND HIGH-ALUMINA REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE AND KEY BRICK



Straight *Arch* *Wedge* *Key*

Name of Brick	Dimensions of Brick	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ x 9″ x 2½″ Straight	9″ x 9″ x 2½″	...	.....	.....
9″ x 9″ x 2½″ No. 1-X Wedge	9″ x 9″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
9″ x 9″ x 2½″ No. 1 Wedge	9″ x 9″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ x 9″ x 2½″ No. 2 Wedge	9″ x 9″ x (2½″–1½″)	57	2′- 3″	3′- 9″
9″ x 9″ x 3″ Straight	9″ x 9″ x 3″	...	.....	.....
9″ x 9″ x 3″ No. 1 Wedge	9″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 9″ x 3″ No. 2 Wedge	9″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 9″ x 3″ No. 3 Wedge	9″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
9″ x 9″ Gas Flue Straight	9″ x 9″ x 3½″	...	.....	.....
9″ x 9″ No. 3 Gas Flue Arch	9″ x 9″ x (3½″–2¼″)	46	2′- 9″	4′- 3″
9″ x 9″ No. 4 Gas Flue Arch	9″ x 9″ x (3½″–2 17/32″)	60	4′- 0″	5′- 6″
9″ x 9″ No. 5 Gas Flue Arch	9″ x 9″ x (3½″–2 11/16″)	70	5′- 0″	6′- 6″
12″ x 9″ x 3″ Straight	12″ x 9″ x 3″	...	.....	.....
12″ x 9″ x 3″ No. 1 Wedge	12″ x 9″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 9″ x 3″ No. 2 Wedge	12″ x 9″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 9″ x 3″ No. 3 Wedge	12″ x 9″ x (3″–2″)	76	4′- 0″	6′- 0″
13½″ x 4½″ x 2½″ Straight	13½″ x 4½″ x 2½″	...	.....	.....
13½″ x 4½″ x 2½″ No. 1 Arch	13½″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
13½″ x 4½″ x 2½″ No. 2 Arch	13½″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
13½″ x 4½″ x 2½″ No. 3 Arch	13½″ x 4½″ x (2½″–1″)	19	0′- 6″	1′- 3″
13½″ x 9″ x 3″ Straight	13½″ x 9″ x 3″	...	.....	.....
13½″ x 9″ x 3″ No. 1 Arch	13½″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
13½″ x 9″ x 3″ No. 2 Arch	13½″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
13½″ x 9″ x 3″ No. 3 Arch	13½″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
13½″ x 9″ x 3″ No. 1 Wedge	13½″ x 9″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 9″ x 3″ No. 2 Wedge	13½″ x 9″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 9″ x 3″ No. 3 Wedge	13½″ x 9″ x (3″–2″)	85	4′- 6″	6′- 9″
13½″ x 9″ Gas Flue Straight	13½″ x 9″ x 3½″	...	.....	.....
13½″ x 9″ No. 3 Gas Flue Arch	13½″ x 9″ x (3½″–2¼″)	46	2′- 9″	4′- 3″
13½″ x 9″ No. 4 Gas Flue Arch	13½″ x 9″ x (3½″–2 17/32″)	60	4′- 0″	5′- 6″
13½″ x 9″ No. 5 Gas Flue Arch	13½″ x 9″ x (3½″–2 11/16″)	70	5′- 0″	6′- 6″
21″ x 6″ x 3″ Straight	21″ x 6″ x 3″	...	.....	.....
24″ x 6″ x 3″ Straight	24″ x 6″ x 3″	...	.....	.....

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SHAPES OTHER THAN STANDARD IN FIRECLAY AND HIGH-ALUMINA REFRACTORIES

TONGUE AND GROOVE BRICK

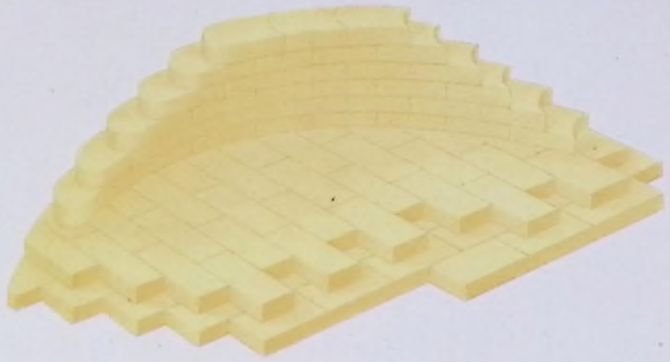


9″ Straight
Single Tongue and Groove
9″ x 4½″ x 2½″

9″ Straight
Double Tongue and Groove
9″ x 4½″ x 2½″



UNIVERSAL CIRCLE BRICK



Typical Assembly for a Circular Shell



Universal Circle Brick

UNIVERSAL CIRCLE BRICK FOR LININGS 4½″ THICK

Shape Nos.
601–1¼
601–2½
601–3
600–1¼
600–2½
600–3

Shape Numbers of the 601 Series serve for linings of 2′-0″ to 5′-5″ inside diameter; those of the 600 Series for linings of 5′-6″ to 30′-0″ inside diameter. The suffix number following the serial number is the thickness of the brick in inches. The brick of 1¼-inch thickness serve for breaking the horizontal joints in double linings.

UNIVERSAL CIRCLE BRICK 601 SERIES

I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring
2′-0″	10	3′-0″	15	4′-0″	19	5′-0″	23
2′-3″	11	3′-3″	16	4′-3″	20	5′-3″	24
2′-6″	12	3′-6″	17	4′-6″	21	5′-4″	24
2′-9″	13	3′-9″	18	4′-9″	22	5′-5″	25

600 SERIES

I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring	I.D. of Ring	No. Per Ring
5′-6″	25	11′-6″	50	17′-6″	75	23′-6″	100
5′-9″	26	11′-9″	51	17′-9″	76	23′-9″	101
6′-0″	27	12′-0″	52	18′-0″	77	24′-0″	103
6′-3″	28	12′-3″	53	18′-3″	78	24′-3″	104
6′-6″	29	12′-6″	54	18′-6″	79	24′-6″	105
6′-9″	30	12′-9″	55	18′-9″	81	24′-9″	106
7′-0″	31	13′-0″	56	19′-0″	82	25′-0″	107
7′-3″	32	13′-3″	57	19′-3″	83	25′-3″	108
7′-6″	33	13′-6″	59	19′-6″	84	25′-6″	109
7′-9″	34	13′-9″	60	19′-9″	85	25′-9″	110
8′-0″	35	14′-0″	61	20′-0″	86	26′-0″	111
8′-3″	37	14′-3″	62	20′-3″	87	26′-3″	112
8′-6″	38	14′-6″	63	20′-6″	88	26′-6″	113
8′-9″	39	14′-9″	64	20′-9″	89	26′-9″	114
9′-0″	40	15′-0″	65	21′-0″	90	27′-0″	115
9′-3″	41	15′-3″	66	21′-3″	91	27′-3″	116
9′-6″	42	15′-6″	67	21′-6″	92	27′-6″	117
9′-9″	43	15′-9″	68	21′-9″	93	27′-9″	118
10′-0″	44	16′-0″	69	22′-0″	94	28′-0″	119
10′-3″	45	16′-3″	70	22′-3″	95	28′-3″	120
10′-6″	46	16′-6″	71	22′-6″	96	28′-6″	121
10′-9″	47	16′-9″	72	22′-9″	97	28′-9″	122
11′-0″	48	17′-0″	73	23′-0″	98	29′-0″	123
11′-3″	49	17′-3″	74	23′-3″	99	29′-6″	126

STANDARD SIZES IN SILICA REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE AND KEY BRICK



Straight *Arch* *Wedge* *Key*

STANDARD 9″ x 4½″ x 2½″ SIZES

The complete list of Standard 9″ x 4½″ x 2½″ sizes is given on Pages 30 and 31

STANDARD 9″ x 4½″ x 3″ SIZES

The complete list of Standard 9″ x 4½″ x 3″ sizes is given on Pages 32 and 33

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 6¾″ x 2½″ SIZES				
9″ x 6¾″ x 2½″ Straight	9″ x 6¾″ x 2½″	...	.....	.....
9″ x 6¾″ x 2½″ No. 1-X Wedge	9″ x 6¾″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
9″ x 6¾″ x 2½″ No. 1 Wedge	9″ x 6¾″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ x 6¾″ x 2½″ No. 2 Wedge	9″ x 6¾″ x (2½″–1½″)	57	2′- 3″	3′- 9″
STANDARD 9″ x 6¾″ x 3″ SIZES				
9″ x 6¾″ x 3″ Straight	9″ x 6¾″ x 3″	...	.....	.....
9″ x 6¾″ x 3″ No. 1 Wedge	9″ x 6¾″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6¾″ x 3″ No. 2 Wedge	9″ x 6¾″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6¾″ x 3″ No. 3 Wedge	9″ x 6¾″ x (3″–2″)	57	3′- 0″	4′- 6″
STANDARD 12″ x 4½″ x 3″ SIZES				
12″ x 4½″ x 3″ Straight	12″ x 4½″ x 3″	...	.....	.....
12″ x 4½″ x 3″ No. 1-X Wedge	12″ x 4½″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 4½″ x 3″ No. 1 Wedge	12″ x 4½″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 4½″ x 3″ No. 2 Wedge	12″ x 4½″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 4½″ x 3″ No. 3 Wedge	12″ x 4½″ x (3″–2″)	76	4′- 0″	6′- 0″

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STANDARD SIZES IN SILICA REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 12″ x 6″ x 3″ SIZES				
12″ x 6″ x 3″ Straight	12″ x 6″ x 3″	...	.....	.....
12″ x 6″ x 3″ No. 1 Arch	12″ x 6″ x (3″–2¾″)	151	11′- 0″	12′- 0″
12″ x 6″ x 3″ No. 2 Arch	12″ x 6″ x (3″–2½″)	76	5′- 0″	6′- 0″
12″ x 6″ x 3″ No. 3 Arch	12″ x 6″ x (3″–2″)	38	2′- 0″	3′- 0″
12″ x 6″ x 3″ No. 1-X Wedge	12″ x 6″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 6″ x 3″ No. 1 Wedge	12″ x 6″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Wedge	12″ x 6″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 6″ x 3″ No. 3 Wedge	12″ x 6″ x (3″–2″)	76	4′- 0″	6′- 0″
12″ x 6″ x 3″ No. 1 Key	12″ x (6″–5½″) x 3″	151	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Key	12″ x (6″–5″) x 3″	76	10′- 0″	12′- 0″
STANDARD 12″ x 9″ x 3″ SIZES				
12″ x 9″ x 3″ Straight	12″ x 9″ x 3″	...	.....	.....
12″ x 9″ x 3″ No. 1-X Wedge	12″ x 9″ x (3″–2⅞″)	604	46′- 0″	48′- 0″
12″ x 9″ x 3″ No. 1 Wedge	12″ x 9″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 9″ x 3″ No. 2 Wedge	12″ x 9″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 9″ x 3″ No. 3 Wedge	12″ x 9″ x (3″–2″)	76	4′- 0″	6′- 0″
STANDARD 13½″ x 4½″ x 3″ SIZES				
13½″ x 4½″ x 3″ Straight	13½″ x 4½″ x 3″	...	.....	.....
13½″ x 4½″ x 3″ No. 1 Arch	13½″ x 4½″ x (3″–2¾″)	113	8′- 3″	9′- 0″
13½″ x 4½″ x 3″ No. 2 Arch	13½″ x 4½″ x (3″–2½″)	57	3′- 9″	4′- 6″
13½″ x 4½″ x 3″ No. 3 Arch	13½″ x 4½″ x (3″–2″)	29	1′- 6″	2′- 3″
13½″ x 4½″ x 3″ No. 4 Arch	13½″ x 4½″ x (3″–1″)	15	0′- 4½″	1′- 1½″
STANDARD 13½″ x 6″ x 3″ SIZES				
13½″ x 6″ x 3″ Straight	13½″ x 6″ x 3″	...	.....	.....
13½″ x 6″ x 3″ No. 1 Arch	13½″ x 6″ x (3″–2¾″)	151	11′- 0″	12′- 0″
13½″ x 6″ x 3″ No. 2 Arch	13½″ x 6″ x (3″–2½″)	76	5′- 0″	6′- 0″
13½″ x 6″ x 3″ No. 3 Arch	13½″ x 6″ x (3″–2″)	38	2′- 0″	3′- 0″
13½″ x 6″ x 3″ No. 1-X Wedge	13½″ x 6″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 6″ x 3″ No. 1 Wedge	13½″ x 6″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 6″ x 3″ No. 2 Wedge	13½″ x 6″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 3 Wedge	13½″ x 6″ x (3″–2″)	85	4′- 6″	6′- 9″
13½″ x 6″ x 3″ No. 1 Key	13½″ x (6″–5″) x 3″	85	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 2 Key	13½″ x (6″–4⅜″) x 3″	52	6′- 0″	8′- 3″
13½″ x 6″ x 3″ No. 3 Key	13½″ x (6″–3″) x 3″	29	2′- 3″	4′- 6″

STANDARD SIZES IN SILICA REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 13½″ x 9″ x 3″ SIZES				
13½″ x 9″ x 3″ Straight	13½″ x 9″ x 3″	...	.....	.....
13½″ x 9″ x 3″ No. 1 Arch	13½″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
13½″ x 9″ x 3″ No. 2 Arch	13½″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
13½″ x 9″ x 3″ No. 3 Arch	13½″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
13½″ x 9″ x 3″ No. 1-X Wedge	13½″ x 9″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 9″ x 3″ No. 1 Wedge	13½″ x 9″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 9″ x 3″ No. 2 Wedge	13½″ x 9″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 9″ x 3″ No. 3 Wedge	13½″ x 9″ x (3″–2″)	85	4′- 6″	6′- 9″
STANDARD 15″ x 6″ x 3″ SIZES				
15″ x 6″ x 3″ Straight	15″ x 6″ x 3″	...	.....	.....
15″ x 6″ x 3″ No. 1-X Wedge	15″ x 6″ x (3″–2⅞″)	754	57′- 6″	60′- 0″
15″ x 6″ x 3″ No. 1 Wedge	15″ x 6″ x (3″–2¾″)	377	27′- 6″	30′- 0″
15″ x 6″ x 3″ No. 2 Wedge	15″ x 6″ x (3″–2½″)	189	12′- 6″	15′- 0″
15″ x 6″ x 3″ No. 3 Wedge	15″ x 6″ x (3″–2″)	95	5′- 0″	7′- 6″
STANDARD 15″ x 9″ x 3″ SIZES				
15″ x 9″ x 3″ Straight	15″ x 9″ x 3″	...	.....	.....
15″ x 9″ x 3″ No. 1-X Wedge	15″ x 9″ x (3″–2⅞″)	754	57′- 6″	60′- 0″
15″ x 9″ x 3″ No. 1 Wedge	15″ x 9″ x (3″–2¾″)	377	27′- 6″	30′- 0″
15″ x 9″ x 3″ No. 2 Wedge	15″ x 9″ x (3″–2½″)	189	12′- 6″	15′- 0″
15″ x 9″ x 3″ No. 3 Wedge	15″ x 9″ x (3″–2″)	95	5′- 0″	7′- 6″
STANDARD 18″ x 6″ x 3″ SIZES				
18″ x 6″ x 3″ Straight	18″ x 6″ x 3″	...	.....	.....
18″ x 6″ x 3″ No. 1-X Wedge	18″ x 6″ x (3″–2⅞″)	905	69′- 0″	72′- 0″
18″ x 6″ x 3″ No. 1 Wedge	18″ x 6″ x (3″–2¾″)	453	33′- 0″	36′- 0″
18″ x 6″ x 3″ No. 2 Wedge	18″ x 6″ x (3″–2½″)	227	15′- 0″	18′- 0″
18″ x 6″ x 3″ No. 3 Wedge	18″ x 6″ x (3″–2″)	113	6′- 0″	9′- 0″
STANDARD 18″ x 9″ x 3″ SIZES				
18″ x 9″ x 3″ Straight	18″ x 9″ x 3″	...	.....	.....
18″ x 9″ x 3″ No. 1-X Wedge	18″ x 9″ x (3″–2⅞″)	905	69′- 0″	72′- 0″
18″ x 9″ x 3″ No. 1 Wedge	18″ x 9″ x (3″–2¾″)	453	33′- 0″	36′- 0″
18″ x 9″ x 3″ No. 2 Wedge	18″ x 9″ x (3″–2½″)	227	15′- 0″	18′- 0″
18″ x 9″ x 3″ No. 3 Wedge	18″ x 9″ x (3″–2″)	113	6′- 0″	9′- 0″

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SIZES OTHER THAN STANDARD IN SILICA REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE AND KEY BRICK

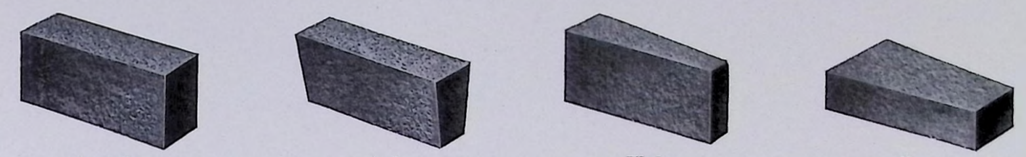


Straight *Arch* *Wedge* *Key*

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ x 9″ x 2½″ Straight	9″ x 9″ x 2½″	....	.....	.....
9″ x 9″ x 2½″ No. 1-X Wedge	9″ x 9″ x (2½″–2¼″)	227	13′- 6″	15′- 0″
9″ x 9″ x 2½″ No. 1 Wedge	9″ x 9″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ x 9″ x 2½″ No. 2 Wedge	9″ x 9″ x (2½″–1½″)	57	2′- 3″	3′- 9″
9″ x 9″ x 3″ Straight	9″ x 9″ x 3″	....	.....	.....
9″ x 9″ x 3″ No. 1 Wedge	9″ x 9″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 9″ x 3″ No. 2 Wedge	9″ x 9″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 9″ x 3″ No. 3 Wedge	9″ x 9″ x (3″–2″)	57	3′- 0″	4′- 6″
13½″ x 4½″ x 2½″ Straight	13½″ x 4½″ x 2½″	....	.....	.....
13½″ x 4½″ x 2½″ No. 1 Arch	13½″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
13½″ x 4½″ x 2½″ No. 2 Arch	13½″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
13½″ x 4½″ x 2½″ No. 3 Arch	13½″ x 4½″ x (2½″–1″)	19	0′- 6″	1′- 3″
13½″ x 4½″ x 3″ No. 1-X Wedge	13½″ x 4½″ x (3″–2⅞″)	679	51′- 9″	54′- 0″
13½″ x 4½″ x 3″ No. 1 Wedge	13½″ x 4½″ x (3″–2¾″)	340	24′- 9″	27′- 0″
13½″ x 4½″ x 3″ No. 2 Wedge	13½″ x 4½″ x (3″–2½″)	170	11′- 3″	13′- 6″
13½″ x 4½″ x 3″ No. 3 Wedge	13½″ x 4½″ x (3″–2″)	85	4′- 6″	6′- 9″
21″ x 6″ x 3″ Straight	21″ x 6″ x 3″	....	.....	.....
21″ x 6″ x 3″ No. 1-X Wedge	21″ x 6″ x (3″–2⅞″)	1056	80′- 6″	84′- 0″
21″ x 6″ x 3″ No. 1 Wedge	21″ x 6″ x (3″–2¾″)	528	38′- 6″	42′- 0″
21″ x 6″ x 3″ No. 2 Wedge	21″ x 6″ x (3″–2½″)	264	17′- 6″	21′- 0″
21″ x 6″ x 3″ No. 3 Wedge	21″ x 6″ x (3″–2″)	132	7′- 0″	10′- 6″
21″ x 9″ x 3″ Straight	21″ x 9″ x 3″	....	.....	.....
21″ x 9″ x 3″ No. 1-X Wedge	21″ x 9″ x (3″–2⅞″)	1056	80′- 6″	84′- 0″
21″ x 9″ x 3″ No. 1 Wedge	21″ x 9″ x (3″–2¾″)	528	38′- 6″	42′- 0″
21″ x 9″ x 3″ No. 2 Wedge	21″ x 9″ x (3″–2½″)	264	17′- 6″	21′- 0″
21″ x 9″ x 3″ No. 3 Wedge	21″ x 9″ x (3″–2″)	132	7′- 0″	10′- 6″

STANDARD SIZES IN BASIC REFRACTORIES

TYPICAL STRAIGHT, ARCH, WEDGE AND KEY BRICK



Straight *Arch* *Wedge* *Key*

STANDARD 9″ x 4½″ x 2½″ SIZES

The complete list of Standard 9″ x 4½″ x 2½″ sizes is given on Pages 30 and 31

STANDARD 9″ x 4½″ x 3″ SIZES

The complete list of Standard 9″ x 4½″ x 3″ sizes is given on Pages 32 and 33

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 9″ x 6¾″ x 2½″ SIZES				
9″ x 6¾″ x 2½″ Straight	9″ x 6¾″ x 2½″	...	.....	.....
9″ x 6¾″ x 2½″ No. 1 Wedge	9″ x 6¾″ x (2½″–1⅞″)	91	4′- 6″	6′- 0″
9″ x 6¾″ x 2½″ No. 2 Wedge	9″ x 6¾″ x (2½″–1½″)	57	2′- 3″	3′- 9″
STANDARD 9″ x 6¾″ x 3″ SIZES				
9″ x 6¾″ x 3″ Straight	9″ x 6¾″ x 3″	...	.....	.....
9″ x 6¾″ x 3″ No. 1 Wedge	9″ x 6¾″ x (3″–2¾″)	227	16′- 6″	18′- 0″
9″ x 6¾″ x 3″ No. 2 Wedge	9″ x 6¾″ x (3″–2½″)	113	7′- 6″	9′- 0″
9″ x 6¾″ x 3″ No. 3 Wedge	9″ x 6¾″ x (3″–2″)	57	3′- 0″	4′- 6″
STANDARD 12″ x 6″ x 3″ SIZES				
12″ x 6″ x 3″ Straight	12″ x 6″ x 3″	...	.....	.....
12″ x 6″ x 3″ No. 1 Wedge	12″ x 6″ x (3″–2¾″)	302	22′- 0″	24′- 0″
12″ x 6″ x 3″ No. 2 Wedge	12″ x 6″ x (3″–2½″)	151	10′- 0″	12′- 0″
12″ x 6″ x 3″ No. 3 Wedge	12″ x 6″ x (3″–2″)	76	4′- 0″	6′- 0″
STANDARD 13½″ x 4½″ x 2½″ SIZES				
13½″ x 4½″ x 2½″ Straight	13½″ x 4½″ x 2½″	...	.....	.....
13½″ x 4½″ x 2½″ No. 1 Arch	13½″ x 4½″ x (2½″–2⅛″)	76	4′- 3″	5′- 0″
13½″ x 4½″ x 2½″ No. 2 Arch	13½″ x 4½″ x (2½″–1¾″)	38	1′- 9″	2′- 6″
13½″ x 4½″ x 2½″ No. 3 Arch	13½″ x 4½″ x (2½″–1″)	19	0′- 6″	1′- 3″

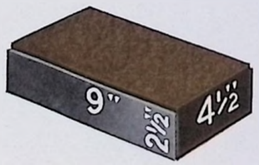
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STANDARD SIZES IN BASIC REFRACTORIES

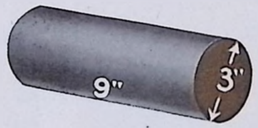
Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
STANDARD 13½" x 4½" x 3" SIZES				
13½" x 4½" x 3" Straight	13½" x 4½" x 3"	...	.....	.....
13½" x 4½" x 3" No. 1 Arch	13½" x 4½" x (3"–2¾")	113	8'- 3"	9'- 0"
13½" x 4½" x 3" No. 2 Arch	13½" x 4½" x (3"–2½")	57	3'- 9"	4'- 6"
13½" x 4½" x 3" No. 3 Arch	13½" x 4½" x (3"–2")	29	1'- 6"	2'- 3"
13½" x 4½" x 3" No. 4 Arch	13½" x 4½" x (3"–1")	15	0'- 4½"	1'- 1½"
STANDARD 13½" x 6" x 2½" SIZES				
13½" x 6" x 2½" Straight	13½" x 6" x 2½"	...	.....	.....
13½" x 6" x 2½" No. 1 Key	13½" x (6"–5") x 2½"	85	11'- 3"	13'- 6"
13½" x 6" x 2½" No. 2 Key	13½" x (6"–4⅜") x 2½"	52	6'- 0"	8'- 3"
13½" x 6" x 2½" No. 3 Key	13½" x (6"–3") x 2½"	29	2'- 3"	4'- 6"
STANDARD 13½" x 6" x 3" SIZES				
13½" x 6" x 3" Straight	13½" x 6" x 3"	...	.....	.....
13½" x 6" x 3" No. 1 Key	13½" x (6"–5") x 3"	85	11'- 3"	13'- 6"
13½" x 6" x 3" No. 2 Key	13½" x (6"–4⅜") x 3"	52	6'- 0"	8'- 3"
13½" x 6" x 3" No. 3 Key	13½" x (6"–3") x 3"	29	2'- 3"	4'- 6"

METALKASE BRICK

Sizes which are Standard in other basic refractories are also Standard in Metalkase Brick



9" Straight
9" x 4½" x 2½"



9" Round
9" long, 3" diameter
13½" Round
13½" long, 3" diameter
18" Round
18" long, 3" diameter



13½" x 6¾" x 2½" Straight



13½" x 6¾" x 3" Straight

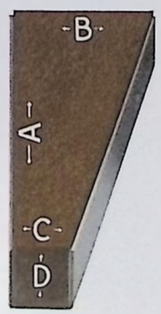
SIZES OTHER THAN STANDARD IN BASIC REFRACTORIES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9" x 6¾" x 2½" No. 1-X Wedge	9" x 6¾" x (2½"–2¼")	227	13'- 6"	15'- 0"
12" x 6" x 3" No. 1-X Wedge	12" x 6" x (3"–2⅞")	604	46'- 0"	48'- 0"
12" x 9" x 3" Straight	12" x 9" x 3"	...	.....	.....
12" x 9" x 3" No. 1-X Wedge	12" x 9" x (3"–2⅞")	604	46'- 0"	48'- 0"
12" x 9" x 3" No. 1 Wedge	12" x 9" x (3"–2¾")	302	22'- 0"	24'- 0"
12" x 9" x 3" No. 2 Wedge	12" x 9" x (3"–2½")	151	10'- 0"	12'- 0"
12" x 9" x 3" No. 3 Wedge	12" x 9" x (3"–2")	76	4'- 0"	6'- 0"
13½" x 6" x 3" No. 1 Arch	13½" x 6" x (3"–2¾")	151	11'- 0"	12'- 0"
13½" x 6" x 3" No. 2 Arch	13½" x 6" x (3"–2½")	76	5'- 0"	6'- 0"
13½" x 6" x 3" No. 3 Arch	13½" x 6" x (3"–2")	38	2'- 0"	3'- 0"
13½" x 6" x 3" No. 1-X Wedge	13½" x 6" x (3"–2⅞")	679	51'- 9"	54'- 0"
13½" x 6" x 3" No. 1 Wedge	13½" x 6" x (3"–2¾")	340	24'- 9"	27'- 0"
13½" x 6" x 3" No. 2 Wedge	13½" x 6" x (3"–2½")	170	11'- 3"	13'- 6"
13½" x 6" x 3" No. 3 Wedge	13½" x 6" x (3"–2")	85	4'- 6"	6'- 9"
13½" x 9" x 3" Straight	13½" x 9" x 3"	...	.....	.....
13½" x 9" x 3" No. 1 Arch	13½" x 9" x (3"–2¾")	227	16'- 6"	18'- 0"
13½" x 9" x 3" No. 2 Arch	13½" x 9" x (3"–2½")	113	7'- 6"	9'- 0"
13½" x 9" x 3" No. 3 Arch	13½" x 9" x (3"–2")	57	3'- 0"	4'- 6"
13½" x 9" x 3" No. 1-X Wedge	13½" x 9" x (3"–2⅞")	679	51'- 9"	54'- 0"
13½" x 9" x 3" No. 1 Wedge	13½" x 9" x (3"–2¾")	340	24'- 9"	27'- 0"
13½" x 9" x 3" No. 2 Wedge	13½" x 9" x (3"–2½")	170	11'- 3"	13'- 6"
13½" x 9" x 3" No. 3 Wedge	13½" x 9" x (3"–2")	85	4'- 6"	6'- 9"

METALKASE STRAIGHTS

18" x 4½" x 2½" Straight | 18" x 4½" x 3" Straight | 18" x 6¾" x 2½" Straight | 18" x 6¾" x 3" Straight

METALKASE DOOR JAMB BRICK



Name of Brick	Dimensions			
	A	B	C	D
DJ-1-2½	9"	4½"	1½"	2½"
DJ-1-3	9"	4½"	1½"	3"
DJ-2-2½	9"	6¾"	3¾"	2½"
DJ-2-3	9"	6¾"	3¾"	3"
DJ-3-2½	9"	9"	6"	2½"
DJ-3-3	9"	9"	6"	3"
BS-115-2½	13½"	6¾"	2¾"	2½"
BS-115-3	13½"	6¾"	2¾"	3"
BS-116-2½	13½"	9"	5"	2½"
BS-116-3	13½"	9"	5"	3"
DJ-18-1-2½	18"	6¾"	2¾"	2½"
DJ-18-1-3	18"	6¾"	2¾"	3"
DJ-18-2-2½	18"	9"	5"	2½"
DJ-18-2-3	18"	9"	5"	3"

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STANDARD SIZES IN INSULATING FIRE BRICK

		Page
H-W 16	Standard 9″ x 4½″ x 2½″ Straight	30, 31
H-W 20	All Standard 9″ x 4½″ x 2½″ and 9″ x 4½″ x 3″ Sizes	30–33
H-W 23	All Standard 9″ x 4½″ x 2½″ and 9″ x 4½″ x 3″ Sizes	30–33
H-W 26	All Standard 9″ x 4½″ x 2½″ and 9″ x 4½″ x 3″ Sizes	30–33
H-W 28	All Standard 9″ x 4½″ x 2½″ and 9″ x 4½″ x 3″ Sizes	30–33
H-W 444	Standard 9″ x 4½″ x 2½″ Straight	30, 31

STANDARD SIZES IN ACID-PROOF BRICK

STANDARD 9″ x 4½″ x 2½″ SIZES

The complete list of Standard 9″ x 4½″ x 2½″ sizes is given on Pages 30 and 31

STANDARD 9″ x 4½″ x 3″ SIZES

The complete list of Standard 9″ x 4½″ x 3″ sizes is given on Pages 32 and 33

STANDARD 9″ x 4½″ x 2½″ CIRCLE BRICK

Name	Outside Chord	Inside Chord	Radial Dimension	Thickness	Diameter of Ring		Number Per Ring
					Inside	Outside	
24–33 Circle	9″	6 17/32″	4½″	2½″	24″	33″	12
36–45 Circle	9″	7 3/16″	4½″	2½″	36″	45″	16
48–57 Circle	9″	7 19/32″	4½″	2½″	48″	57″	20
60–69 Circle	9″	7 13/16″	4½″	2½″	60″	69″	24
72–81 Circle	9″	8″	4½″	2½″	72″	81″	29
84–93 Circle	9″	8 1/8″	4½″	2½″	84″	93″	33
96–105 Circle	9″	8 7/32″	4½″	2½″	96″	105″	37
108–117 Circle	9″	8 5/16″	4½″	2½″	108″	117″	41
120–129 Circle	9″	8 3/8″	4½″	2½″	120″	129″	45

TYPICAL SHAPES FOR BLAST FURNACE LININGS



9″ x 6″ x 2½″ Straight and 9″ x 6″ x 3″ Straight



9″ x 6″ x 2½″ Key and 9″ x 6″ x 3″ Key



13½″ x 6″ x 2½″ Straight and 13½″ x 6″ x 3″ Straight



13½″ x 6″ x 2½″ Key and 13½″ x 6″ x 3″ Key

STANDARD SIZES

Name	Dimensions	Number Per Ring	Diameter of Ring	
			Inside	Outside
9″ x 6″ x 2½″ Straight	9″ x 6″ x 2½″	..	.....	.....
9″ x 6″ x 2½″ No. 1 Key	9″ x (6″–5 3/8″) x 2½″	91	13′- 0″	14′- 6″
9″ x 6″ x 2½″ No. 2 Key	9″ x (6″–4 13/16″) x 2½″	48	6′- 0″	7′- 6″
9″ x 6″ x 2½″ No. 3 Key	9″ x (6″–3″) x 2½″	19	1′- 6″	3′- 0″
9″ x 6″ x 3″ Straight	9″ x 6″ x 3″	..	.....	.....
9″ x 6″ x 3″ No. 1 Key	9″ x (6″–5 3/8″) x 3″	91	13′- 0″	14′- 6″
9″ x 6″ x 3″ No. 2 Key	9″ x (6″–4 13/16″) x 3″	48	6′- 0″	7′- 6″
9″ x 6″ x 3″ No. 3 Key	9″ x (6″–3″) x 3″	19	1′- 6″	3′- 0″
13½″ x 6″ x 2½″ Straight	13½″ x 6″ x 2½″	..	.....	.....
13½″ x 6″ x 2½″ No. 1 Key	13½″ x (6″–5″) x 2½″	85	11′- 3″	13′- 6″
13½″ x 6″ x 2½″ No. 2 Key	13½″ x (6″–4 3/8″) x 2½″	52	6′- 0″	8′- 3″
13½″ x 6″ x 2½″ No. 3 Key	13½″ x (6″–3″) x 2½″	29	2′- 3″	4′- 6″
13½″ x 6″ x 3″ Straight	13½″ x 6″ x 3″	..	.....	.....
13½″ x 6″ x 3″ No. 1 Key	13½″ x (6″–5″) x 3″	85	11′- 3″	13′- 6″
13½″ x 6″ x 3″ No. 2 Key	13½″ x (6″–4 3/8″) x 3″	52	6′- 0″	8′- 3″
13½″ x 6″ x 3″ No. 3 Key	13½″ x (6″–3″) x 3″	29	2′- 3″	4′- 6″

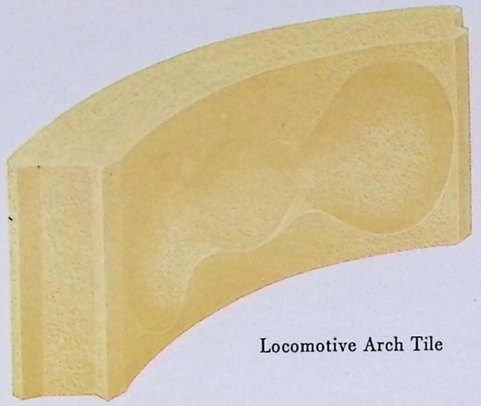
STANDARD BLAST FURNACE BOTTOM BLOCKS — 18″ x 9″ x 4½″

Number per course for blocks laid on end

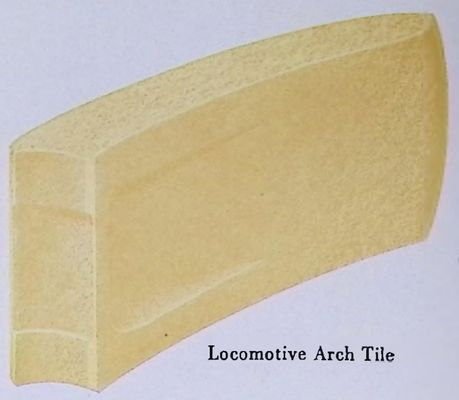
Diameter of Hearth Jacket	No. of Blocks	Diameter of Hearth Jacket	No. of Blocks	Diameter of Hearth Jacket	No. of Blocks	Diameter of Hearth Jacket	No. of Blocks
10′- 0″	303	17′- 0″	847	24′- 0″	1665	31′- 0″	2756
10′- 6″	333	17′- 6″	897	24′- 6″	1734	31′- 6″	2845
11′- 0″	364	18′- 0″	947	25′- 0″	1804	32′- 0″	2935
11′- 6″	397	18′- 6″	999	25′- 6″	1876	32′- 6″	3026
12′- 0″	431	19′- 0″	1053	26′- 0″	1949	33′- 0″	3119
12′- 6″	466	19′- 6″	1108	26′- 6″	2023	33′- 6″	3213
13′- 0″	503	20′- 0″	1164	27′- 0″	2099	34′- 0″	3308
13′- 6″	541	20′- 6″	1222	27′- 6″	2176	34′- 6″	3405
14′- 0″	581	21′- 0″	1281	28′- 0″	2255	35′- 0″	3503
14′- 6″	621	21′- 6″	1342	28′- 6″	2335	35′- 6″	3603
15′- 0″	664	22′- 0″	1403	29′- 0″	2417	36′- 0″	3704
15′- 6″	708	22′- 6″	1467	29′- 6″	2500	36′- 6″	3806
16′- 0″	753	23′- 0″	1531	30′- 0″	2584	37′- 0″	3909
16′- 6″	799	23′- 6″	1598	30′- 6″	2669	37′- 6″	4013

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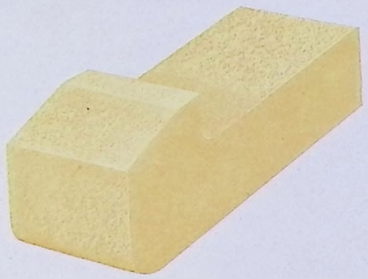
TYPICAL SHAPES FOR BOILER SETTINGS



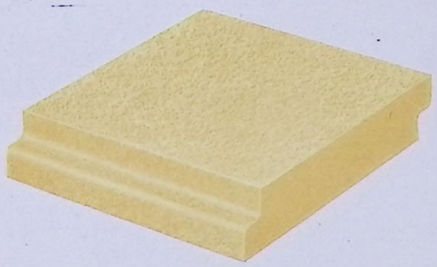
Locomotive Arch Tile



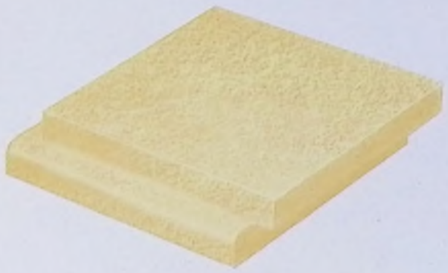
Locomotive Arch Tile



Header Tile



Shiplap Tile (SL-2)
(Lapped on Two Sides)



Shiplap Tile (SL-4)
(Lapped on Four Sides)



Wedge Baffle Tile



Marine Boiler Tile
9″ x 4½″ x 2½″ overall



Horizontal Baffle Tile



Marine Boiler Tile
9″ x 4½″ x 2½″ overall

TYPICAL SHAPES FOR BOILER SETTINGS

SQUARE EDGE TILE
or
RECTANGULAR BAFFLE TILE

12″ x 6″ x 2″	18″ x 6″ x 2″
12″ x 6″ x 2½″	18″ x 6″ x 2½″
12″ x 6″ x 3″	18″ x 6″ x 3″
12″ x 9″ x 2″	18″ x 9″ x 2″
12″ x 9″ x 2½″	18″ x 9″ x 2½″
12″ x 9″ x 3″	18″ x 9″ x 3″
12″ x 12″ x 2″	18″ x 12″ x 2″
12″ x 12″ x 2½″	18″ x 12″ x 2½″
12″ x 12″ x 3″	18″ x 12″ x 3″



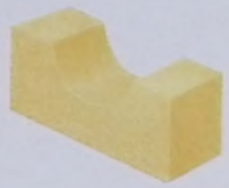
The above sizes are the ones most commonly used. However, square edge tile are available in various other lengths, widths and thicknesses.



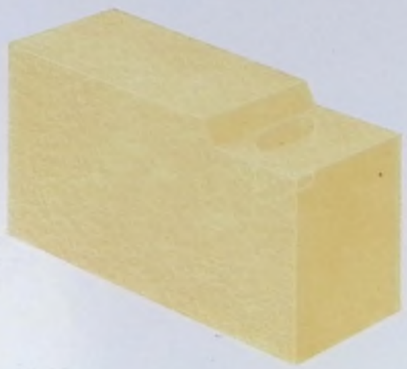
Tube Tile



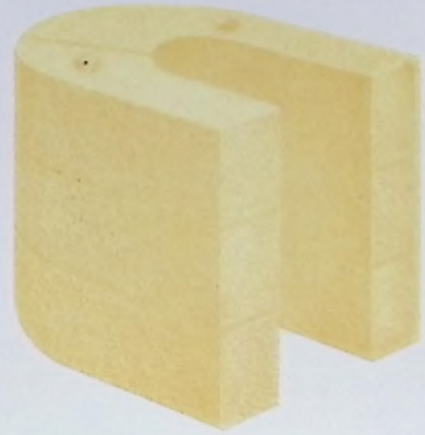
Tube Tile



C Tile



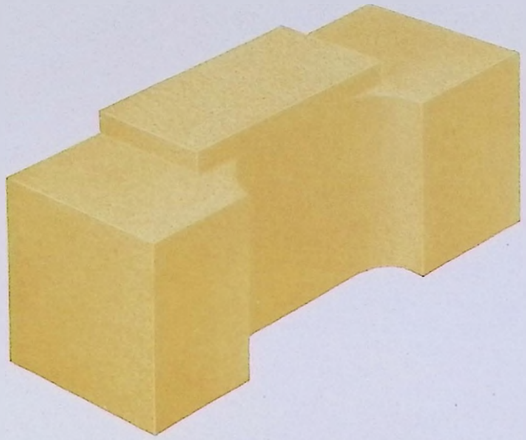
Anchor Tile



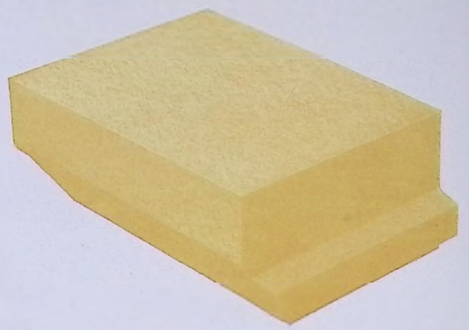
Assembly of Blow-off Protection Tile

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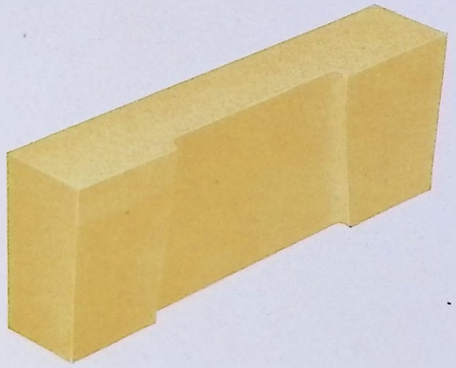
TYPICAL SHAPES FOR CERAMIC KILNS



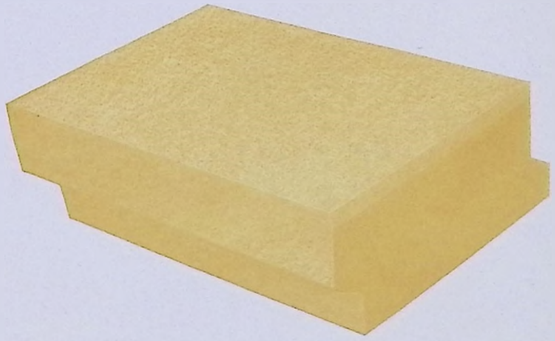
Riddle Tile



Car Top Shape



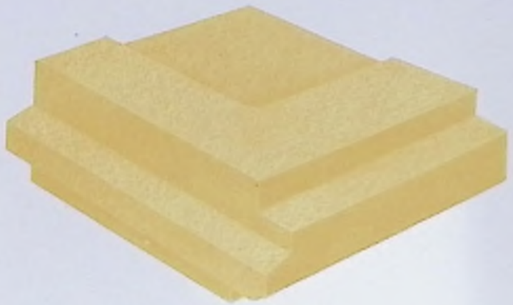
Riddle Tile



Car Top Shape



Muffle Tile

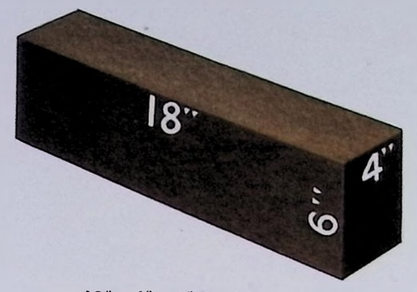


Car Top Shape

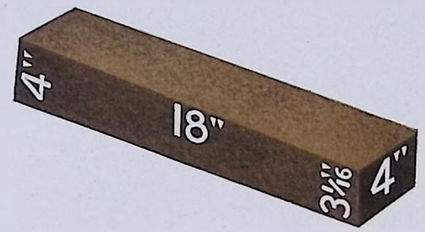
TYPICAL SHAPES FOR COPPER CONVERTERS



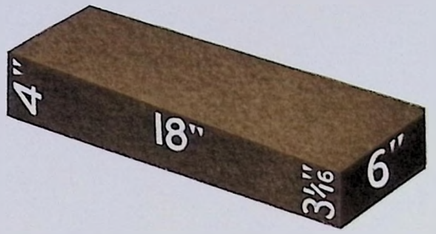
18″ x 4″ x 4″ Straight
and
15″ x 4″ x 4″ Straight
13″ x 4″ x 4″ Straight
12″ x 4″ x 4″ Straight



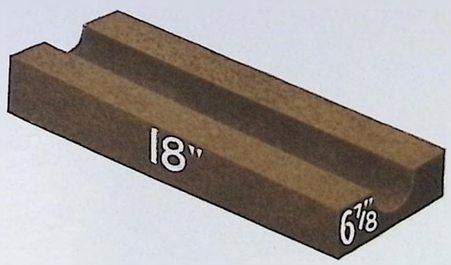
18″ x 6″ x 4″ Straight
and
15″ x 6″ x 4″ Straight



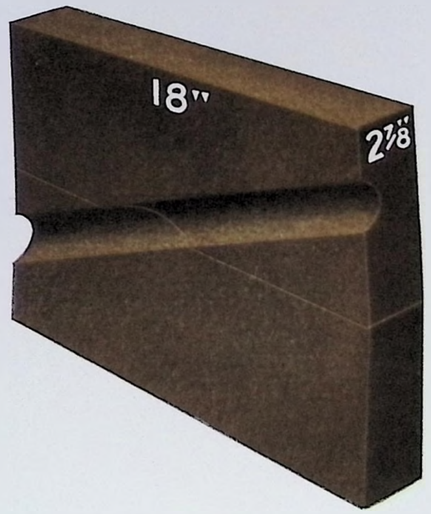
18″ x 4″ x (4″—3$\frac{1}{16}$″) Wedge
and
18″ x 4″ x (4″—2$\frac{13}{16}$″) Wedge
15″ x 4″ x (4″—3$\frac{1}{4}$″) Wedge
13″ x 4″ x (4″—3$\frac{5}{16}$″) Wedge
13″ x 4″ x (4″—3$\frac{3}{32}$″) Wedge
13″ x 4″ x (4″—3″) Wedge



18″ x 6″ x (4″—3$\frac{1}{16}$″) Wedge
and
15″ x 6″ x (4″—3$\frac{1}{4}$″) Wedge



Tuyere Shape



Tuyere Shapes

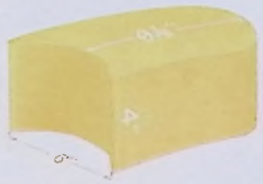
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TYPICAL SHAPES FOR CUPOLA LININGS

UNIVERSAL CUPOLA BLOCKS



Typical Assembly



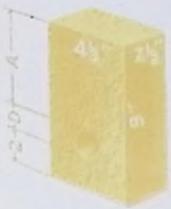
Shape 602-4

For Linings 6 Inches Thick

Diameter Inside Brickwork	No. Per Ring	Diameter Inside Brickwork	No. Per Ring	Diameter Inside Brickwork	No. Per Ring
....	..	4′-0″	18	6′-0″	26
....	..	4′-3″	19	6′-3″	27
2′-6″	12	4′-6″	20	6′-6″	28
2′-9″	13	4′-9″	21	6′-9″	29
3′-0″	14	5′-0″	22	7′-0″	30
3′-3″	15	5′-3″	23	7′-3″	31
3′-6″	16	5′-6″	24	7′-6″	32
3′-9″	17	5′-9″	25	8′-0″	34

Universal Cupola Blocks for linings 4½ inches thick and 9 inches thick also are available.

TAP-OUT AND SLAG HOLE BLOCKS FOR CUPOLAS



Tap-Out Block
(One-Hole Type)



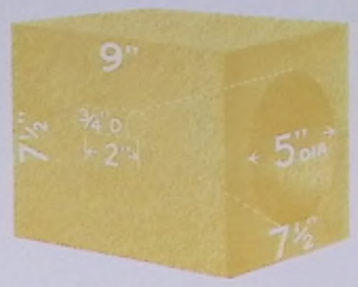
Tap-Out Block
(Two-Hole Type)



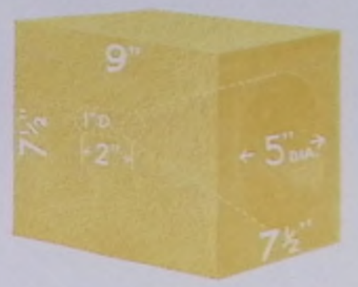
Slag Hole Block

Name of Block	A	D	Name of Block	A	D	Name of Block	D	Inside Diam.	Outside Diam.
T-1-A	6½″	½″	T-2-A	4″	½″	S-1-A	1½″	51″	60″
T-1-B	6¼″	¾″	T-2-B	3½″	¾″	S-1-B	2″	51″	60″
T-1-C	6″	1″	T-2-C	3″	1″				
T-1-D	5¾″	1¼″	T-2-D	2½″	1¼″				
T-1-E	5½″	1½″	T-2-E	2″	1½″				
T-1-F	5⅞″	1⅛″	T-2-F	3¾″	⅝″				

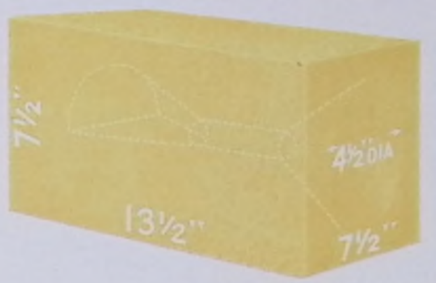
TYPICAL SHAPES FOR MALLEABLE IRON FURNACES



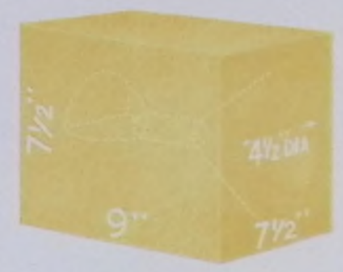
T.O.1. Tap-Out Block
9″ x 7½″ x 7½″
With ¾″ hole for Hand ladles



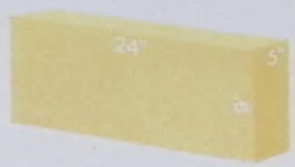
T.O.2. Tap-Out Block
9″ x 7½″ x 7½″
With 1″ hole for Bull ladles



Special Tap-Out Block
13½″ x 7½″ x 7½″



Special Tap-Out Block
9″ x 7½″ x 7½″



D.T.1. Door-Opening Tile
24″ x 9″ x 5″

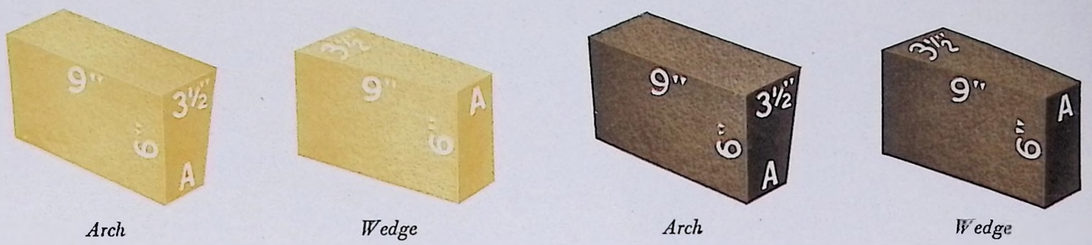


D.T.2. Door-Opening Tile
24″ x 13½″ x 5″

Standard Bung Sizes for Malleable Iron Furnaces are listed and illustrated on Page 36.

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ARCH AND WEDGE SHAPES FOR ROTARY KILNS



Arch *Wedge* *Arch* *Wedge*

FIRECLAY AND HIGH-ALUMINA BLOCKS — BASIC BLOCKS

Block Number	Inside Chord "A" of Block	Diameter of Brick Lining		Fireclay and High-Alumina Linings		Basic Linings	
				Number Required		Number Required Using No. 16 Gauge Plates	
		Inside	Outside	Per Ring	Per Foot	Per Ring	Per Foot
ARCH TYPE ROTARY KILN BLOCKS							
60-A-72	2 29/32"	60"	72"	64	85	63	84
66-A-78	2 31/32"	66"	78"	70	93	68	91
72-A-84	3"	72"	84"	75	100	74	98
78-A-90	3 1/32"	78"	90"	80	107	79	105
84-A-96	3 1/16"	84"	96"	86	114	84	112
90-A-102	3 3/32"	90"	102"	91	121	89	119
96-A-108	3 1/8"	96"	108"	96	128	95	126
102-A-114	3 1/8"	102"	114"	102	136	100	133
108-A-120	3 5/32"	108"	120"	107	143	105	140
114-A-126	3 5/32"	114"	126"	113	150	111	148
120-A-132	3 3/16"	120"	132"	118	157	116	155
123-A-135	3 3/16"	123"	135"	121	161	119	158
126-A-138	3 3/16"	126"	138"	123	164	122	162
132-A-144	3 7/32"	132"	144"	129	172	127	169
138-A-150	3 7/32"	138"	150"	134	179	132	176
WEDGE TYPE ROTARY KILN BLOCKS							
66-W-84	2 3/4"	66"	84"	75	150	74	148
72-W-90	2 15/16"	72"	90"	80	160	79	158
78-W-96	2 27/32"	78"	96"	86	172	84	168
84-W-102	2 7/8"	84"	102"	91	182	89	178
90-W-108	2 29/32"	90"	108"	96	192	95	190
96-W-114	2 15/16"	96"	114"	102	204	100	200
102-W-120	2 31/32"	102"	120"	107	214	105	210
108-W-126	3"	108"	126"	113	226	111	222
114-W-132	3 1/32"	114"	132"	118	236	116	232
117-W-135	3 1/32"	117"	135"	121	242	119	238
120-W-138	3 1/32"	120"	138"	123	246	122	244
126-W-144	3 1/16"	126"	144"	129	258	127	254
132-W-150	3 3/32"	132"	150"	134	268	132	264

NOTE: To facilitate the keying of Standard Arch Type or Wedge Type Rotary Kiln Blocks, Split Blocks are available of both two-third (⅔) and three-quarter (¾) thickness. Two (2) each of these should be included for each ring of standard full size blocks. They are correctly specified by the Block Number followed by a dash and the fraction to indicate the thickness desired, thus, 60-A-72-⅔ and 60-A-72-¾ or 66-W-84-⅔ and 66-W-84-¾.

TYPICAL SKEWBACK SHAPES

STANDARD 9 INCH SIZES

2½ Inch Series
9" Edge Skew
9" 48° End Skew
9" 60° End Skew
9" 48° Side Skew
9" 60° Side Skew
See Illustrations, Page 31

3 Inch Series
9" Edge Skew
9" 48° End Skew
9" 60° End Skew
9" 48° Side Skew
9" 60° Side Skew
See Illustrations, Page 33

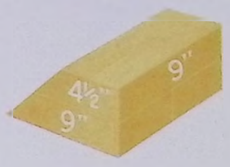
SKEWBACKS BUILT WITH STANDARD 9 INCH SIZES



For Arch 4½" Thick
Rise 1½" Per Foot of Span

Skewback consists of
1—2" Split Brick 2½" Series
1—9" Feather Edge 2½" Series

See Illustrations, Page 31



For Arch 4½" Thick
Rise 2⅝" Per Foot of Span

Skewback consists of
2—9" 48° End Skew 2½" Series
1—9" 48° Side Skew 2½" Series
1—9" Soap 2½" Series

See Illustrations, Page 31



For Arch 9" Thick
Rise 2⅝" Per Foot of Span

Skewback consists of
2—9" 48° End Skew 2½" Series
2—9" 48° Side Skew 2½" Series
1—9" Soap 2½" Series

See Illustrations, Page 31

SKEWBACK SHAPES OTHER THAN STANDARD



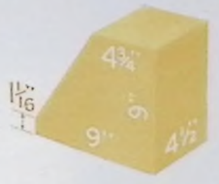
Angle "A" Skew
(9"—4½") x 4½" x 2½"



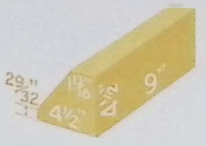
Angle "B" Skew
(9"—0") x 4½" x 2½"



Angle "C" Skew
(9"—4½") x 4½" x 2½"



Shape 56-9
For Arch 9" Thick
Rise 1½" Per Foot of Span



Shape 74-4½
For Arch 4½" Thick
Rise 2" Per Foot of Span



Shape 74-9
For Arch 9" Thick
Rise 2" Per Foot of Span

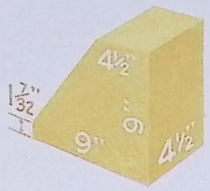
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SKEWBACK SHAPES OTHER THAN STANDARD (Continued)

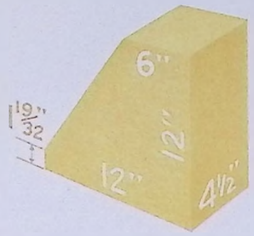
FOR ARCHES WITH RISE 1 19/32" * PER FOOT OF SPAN
CENTRAL ANGLE 60 DEGREES



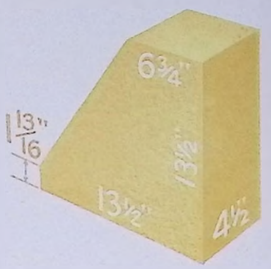
60-4½
For Arch 4½" Thick



60-9
For Arch 9" Thick

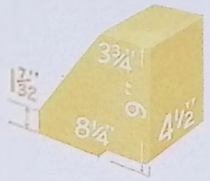


60-12
For Arch 12" Thick

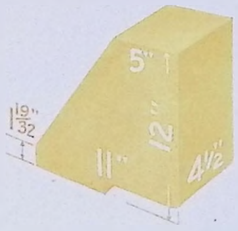


60-13½
For Arch 13½" Thick

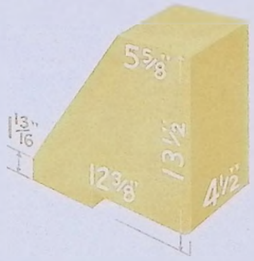
SKEWBACK BRICK WITH CUTOUTS FOR STEEL ANGLE SUPPORTING FRAMEWORK



60-9-A
For Arch 9" Thick



60-12-A
For Arch 12" Thick



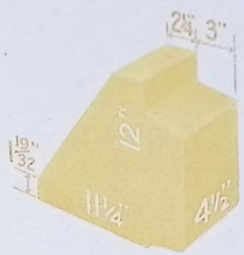
60-13½-A
For Arch 13½" Thick

Skewback	Maximum Dimensions of Steel Angle	
	Shorter Leg	Thickness
60- 9-A	4"	¾"
60-12-A	6"	1"
60-13½-A	8"	1⅛"

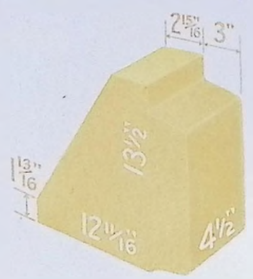
SKEWBACK BRICK WITH CUTOUTS FOR STEEL CHANNEL SUPPORTING FRAMEWORK



60-9-C
For Arch 9" Thick



60-12-C
For Arch 12" Thick

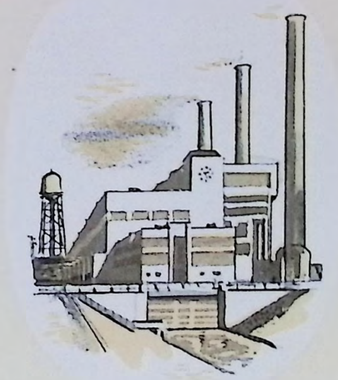


60-13½-C
For Arch 13½" Thick

Skewback	Maximum Dimensions of Steel Channel		
	Channel Size	Flange Width	Web Thickness
60- 9-C	12"	3 13/32"	¾"
60-12-C	12"	3 13/32"	¾"
60-13½-C	15"	3 13/16"	13/16"

* More exactly, 1.608"

FIRECLAY REFRACTORIES



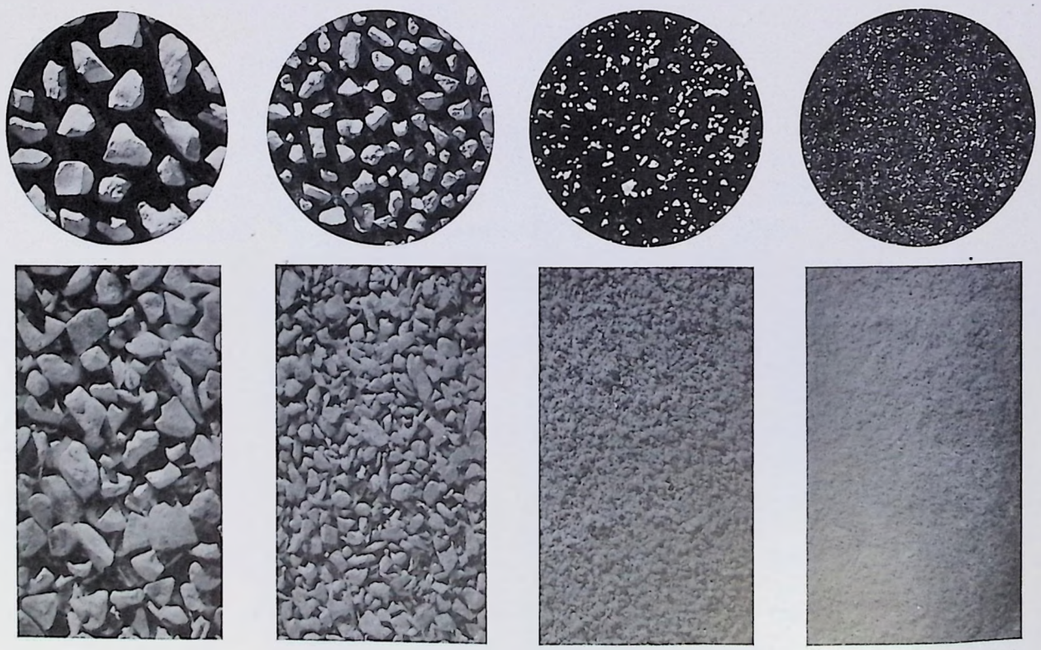
HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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FIRECLAY REFRACTORIES

THE plants at which Harbison-Walker manufactures fireclay brick are situated in Alabama, Kentucky, Missouri, Ohio, Pennsylvania and Texas. The clays used are taken from mines in those states and in Georgia, and include a wide variety of high-grade flint, semi-flint, and plastic bond clays as well as kaolin. The various sizes and shapes of brick are formed by three principal methods, known as the power press, the extrusion, and the hand-made processes. Certain shapes, however, are made by the air-ramming process. Each method produces brick of characteristic texture.

Most Harbison-Walker fireclay brick of the standard sizes are made by the power press process. The clays are ground in a dry pan, screened to the desired sizes, blended and thoroughly mixed with a small but definitely controlled amount of water. The moistened batch is then fed to a mechanically operated press in which the brick are formed under high pressure. One of the outstanding contributions to the refractories art has been the development of the power press process to its present state of perfection, with resultant improvement in the resistance of the brick to spalling and to slag attack, and in their ability to withstand pressure while hot. Proper proportioning of the various particle sizes is accomplished most accurately by screening the ground brick batch into various size fractions, storing these fractions in separate bins, and later recombining them. A close approximation of the proper sizing is also attainable without separation of the brick batch into various fractions, by definite control of each step in the grinding operation.



A ground flint clay separated into its component sizes by screening. These fractions are later blended in definite proportions for use in making power pressed brick.

In making machine-made brick of the extruded type the clays are ground in a dry pan, blended and tempered with water in a mixer, and extruded through a die in the form of a dense column. This column is cut by means of wires into brick, which are re-pressed to give them sharp corners and edges and smooth surfaces. Most extruded brick are of high density.

An important development of relatively recent years is a method by which a high vacuum is applied during the forming of brick made by either the power press or the extrusion process. While blends of certain clays of optimum particle sizing are not benefited by vacuum pressing, many brick made in this way have a more homogeneous texture, and are harder, stronger, less porous, and heavier than those made without vacuum. As a consequence they are more resistant to impregnation and corrosion by slags and to penetration by gases. For these obvious reasons the vacuum method of manufacture is of particular value in the production of fireclay refractories for use in blast furnace linings and in regenerator checkers.

The hand molding of standard sizes has been almost entirely supplanted by machine molding. The hand-made process, when employed for the manufacture of standard sizes, consists in grinding the clay batch in a wet pan, hand-molding, partial drying on a hot floor, and re-pressing in a press operated by hand.

Special shapes, especially if large or intricate, are usually molded by hand. The clays are ground and blended in proper proportion in a wet pan with sufficient water to give the most desirable consistency. Shapes which must be made from mixes containing high percentages of calcined clays are often molded by the air-ramming method. Shape-molding requires a high degree of skill and experience on the part of the molders. The high quality and excellent workmanship of special shapes made by Harbison-Walker are well known throughout the consuming industries.

The brick formed by any of the processes described are dried either on hot floors or in tunnel or humidity driers, and fired in periodic down-draft kilns, or in continuous car-type tunnel kilns. The temperature of firing depends upon the maturing temperature of the clays, and upon the service for which the brick are intended.

The properties of the finished product are dependent upon the character and amounts of the different clays in the mix, the fineness of grind, the relative proportions of particles of different sizes, the process of manufacture, the moisture content during forming, the forming pressure and the firing temperature. Flexibility in the firing procedure is obtained by Harbison-Walker through the use of both periodic kilns and continuous tunnel kilns.

Chemical analyses and tests for refractoriness and other physical properties render possible the selection of the most suitable clays for each specific purpose. By controlled variations in the details of manufacture, brick are produced having the physical properties required for any particular service. Constant laboratory control of all steps in the process of manufacture contributes to uniformity of chemical and physical properties, workmanship and size of the finished product.

SUPER-DUTY FIRECLAY BRICK

The outstanding properties of super-duty fireclay brick are high refractoriness, alumina content of 40 to 44%, strength and constancy of volume at high temperatures, low porosity, high resistance to fluxing, and remarkable resistance to thermal spalling. Harbison-Walker

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brands of super-duty fireclay brick are better than it once seemed possible that any fireclay brick could be. Millions of these brick in service testify to the savings effected by their use.

The superior properties of H-W super-duty brick result from the high quality and purity of the clays used, and from the operating technique followed in their manufacture. By controlled sizing of the grains, a texture is obtained which is relatively coarse, yet dense and impervious, and which imparts to the brick high resistance to thermal shock over the entire range of furnace operating temperatures.

In the application of super-duty fireclay brick, it is important that standard sizes which can be made by the power press method of manufacture be used to the greatest possible extent. Large or intricate shapes must necessarily be made by hand or by the air-ramming method. While super-duty shapes so made have the same refractoriness as those manufactured by the power-press process, they do not possess some of the other desirable physical properties to the fullest degree.

HIGH DUTY FIRECLAY BRICK

Before the introduction of super-duty fireclay brick, those now classified as high duty brick had to meet all the demands of industry for fireclay refractories for service under severe operating conditions. This they did with marked success. As furnace conditions in many industries became increasingly severe, a field developed which could be served adequately only by products of higher refractoriness. In their own field, however, high duty fireclay brick still are used most economically, and they will continue to be used to the amount of hundreds of millions annually.

In all districts in which the company manufactures fireclay refractories, Harbison-Walker has extensive reserves of clays adapted to the manufacture of high duty fireclay brick. Blending of these clays in different proportions and variations in the methods of processing make possible the production of brick having a wide range in their physical properties and utility for many different service requirements.

Even within the temperature range for which intermediate and low duty brick are amply refractory, the use of high duty brick is often an economy, since temperature of furnace operation is not the only factor which affects the life of the refractories. High duty brick are more resistant to spalling influences than are fireclay products of lower refractoriness; and unlike intermediate or low duty brick they may be burned hard enough to render them very resistant to disintegration by carbon monoxide gas. When costs of transportation and of handling and laying are considered, it is evident that structures built of high duty brick cost little more than those built of less refractory materials.

INTERMEDIATE AND LOW DUTY FIRECLAY BRICK

In certain portions of many industrial furnaces, the refractory structure is subjected to temperatures which are relatively moderate or low. For such conditions, brick of the intermediate or even the low duty class may give excellent service. In the low temperature range, these brick are sometimes stronger and more resistant to abrasion than high duty brick.

Harbison-Walker manufactures intermediate duty fireclay brick by the power press and extrusion processes. Equal care in workmanship and maintenance of quality is exercised as in the making of more refractory products. The standard sizes are the same, hence in construction no difficulties arise from the use of Harbison-Walker intermediate or low duty brick as backing for brick of higher refractoriness in the same furnace walls.

Intermediate and low duty brick in general are dense, mechanically strong, tough and resistant to abrasion and to slag action at moderate temperatures. For service in which there are rapidly fluctuating temperatures, power pressed brick are to be preferred to those made by the extrusion process. Intermediate and low duty brick show little permanent change in volume when heated within the temperature ranges for which they are suited.

MORTAR MATERIALS

It is important that fireclay brick be laid with mortar material of proper quality. This may be either finely ground fire clay, or high temperature bonding mortar, such as HARWACO BOND, FIREBOND, or THERMOLITH, as governed by the specific service requirements.

Harbison-Walker super-duty brick are usually laid with HARWACO BOND. For conditions requiring a hot-setting bonding mortar, H-W SUPER-DUTY MORTAR is supplied. For service in which a bonding mortar with a chrome base is desired, THERMOLITH is recommended.

STOCKS

At all Harbison-Walker plants where fireclay refractories are made, ample stocks are maintained of standard 9-inch straight brick and the corresponding series of sizes, as well as of other standard sizes and modified shapes for which there is a continuing demand for substantial quantities. The stocks include the sizes normally required for the linings of boiler furnaces, cupolas, malleable iron furnaces, rotary lime and cement kilns, and shaft lime kilns.

An adequate stock of locomotive arch tile, of tile for suspended arches, and of rectangular checker brick expedites shipment. At the company's plants where blast furnace refractories are manufactured, an endeavor is made to keep in stock complete furnace linings, as well as refractories for the walls and domes of stoves.

Shipments can be made of either straight or mixed carloads of all of the brands manufactured at any one plant.

For Provision to be Made for Thermal Expansion — *See page 255*

For Weights of Refractory Brick — *See page 247*

For Amounts of Mortar Material Required for Laying Brick — *See page 247*

For Other Data on Mortar Materials — *See pages 111 – 118*

For Standard and Other Sizes — *See pages 29 – 48*

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BRANDS MADE IN ALABAMA

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
High Duty	H-W Crown	P.P., V.P., Ext., S.M.	General high duty service.
Intermediate Duty	Wylam	P.P., Ext.	Used as backing for high duty brick, as stack linings, and for general intermediate duty service, especially where resistance to abrasion is important.
Abrasion Resistant	Wylam-A	P.P., Ext.	Rotary and shaft kiln linings.

* *P.P. = Power Pressed V.P. = Vacuum Pressed Ext. = Extruded S.M. = Shape Molded*

Early in the present century, when the Alabama steel industry was just beginning to assume a position of importance, Harbison-Walker built a plant at Fairfield near Birmingham. The plant produced both silica and fireclay brick, and was initially of ample size to supply the needs of the growing southern industries. Some years later the demand for refractories in the south had increased to such an extent that the output of the Fairfield plant was insufficient to meet the needs. A second plant was then erected at Bessemer, Alabama. At present, fireclay brick are made at Bessemer and silica brick at Fairfield.

From the beginning of the company's operations in Alabama, bonding clay has been secured from that state. For many years, high grade flint clay needed for the production of high duty fireclay brick was necessarily obtained from Kentucky. Eventually, a successful method was developed for treatment of the high quality southern clays and kaolins, which are now used in place of the Kentucky flint clay. The kaolin, which in its natural state is subject to high shrinkage in drying and firing, is now completely shrunk before use by calcination at high temperatures in a rotary kiln in the company's plant at Bessemer.

FOR HIGH DUTY SERVICE

H-W Crown is a high duty fireclay brick of exceptional merit. Its major constituent is highly refractory Georgia kaolin. The notable advance in the preparation of the clays by high temperature calcination in a rotary kiln has contributed greatly to the outstanding properties of H-W Crown. The constituent materials for this brick are ground and screened to give the proper grain sizing. The brick are formed either by the vacuum power press or by the de-aired extrusion process. The firing procedure is such as to develop the desirable properties of the brick to the maximum degree.

The workmanship of H-W Crown corresponds to the best in the industry. The high refractoriness of this brand is evidenced by its Pyrometric Cone Equivalent of 32½, corresponding to a temperature of 3131° F. Other physical properties include mechanical strength, stability of volume at high temperatures, and exceptional resistance to thermal shock.

H-W Crown brick are well adapted for service wherever high duty fireclay brick are required, as for example in boiler settings, in various metallurgical furnace constructions, in glass furnaces and in rotary kiln linings.

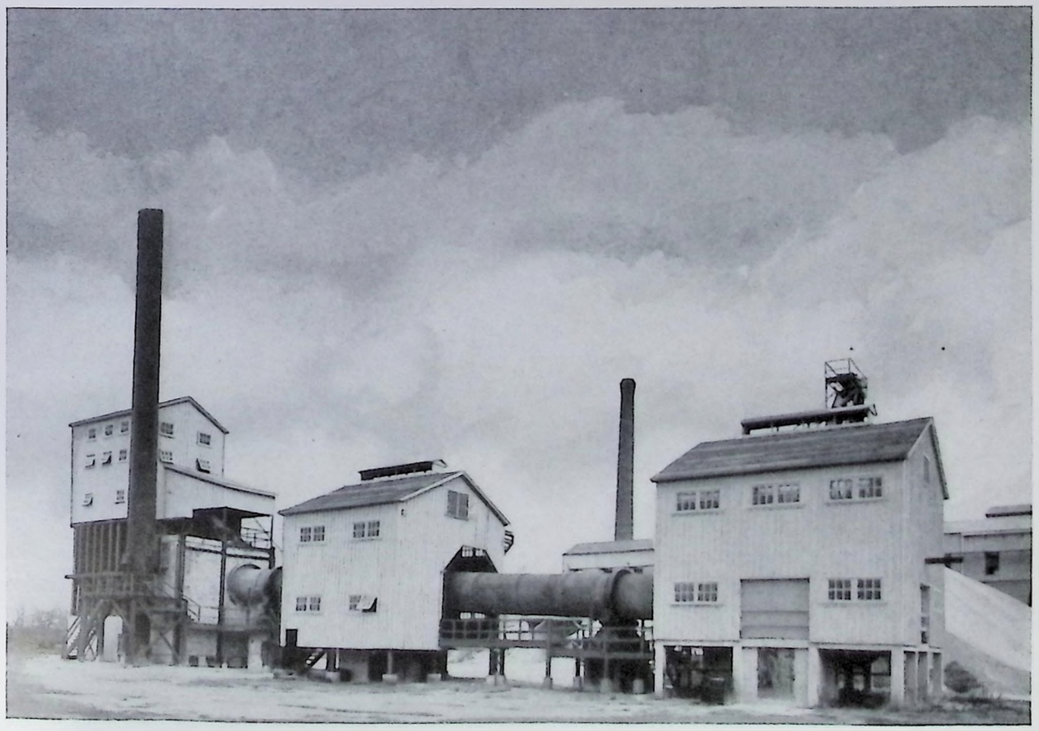
FOR INTERMEDIATE DUTY SERVICE

Wylam fireclay brick are made from a blend of selected refractory clays with a proportion of pre-calcined material. They are formed by both the de-aired extrusion process and the vacuum power process and are dense and of low porosity. Wylam brick have a P.C.E. of Cone 28, corresponding to 2939° F. They are strong, of good workmanship, and uniform in size. These properties are essential for good construction and contribute to low cost of bricklaying.

Wylam brick are used for backing up courses in boiler settings, for stack linings and for various other uses where intermediate duty brick may be employed to advantage.

FOR HIGHEST RESISTANCE TO ABRASION

Wylam A brick are used for the linings of furnaces in which the brick are subjected to the most severe abrasion at moderate temperature. They render outstanding service in the chain sections of rotary lime sludge kilns and rotary cement kilns, and in the feed ends of rotary lime and dolomite kilns. In shaft kilns for burning limestone, Wylam A is used in the top sections of the linings, which are subjected to greatest mechanical wear. Another important application of Wylam A is in coolers, of rotary and other types.



Rotary Kiln Plant for Calcination of Kaolin at Bessemer Works, Bessemer, Alabama

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BRANDS MADE IN KENTUCKY

CLASS	BRAND	PROCESS *	TYPICAL SERVICE
Super-Duty	Boone	V.P., Ext., S.M.	General super-duty service.
	Kenmore	V.P., Ext., S.M.	For severe super-duty service, where maximum constancy of volume at high temperatures and high resistance to spalling are important.
High Duty	H-W High Grade XX	V.P., Ext., S.M.	General high duty service.
	H-W High Grade XX Bung	P.P.	Malleable and air furnace roofs.
	H-W High Grade S	V.P.	Cupola linings, malleable furnace side walls, and other service for which a very dense brick is needed.
BLAST FURNACE BRICK			
Blast Furnace	H-W H & B	V.P.	Blast furnace hearth and bosh and lower inwall.
	H-W Inwall	V.P.	Blast furnace upper inwall.
	H-W Top	V.P.	Blast furnace top.
	H-W 18-Ky	V.P.	Blast furnace hearth and bosh, inwall and top.
	H-W Bottom Blocks	V.P.	Blast furnace hearths.
	H-W Stove	V.P., Ext.	Blast furnace stoves.

* *P.P. = Power Pressed* *V.P. = Vacuum Pressed* *Ext. = Extruded* *S.M. = Shape Molded*

For more than forty years the products of Harbison-Walker's Kentucky Works have met the highest standards of quality for refractories of fireclay material. The plant is modern in every respect, and includes both periodic kilns and a car-type continuous tunnel kiln, new in the Kentucky field. A well-equipped control laboratory aids in the development of constantly improving methods of manufacture and in the maintenance of superior quality.

FOR SUPER-DUTY SERVICE

Boone brick are dense and resistant to corrosive slags and destructive gases. As compared with high duty fireclay brick, they have the advantages of higher refractoriness, lower porosity, greater stability of volume and greater rigidity under load at high temperatures, and greater resistance to the spalling influences of rapid changes in temperature. They are adapted to service in which they are subjected to pressure, to localized high temperatures, or to corrosion and erosion by fuel ash.

Kenmore brick are made from the same clays as those used in making Boone brick and by the same process of molding. However, Kenmore brick are given an exceptionally hard burn which stabilizes the crystal structure through the growth of the mullite crystals, and imparts greater strength and rigidity under load at high temperatures. Although the differences between Boone and Kenmore as measured by laboratory tests may appear slight, they provide a significant added margin of safety for furnace conditions of marked severity.

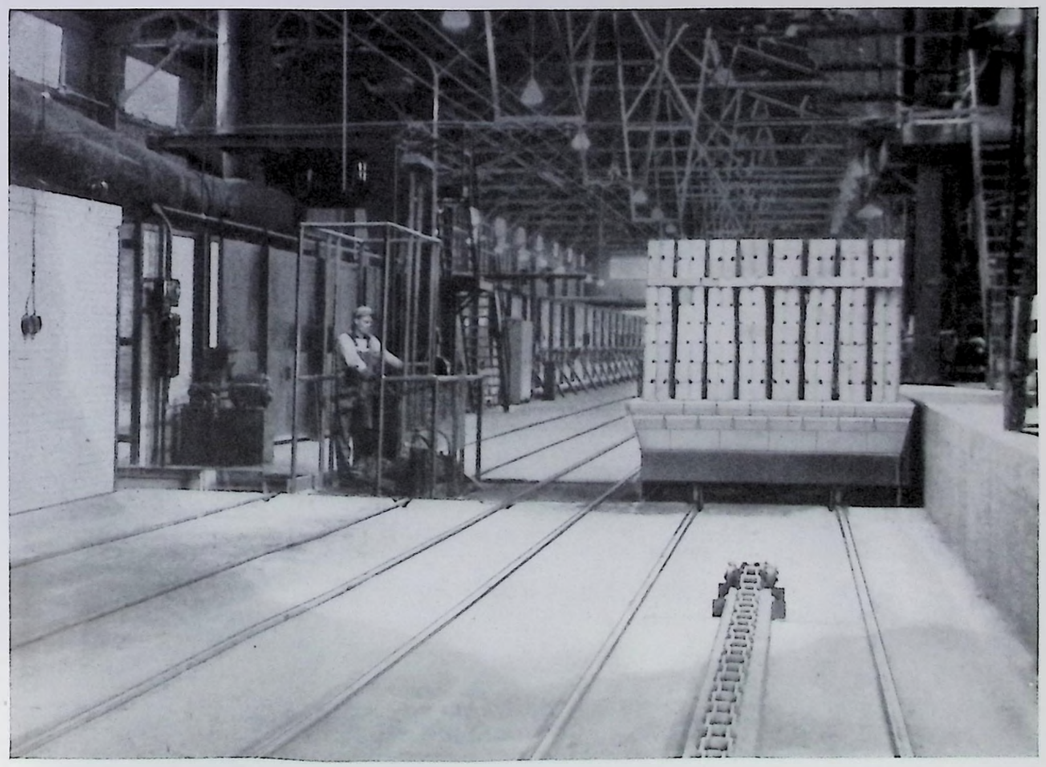
Boone and Kenmore have demonstrated their superiority over high duty fireclay refractories in applications where highly refractory dense brick of low spalling tendency are required, such as the bottoms of malleable iron furnaces, and the checkers of blast furnace stoves, open-hearth steel furnaces and glass tanks.

FOR HIGH DUTY SERVICE

H-W High Grade XX brick embody a happy combination of high refractoriness, low porosity, low permeability, and superior resistance to spalling. Their excellence of workmanship and uniformity of size facilitate bricklaying and appeal strongly to brick masons, boiler setting contractors and furnace builders. They serve in many and varied applications. H-W High Grade XX is one of Harbison-Walker's best established brands in the glass industry for use in checkers, regenerator chambers and ports.

H-W High Grade XX Bung brick successfully withstand the extremely severe service conditions to which they are subjected in malleable furnace bungs, especially those of the removable type. This service requires brick of high refractoriness and low spalling tendency, and of sufficient strength to withstand compressive stresses and physical abuse.

H-W High Grade S brick possess the desirable properties of high refractoriness and high density, and are highly resistant to the spalling effects of rapid changes in temperature. They are exceptionally dense and therefore they are more resistant to attack by slags than are other fireclay brick of equally high refractoriness. H-W High Grade S is one of the outstanding brands of brick for side wall service, particularly in furnaces used for the production of malleable iron.



Special Shapes on Their Way to Tunnel Kiln — Kentucky Works

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BRANDS MADE IN MISSOURI

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Super-Duty	ALAMO	P.P., S.M.	General super-duty service.
	VARNON	P.P., S.M.	For severe super-duty service, that is, when constancy of volume at high temperatures, with resistance to spalling or exceptionally high load carrying capacity is important.
High Duty	WALSH XX	P.P., S.M.	Lining of rotary kilns. General high duty service, especially where high resistance to thermal shock is required.
	WALSH XX BUNG	P.P.	Malleable and air furnace roofs.
	WALSH	P.P., S.M.	For high duty service, especially where high strength and density are of major importance.
	WALSH S	Ext.	High duty service, principally in malleable furnace walls. Cupola linings.
	WALSH T	Ext.	General high duty service, where low porosity or resistance to abrasion is required.
Intermediate Duty	SALAMANDER	P.P., Ext.	Intermediate duty service. Used as backing for high duty brick and as stack linings.

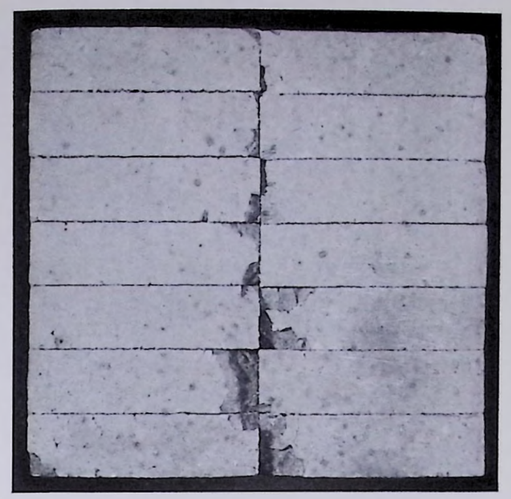
** P.P. = Power Pressed Ext. = Extruded S.M. = Shape Molded*

Missouri has been favored with a great abundance of high grade refractory fire clays suitable for the manufacture of refractories. Harbison-Walker's plants at Vandalia and Fulton are large manufacturing units capable of handling orders for any quantity of standard sizes or special shapes, made by the most modern manufacturing processes. Firing is done either in tunnel kilns or in periodic kilns, as conditions may require. The new Fulton plant, which was placed in operation in the summer of 1948, embodies developments based upon experience of more than three quarters of a century in the manufacture of refractories.

FOR SUPER-DUTY SERVICE

ALAMO, as compared with the best high duty fireclay brick, is more refractory — has a higher point of vitrification — is denser — has greater stability of volume at high temperatures — remains more rigid at high soaking heats — is far more resistant to influences which tend to cause spalling. Because of its somewhat higher alumina content and lower percentage of basic oxides, ALAMO is also more resistant to the chemical action of many fluxes. For use as checkers, the high immunity which this brick offers to the destructive influences of gases and fluxes, is especially important.

VARNON is similar in chemical composition to ALAMO, but the desirable physical properties are definitely enhanced by an especially hard burn which develops the most desirable mineral constitution. VARNON is somewhat denser and stronger than ALAMO, has greater stability of volume at high temperatures, greater rigidity under conditions of soaking heat, and somewhat greater resistance to spalling influences. While the difference in the properties of these two brands of super-duty brick may appear small when expressed numerically, they are nevertheless adequate to account for the decidedly longer life of VARNON linings, under furnace conditions which are very severe.



A Panel of ALAMO *Super-Duty Fireclay Brick after Spalling Test. Preheat 3000° F.*



A Panel of High Duty Fireclay Brick after Spalling Test. Preheat 2910° F.

Typical Appearance of Fireclay Brick after Panel Spalling Test

(The test is described on page 329)

FOR HIGH DUTY SERVICE

WALSH XX brand for many years has been a leader among Missouri high duty fireclay brick. Selection of raw material of high quality, a carefully developed manufacturing technique, and control of every step in the manufacturing process result in the production of brick of high refractoriness, unusual uniformity in quality and size, exceptionally fine workmanship, and outstanding resistance to spalling. Standard sizes are made by the power press method, while most special shapes are formed by hand.

WALSH XX brick serve many and varied requirements. They are used for the construction of boiler settings fired with all kinds of fuel; in the furnaces of oil refining, cracking and topping plants; in heat treating and forge furnaces; in lime kilns and in all other types of industrial furnaces in which the operating conditions are such that the firebrick linings are exposed to severe service.

WALSH XX BUNG brick possess the properties of high refractoriness and low spalling tendency so essential to service in the removable bungs of malleable iron furnaces. Excellence of workmanship and uniformity in size are outstanding characteristics of WALSH XX BUNG brick.

WALSH is a brand of high duty fireclay brick manufactured by the power press process. The brick are made from refractory clays carefully selected and processed to impart greater strength and density than is ordinarily found in brick of the high duty class. WALSH brick are widely used in industrial furnaces where strength is of major importance, as well as in open-hearth checkers, and in the linings of intermediate zones in rotary kilns.

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WALSH S and WALSH T are high duty fireclay brick manufactured by the extrusion process. They are very dense and of low porosity. These properties render them especially resistant at high temperatures to abrasion, to penetration by slags and fluxes, and to deformation due to load under conditions of soaking heat. Both brands possess the characteristic Harbison-Walker uniformity in quality and size and excellence of workmanship. In many applications they may be used interchangeably. However, service performance indicates that WALSH S brick are somewhat more resistant to spalling, and WALSH T are somewhat more resistant to abrasion.

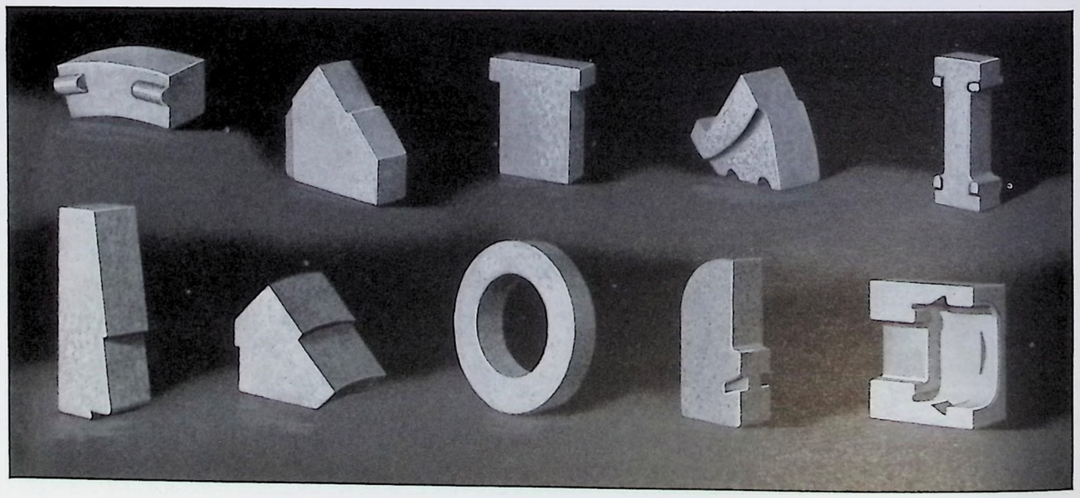
WALSH S brick give excellent results in the combustion chambers of boiler settings in which they must resist corrosion by fuel ash. They are likewise widely used in side walls of malleable iron and other metallurgical furnaces where severe slag action is encountered.

WALSH T brick find wide application as linings for the cold zone and the discharge end zone of rotary kilns used for burning cement, lime, and dolomite, and as linings for cupolas. They are especially well adapted for service in the side walls and bottoms of furnaces used in non-ferrous metallurgy, as for example, in the linings of brass and lead melting furnaces.

FOR INTERMEDIATE DUTY SERVICE

SALAMANDER intermediate duty fireclay brick are made from selected fire clays by both the extrusion and the power press processes. The same care is exercised in their manufacture as in that of Harbison-Walker high duty fireclay brick, and they possess an equal degree of uniformity in quality, size and workmanship.

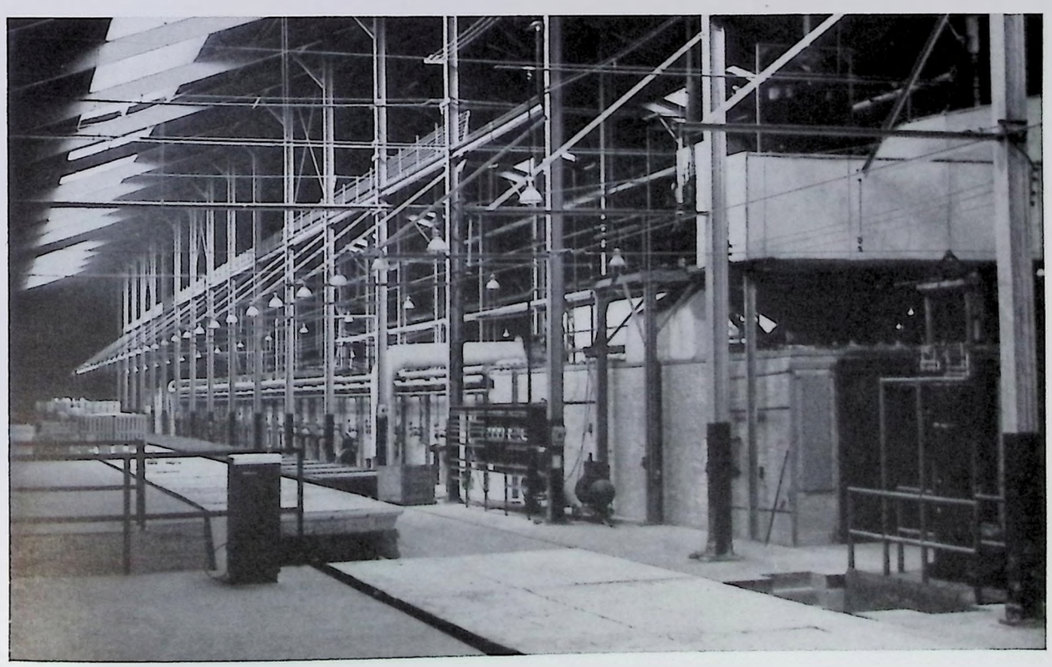
SALAMANDER brick give excellent service where the prevailing furnace temperature and the operating conditions in general do not necessitate the use of high duty fireclay brick. For example, they are used in the upper portion of cupola linings, in the linings of brick and tile kilns, in flue linings, in moderate temperature zones of boiler settings, in combustion chambers of boiler settings where the operating temperatures are relatively low, in stack linings, and as back-up brick.



Typical Shapes Made in Harbison-Walker Plants in Missouri



Special Shapes on Hot Floor for Drying — Vandalia Works, Vandalia, Missouri



View of Tunnel Kiln at Fulton Plant in Missouri

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BRANDS MADE IN OHIO

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
High Duty	Franklin Crown	P.P., Ext., S.M.	General high duty service.
Intermediate Duty	Webster	P.P., Ext., S.M.	Intermediate duty service.
Low Duty	Temple	P.P.	Low duty service; backing for high duty brick; stack linings.
	Temple Ladle	P.P.	Ladle linings.

* *P.P. = Power Pressed* *Ext. = Extruded* *S.M. = Shape Molded*

Modern improved equipment and methods of manufacture have made Portsmouth Works a model unit for the production of fireclay refractories of excellent quality and workmanship. Both periodic kilns and a continuous car-type tunnel kiln serve for firing. The Portsmouth plant is ideally balanced for the production of refractories for steel mills, iron and steel foundries, power plants, locomotive boilers, lime and cement plants and for domestic heating furnaces and similar applications. In the manufacture of special shapes, it is outstanding.

FOR HIGH DUTY SERVICE

Franklin Crown brick have been well established in industry for many years. They are widely used for general applications in the steel plant, as open-hearth checkers, and for the linings and checkers of hot blast stoves; for cupola linings, rotary cement and lime kiln linings, and shaft lime kiln linings, and for the high temperature sections of boiler settings. In the form of special shapes, Franklin Crown is a popular brand for the linings of domestic heating furnaces. The shapes are supplied in complete sets, and for furnaces of various diameters.

Franklin Crown 9-inch straights and standard sizes are manufactured by the power press and extrusion processes. Special shapes are molded by hand.

FOR INTERMEDIATE DUTY SERVICE

Webster is an intermediate duty brick of unusual merit. It is admirably adapted for service in which high refractoriness is not the most essential requirement but in which density and resistance to penetration by liquid slag are of paramount importance. Webster brick are outstanding for service in cupola linings. They are extensively used also in lime kilns, heating furnaces, and in other applications for which intermediate duty fireclay brick are suitable.

FOR LOW DUTY SERVICE

Temple brick, in the low duty class, are used mainly in the back-up courses of furnace walls. They are true to size and of excellent workmanship. Consequently, substantial savings are made in bricklaying costs when Temple brick are used for backing up fireclay brick of the high duty class. Temple Ladle brick are used in the ladles of iron and steel foundries. The different sizes used in combination, for linings of various diameters, are always available.

BRANDS MADE IN PENNSYLVANIA

CLASS	BRAND	PROCESS*	TYPICAL SERVICE
Super-Duty	Dean	P.P., S.M.	General super-duty service.
High Duty	Benezet	P.P., V.P., S.M.	General high duty service.
	Gas Widemire	P.P.	Mainly checkers in water gas sets.
	H & B Woodland	P.P., V.P., Ext., S.M.	High duty service where high density and strength and low porosity are desired.
	H-W Special	P.P., V.P., Ext., S.M.	Linings of rotary kilns.
	H-W	P.P., V.P., Ext., S.M.	Cupola linings; general high duty service.
	Stove Clearfield	P.P., V.P., Ext., S.M.	Blast furnace stove checkers.
	Tyrone	P.P., H.M., S.M.	Water gas sets; metal mixers; other special service.
	Woodland	P.P., V.P., Ext., H.M., S.M.	General high duty service.
	Woodland Bung	P.P., S.M.	Air furnace bungs.
	Woodland X	P.P., H.M., S.M.	Sprung and suspended roof arches and other high duty services.
	Woodland X Dash	P.P., S.M.	Incinerators and other constructions, subjected to severe spalling influences.
Intermediate Duty	Widemire	P.P., Ext.	Intermediate duty service. Also backing for high duty brick; stack linings.
Low Duty	Temple	P.P.	Low duty service. Also backing for high duty brick; stack linings.
	Temple Ladle	P.P.	Ladle linings.
Abrasion Resistant	Duro	Ext.	Rotary and shaft kiln linings.

BLAST FURNACE BRICK

	Benezet H & B	V.P.	Blast furnace hearth and bosh and lower inwall.
	Benezet Inwall	V.P.	Blast furnace upper inwall.
	Benezet Top	V.P.	Blast furnace top.
	H-W 18-Pa	V.P.	Blast furnace hearth and bosh, inwall and top.
	H-W Bottom Blocks	V.P.	Blast furnace hearths.
	H-W Stove	V.P., Ext., S.M.	Blast furnace stoves.
	Stove Clearfield	V.P., Ext., S.M.	Blast furnace stoves.

* *P.P. = Power Pressed* *V.P. = Vacuum Pressed* *Ext. = Extruded* *H.M. = Hand Made* *S.M. = Shape Molded*

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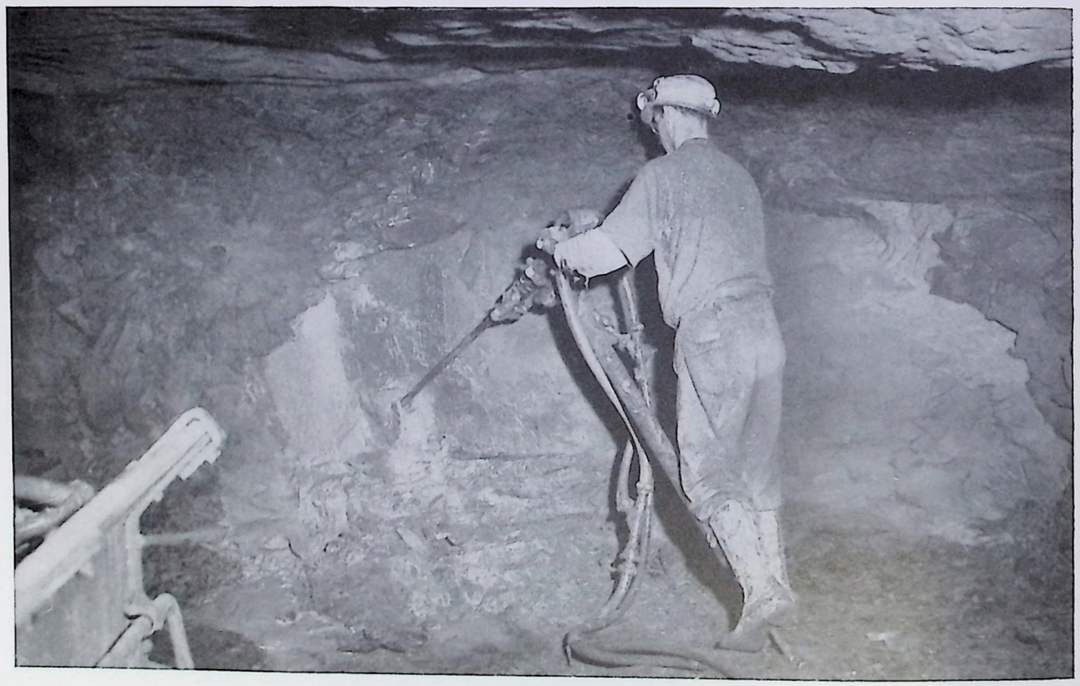
From the beginnings of the refractories industry in Pennsylvania, the state has been noted for the production of refractories of high quality. Few states possess such large reserves of high-grade flint and bonding fire clays.

Among the group of nine fireclay brick plants operated by Harbison-Walker in Pennsylvania are three at Clearfield. Completed in 1942, Clearfield No. 3 embraces the most modern methods of processing and manufacture. Other plants are situated at Barrett and Wallaceton in Clearfield County, Retort and Monument in Center County, Blandburg in Cambria County and Templeton in Armstrong County. The No. 2 and No. 3 plants at Clearfield and the plant at Templeton are equipped with modern continuous tunnel kilns. The Templeton plant is devoted almost exclusively to the production of BENEZET vacuum-pressed blast furnace and stove refractories.

FOR SUPER-DUTY SERVICE

DEAN super-duty fireclay brick, like other brick of their class, are made of clays of the highest quality. The alumina content is somewhat higher than usual for super-duty brick. The temperature of firing is unusually high; this is the important factor which accounts for the stability in volume, and negligible shrinkage of DEAN brick when used for service at very high operating temperatures.

DEAN brick are used in boiler settings in which the prevailing conditions are too severe for high duty fireclay brick. Other applications correspond in general to those for which super-duty fireclay refractories afford advantages.



Underground Mining of Flint Clay in Pennsylvania

FOR HIGH DUTY SERVICE

BENEZET brand of fireclay brick was already serving the needs of industry when the great-grandfathers of the present day were children. Throughout the years, the basic quality of this brand has been zealously maintained, while improvements in processing have been introduced. It is manufactured by the power press or vacuum press process, depending upon the service in which the brick are to be employed. BENEZET brick are widely used for boiler settings, for the linings of metallurgical furnaces and enamel frit furnaces, and for many other refractory constructions.

GAS WIDEMIRE is a special service brand which was developed primarily for the checkers of carburetors and superheaters in water gas sets. It is made by the power press process.

H & B WOODLAND brick are especially processed for service in which high density, high strength and low porosity are important, as in the sidewalls of metallurgical furnaces. Standard sizes are formed by the power press, vacuum press, and extrusion processes. Special shapes are molded by hand.

H-W SPECIAL high duty fireclay brick for many years have been the accepted standard for rotary kiln blocks to be used in the intermediate and cold zones of cement, lime, lime sludge, and dolomite kilns. They possess to a well-balanced degree resistance to spalling and resistance to abrasion.

H-W brand corresponds in most of its physical properties to the best high duty fireclay brick. It is a special refractory in this general class, which uniquely lends itself to shape molding of brick necessarily made in intricate or unusual designs. It is often used in the manufacture of some standard sizes as well, as for example, cupola and rotary kiln blocks.

STOVE CLEARFIELD brand is widely used for blast furnace stove checkers. These brick are made by the power press, vacuum press and extrusion processes. They have low porosity, high cold strength and excellent resistance to deformation under load at high temperatures. The STOVE CLEARFIELD composition is well adapted to the manufacture of the various patented stove checkers, including those of most intricate design.

TYRONE is a special service brand. It is hard, tough and strong; its principal application is in the linings of water gas sets.

WOODLAND brick, for a period of more than half a century, have been the standard of quality with which other highly refractory fireclay refractories have been compared. WOODLAND brick are used in many types of furnaces in metallurgical and other industries, in boiler settings, and in other constructions where the best high duty fireclay brick are required.

WOODLAND BUNG brick are used with excellent results in the bungs of malleable furnaces.

WOODLAND X brick were developed especially for use in constructions where resistance to rapid changes in temperature is an essential requirement. Their composition and structure are designed to reduce spalling tendency. They are therefore particularly well suited for the construction of furnace roofs and arches of either the sprung or the suspended types.

WOODLAND X DASH brand is similar in its general properties to WOODLAND X. However, it provides an added margin of refractoriness and even greater resistance to spalling under severe conditions. It is used successfully in incinerators, in boiler settings, in various metallurgical furnaces of various types, in soaking pit arches and in other arch construction.

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FOR INTERMEDIATE DUTY SERVICE

WIDEMIRE brand, made by the power press and extrusion processes, is only slightly lower in refractoriness than the standard for high duty brick. It has high strength and low porosity. The excellent properties of WIDEMIRE brick, made possible by the characteristics of the clays of which it is composed and by the method of manufacture, permit its satisfactory use for many applications, such as the linings of heating and annealing furnaces of various types, the upper linings of vertical shaft lime kilns, and certain sections of boiler settings.

FOR LOW DUTY SERVICE

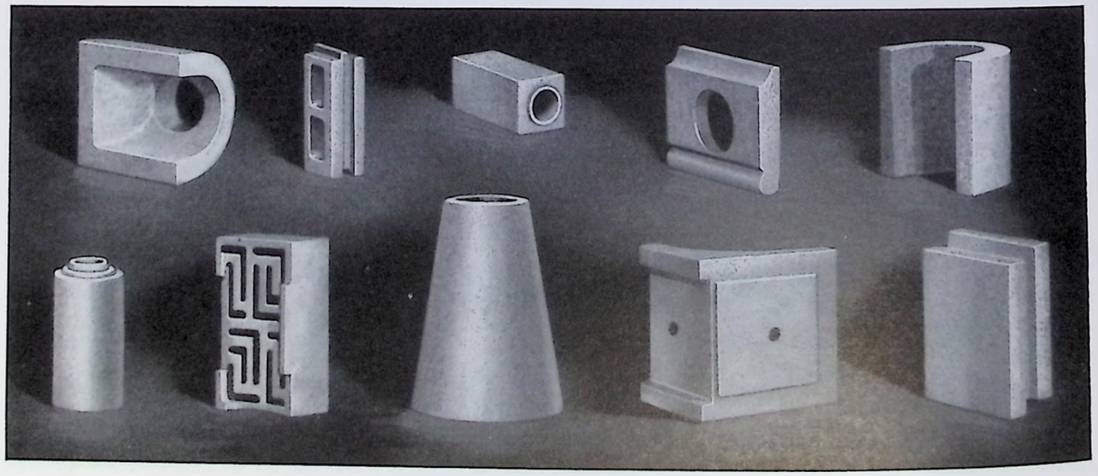
TEMPLE brick are recommended to those requiring a general purpose fire brick for use at moderate temperatures. They are made from selected Pennsylvania fireclays by the power press process. They are uniform in quality, texture, size and workmanship.

TEMPLE brick are used for backing-up high duty fireclay brick in boiler settings. They are used also in linings of second passes of boiler settings, in annealing ovens except fire-boxes, in domestic fireplaces, in stacks, in ladle linings, and in other furnace applications where moderate temperatures are employed.

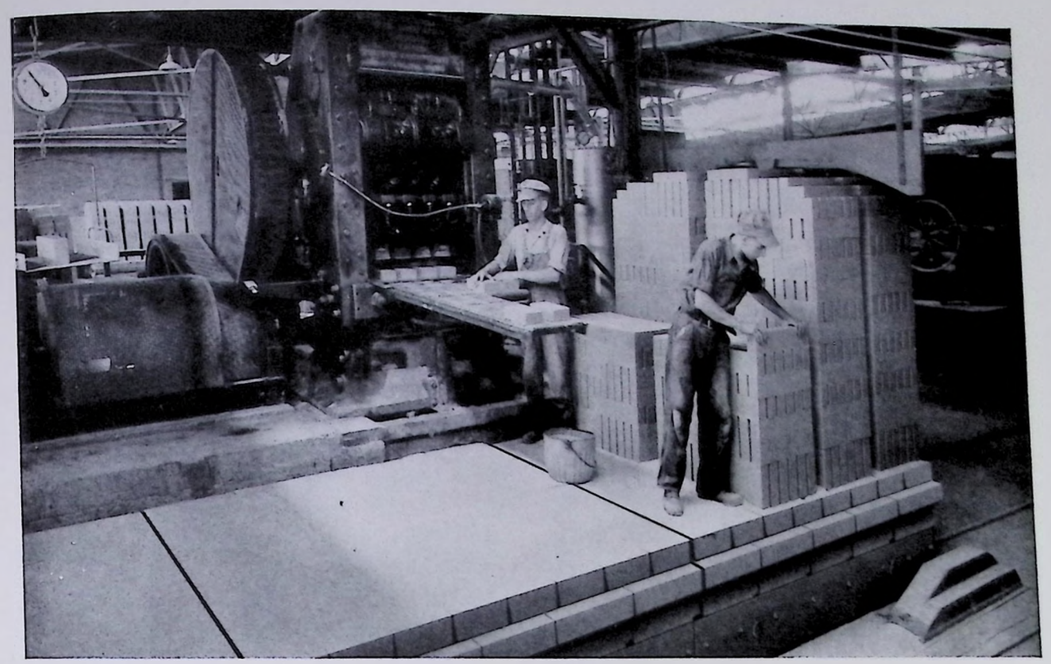
TEMPLE LADLE BRICK are manufactured by the power press process. Their workmanship is excellent and the brick are true to size and shape. In service, they expand sufficiently to form tight joints.

FOR HIGHEST RESISTANCE TO ABRASION

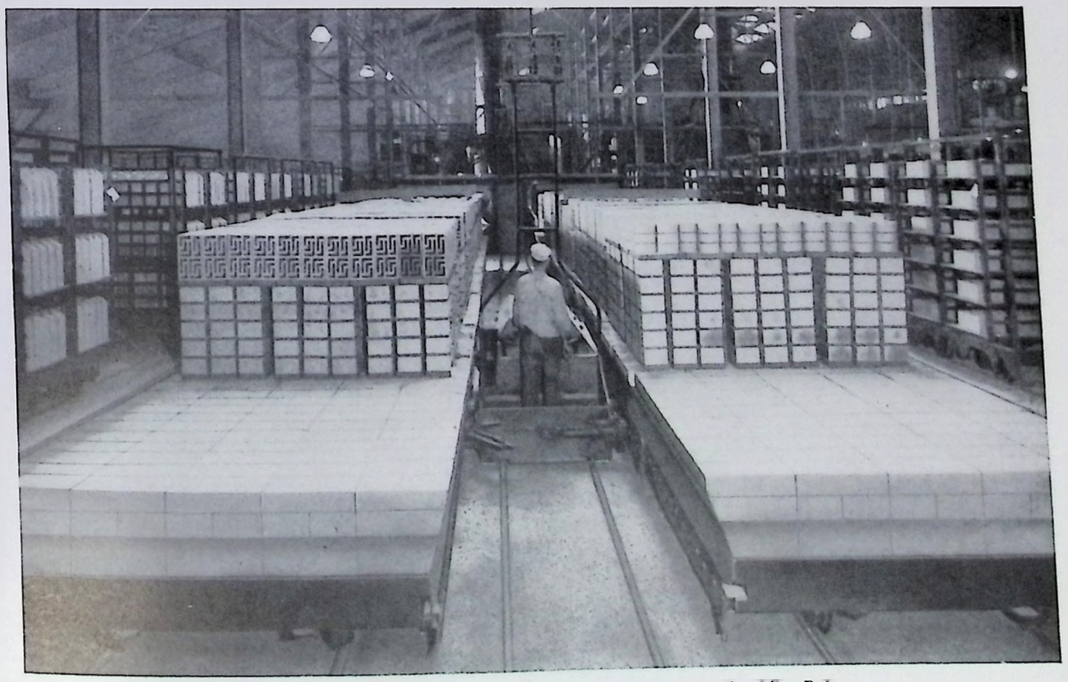
DURO brick are used advantageously for construction of furnace linings which must withstand extremely severe abrasive action at moderate temperatures. Typical applications include the linings of the chain sections of rotary cement kilns and the linings of the moderate temperature zones of lime kilns of both the rotary and shaft types.



Typical Shapes Made in Harbison-Walker Pennsylvania Plants



Setting Power Pressed Blast Furnace Brick on Tunnel Kiln Cars for Firing



Tunnel Kiln Cars Set with Special Shapes on Their Way to Humidity Driers

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BRANDS MADE IN TEXAS

CLASS	BRAND	PROCESS *	TYPICAL SERVICE
High Duty	COLEMAN XX	P.P., S.M.	General high duty service.
Intermediate Duty	COLEMAN	P.P., S.M.	Intermediate duty service; boiler settings.
	COLEMAN T	Ext.	Intermediate duty service requiring high strength and toughness.

** P.P. = Power Pressed Ext. = Extruded S.M. = Shape Molded*

Immediately upon acquiring the clay properties and fire brick manufacturing plant of the Athens Brick and Tile Company at Athens, Texas, in 1940, Harbison-Walker engaged in a program of intensive prospecting, and developed large reserves of fire clay of high quality. At the same time, the company made major improvements in equipment and in manufacturing methods. By the installation of new equipment for grinding and pressing, and of a rotary kiln for calcining clays, the construction of a new drier, the installation of additional kilns and by other important improvements, the company has thoroughly modernized the Athens plant and developed it into a manufacturing unit of substantial size.

FOR HIGH DUTY SERVICE

COLEMAN XX brick are made by the power press process from selected clays of highest quality from the company's mines in Texas. They are highly refractory, and meet in full the requirements for high duty fireclay brick. They are also exceptionally strong and stable in volume at high temperatures. Because of these properties and the high purity of the clay used in its manufacture, COLEMAN XX is an exceptional refractory for withstanding the sustained high temperatures and heavy loads frequently associated with furnace operation. COLEMAN XX brick also possess unusually high resistance to the spalling influence of rapid temperature change. They are recommended for use in the firing zones of ceramic tunnel kilns and in the side walls, combustion chambers and checkers of blast furnace stoves.

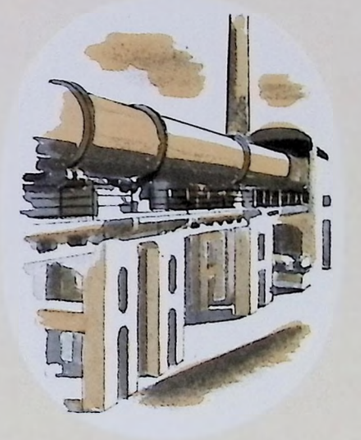
FOR INTERMEDIATE DUTY SERVICE

COLEMAN is an intermediate duty fireclay brick of outstanding quality and of excellent workmanship, made by the power press process. In many instances, when COLEMAN brick are used for the backing of COLEMAN XX, insulation can be applied with a wide factor of safety. COLEMAN is a fireclay brick of the siliceous type, and contains an unusually low percentage of basic oxides; its strength and ability to sustain relatively high pressures under conditions of soaking heat are unusually high for brick of the intermediate duty class.

COLEMAN brick conform to the same size specifications as high duty and super-duty fireclay brick. They can therefore be used in bonded construction in combination with brick of standard size of any other brand.

COLEMAN T brick are fireclay refractories of the siliceous type similar in chemical composition to COLEMAN. They are manufactured for applications in which extruded brick are preferred, and are well adapted for service conditions which require intermediate duty brick of high strength and toughness.

HIGH-ALUMINA REFRACTORIES



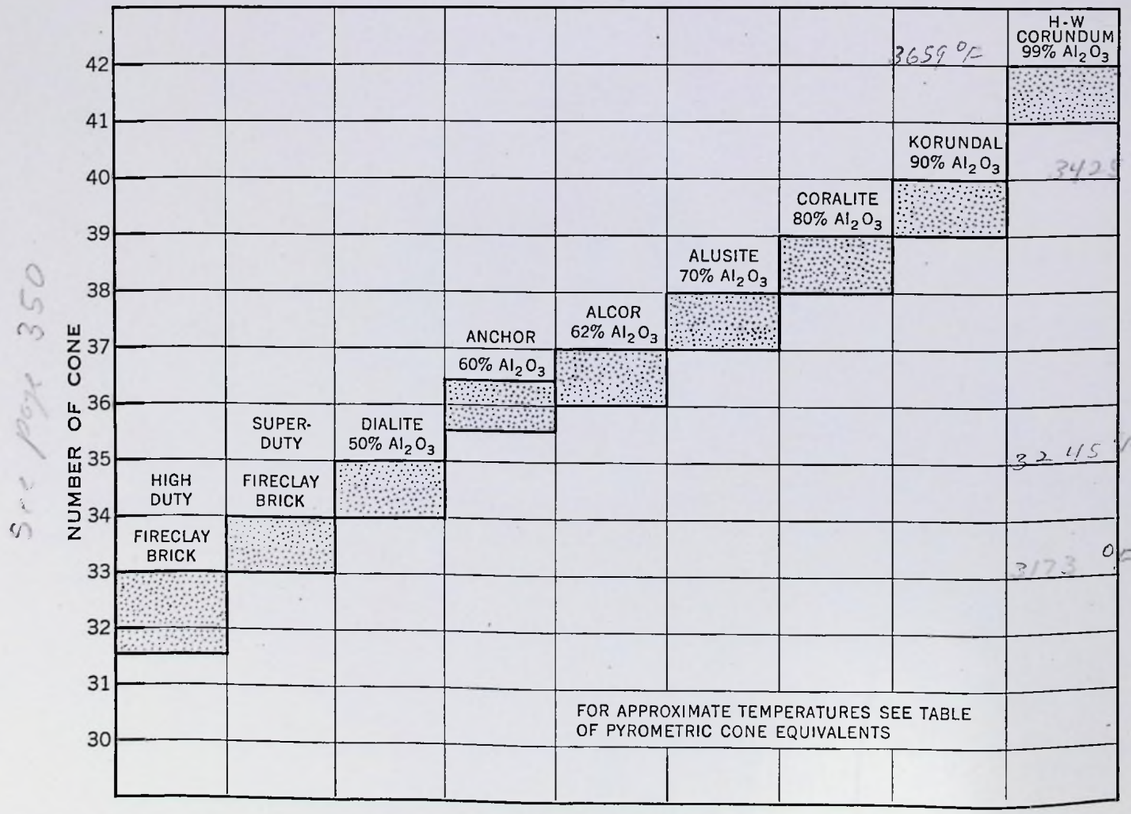
HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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HIGH-ALUMINA REFRACTORIES

In the operation of industrial furnaces, the service conditions in different parts of the same furnace may vary from fairly moderate to extremely severe. Wise selection of different types of refractories to meet the specific requirements renders possible the operation of furnaces at their economical limit with minimum loss in production due to shutdowns for repairs. Harbison-Walker brands of high-alumina brick cover a wide range in refractoriness and other properties, and are designed to meet the requirements of a wide variety of service conditions in vulnerable parts of many types of furnaces. For many applications, high-alumina brick have supplanted fireclay brick, silica brick, and even more costly refractories, to decided advantage. The high refractoriness of high-alumina brick permits insulation of furnace walls at higher temperatures than is practicable for walls built with fireclay brick.

High-alumina brick of all classes are more refractory than fireclay brick, approximately in proportion to their content of alumina. The following diagram gives a graphic representation of the relation between alumina content and Pyrometric Cone Equivalent or P.C.E. As shown on the diagram, the P.C.E. of high duty fireclay brick ranges from Cone 31-32 to 33, of super-duty fireclay brick from Cone 33 to 34, while that of high-alumina brick ranges from Cone 34 to 42.



Refractoriness of Fireclay and High-Alumina Brick Expressed in Pyrometric Cone Equivalents

While the chemical composition of high-alumina brick indicates approximately the ultimate fusion point, it does not reveal mineral constitution, upon which depend many desirable qualities, nor serve as a definite guide to all of the physical properties of a brick. The properties of mechanical strength at high temperatures, shrinkage or expansion under heat, slag resistance, porosity and permeability are dependent upon such factors as the proportion of the batch which has been pre-fired, the method and temperature of pre-firing, the character of the bonding materials, the sizing of the grains, the process of molding, and the final firing temperature.

Harbison-Walker high-alumina brands include all the classes from 50% to 99% alumina. These refractories are manufactured from diaspore clay or from other raw materials high in alumina, which are used in both crude and calcined form. In making some brands, fused crystalline alumina (corundum) is added. During manufacture, the brick are subjected to the particular heat treatment which will effect the necessary mineral changes.

In the manufacture of high-alumina brick, certain important physical properties are developed to a much higher degree when the brick are made by the power press process than when made by hand. Consequently, standard 9-inch straights and standard 9-inch sizes of all Harbison-Walker brands of high-alumina brick are made by the power press process.

It is a decided advantage to use standard sizes, from the standpoint of certain physical properties as well as of cost. For service where special shapes must necessarily be used, they should be so designed if possible that they can be power pressed. When this cannot be done, it is preferable to make them by the air-ramming process rather than by hand.

H-W SPECIAL H.A. ROTARY KILN BLOCKS

H-W Special H.A. rotary kiln blocks are manufactured by the power press process from Pennsylvania diaspore clays. They have an alumina content of approximately 50 per cent and are strong and resistant to fluxing. They do not shrink at the high operating temperatures to which they are subjected in service.

For over thirty years, H-W Special H.A. has been one of the leading brands for lining the burning zone of rotary cement kilns, and has developed an enviable reputation for this service. It provides a wide margin of safety over fireclay brick when so used, as it readily takes on a protective coating of clinker, and retains the coating at the usual operating temperatures. Excellent economies result from the use of H-W Special H.A. rotary kiln blocks in cement kiln service which is too severe for fireclay brick, yet not so severe as to require brick containing 60 per cent or more alumina.

For service in kilns which require a more refractory brick for the burning zone, H-W Special H.A. rotary kiln blocks serve admirably for use in the intermediate zone.

DIALITE — 50% ALUMINA CLASS

Dialite, with a Pyrometric Cone Equivalent of 34 to 35, is more refractory than fireclay brick. It has a high temperature of incipient vitrification, and its resistance to spalling influences is exceptionally high. Other important properties of Dialite are high mechanical strength and constancy of volume at high operating temperatures. By virtue of its high alumina content

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and low porosity, DIALITE is highly resistant to chemical attack by volatile alkalies and some basic slags, and to the effects of reducing atmospheres and sulphur dioxide gas.

DIALITE brick find their most general applications in service where they are exposed to rapid fluctuations in temperature, or to attack by slags at high temperatures. They are widely used in boiler furnace linings, in fire boxes and understructures of pottery kilns, in tunnel kilns, in settings of high temperature oil stills, in heating and forge furnaces, in the uptakes, division walls and upper courses of checkers in the regenerators of glass tanks, and in the hearths of roasters. They are very well adapted to service in the burning zones of rotary kilns, under operating conditions which call for the use of brick of this class. In many rotary kilns used for burning cement, lime or dolomite, the operating conditions are so severe that brick of higher alumina content are required for the burning zones. However, in such kilns DIALITE brick frequently are used to excellent advantage in the intermediate zones.

ANCHOR — 60% ALUMINA CLASS

ANCHOR brick are manufactured from a blend of select Missouri diaspore clay and other high-quality Missouri clays. The P.C.E. value is 35-36 to 36-37, and the corresponding softening temperature is 3268° – 3300° F., which is 45° to 75° higher than that of DIALITE.

The chemical composition of ANCHOR brick is such that they are very resistant to attack by various fluxes, including molten ash from coal or oil fuel, and some basic slags. Because of their dense structure, they resist penetration by even the most fluid slags. They have excellent stability of volume at high temperatures.

ANCHOR brick are well adapted to service in various types of oil-fired furnaces where the temperatures are too high for super-duty fireclay brick. They are used to great advantage in the burning zones of shaft lime kilns, particularly those in which the working conditions are severe. Splendid results are secured from ANCHOR brick in burning zones of rotary kilns used for burning lime, lime sludge and cement. They are recommended for use along the slag line in various types of metallurgical furnaces. Coal ash of high iron content, and wood refuse ash high in alkalies, have appreciably less fluxing action upon ANCHOR than upon fireclay refractories. ANCHOR brick find application in the side walls of nickel anode furnaces, and in the firing walls and front walls of coal-fired copper reverberatory furnaces. They are extensively used in glass tanks for the construction of port walls and uptakes, and for the upper courses of regenerator checkers.

A modification of ANCHOR, which is branded ANCHOR —, has remarkable resistance to spalling, and is recommended for service where the brick are exposed to severe thermal shock.

ALCOR — 60% ALUMINA CLASS

ALCOR brick are made with a considerable proportion of fused alumina, which accounts for their high refractoriness, great strength, and constancy of volume at high working temperatures. Their P.C.E. value is 36 to 37, corresponding to a softening temperature of 3290° to 3308° F. Resistance to chemical attack by certain slags is high.

ALCOR brick give superior service in oil-fired furnaces using heavy residuum oil as fuel. Because of their exceptional ability to support loads under conditions of soaking heat, ALCOR brick are well suited for use in piers of enamel furnaces, and of kilns and other furnaces operated at high temperatures. Another important application is in the construction of muffles of various types. In walls and ports, and in other parts of glass tanks which are exposed to volatile alkalies and alkaline dust, ALCOR brick are more serviceable than brick manufactured entirely from diaspore clay and containing the same percentage of alumina.

ALCOR XX — 60% ALUMINA CLASS

ALCOR XX contains a substantial percentage of fused alumina. Both ALCOR and ALCOR XX are made by processes which develop to the highest degree the physical properties required by each in service. These properties can be attained only with brick made by the power press or air-ramming processes. The porosity of ALCOR XX is very low for a refractory containing somewhat more than 60 per cent alumina. Its resistance to spalling is excellent.

ALCOR XX brick are recommended for service in which high refractoriness, low porosity, stability in volume and rigidity under long sustained loading at high temperatures, and resistance to thermal spalling are essential. Some of their uses include the construction of piers and muffles, electric furnace roofs, parts of the superstructure of glass tanks, and the linings of boiler furnaces operated under extremely severe conditions.

ALUSITE — 70% ALUMINA CLASS

The superiority of ALUSITE long ago established it as the leader in the 70% alumina class. It has a P.C.E. of 37 to 38, with the corresponding high softening temperature of 3308° to 3335° F. Its porosity is much lower than that of most brick of the 70% alumina class and its weight per cubic foot is correspondingly higher.

Harbison-Walker pioneered in the Missouri district by the introduction in 1943 of a modern rotary kiln for high temperature calcination of diaspore and fire clays.

The excellent properties of ALUSITE are accounted for by the purity of the high-alumina minerals used in its manufacture, by the precalcination at a high temperature of a large proportion of the brick batch, by the scientific proportioning of the grains of various sizes, and by the power pressing at high pressures. While the texture of this brick is such that mechanical penetration by molten slags and softened clinker is relatively low, its resistance to rapid temperature changes is high for a refractory of the 70% alumina class.

ALUSITE is the standard refractory at many cement plants in the United States and other countries. Used in the burning zone of kilns, particularly where the conditions are exceptionally difficult to meet, ALUSITE has made a remarkable record over the years. It readily takes on and holds a satisfactory coating.

The excellent economies resulting from the use of ALUSITE in rotary lime, lime sludge, and dolomite kilns have brought about its widespread adoption for such service. The steel industry uses ALUSITE for water-cooled ports and doors of open-hearth furnaces, for soaking pit curb walls and for heating furnace bottoms. Splendid results are secured from ALUSITE in gas generators, in non-ferrous metallurgical refining furnaces, in reverberatory and brass melting furnaces, and in lead softening furnaces. ALUSITE brick have definitely proved their superiority for service in the upper side walls and roofs of lead drossing, cupel and by-product furnaces in which the furnace atmosphere is laden with litharge.

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CORALITE — 80% ALUMINA CLASS

Very few refractories have a P.C.E. as high as that of CORALITE — Cone 38 to 39 — corresponding to a softening temperature of 3335° to 3389° F. The high-temperature treatment to which CORALITE brick are subjected in manufacture gives them a composition consisting essentially of mullite and corundum. Their porosity is low and their rigidity under load at high temperatures is high.

CORALITE brick are materially more refractory and more resistant to the fluxing action of various basic oxides than are brick of lower alumina content. They are very resistant to abrasion at high temperatures. Their principal applications are in the burning zone of rotary kilns, in ports of glass tanks where the service is unusually severe, and along the slag line in metallurgical furnaces of various types.

KORUNDAL — 90% ALUMINA CLASS

The outstanding characteristics of KORUNDAL brick are extremely high refractoriness, exceptional stability of volume at high temperatures, high resistance to thermal spalling, and high resistance to corrosion by slags and by the volatile alkalies and alkali dusts present in the atmosphere of glass tanks.

KORUNDAL is made mainly from fused alumina, and contains approximately 91% alumina, 8% silica and less than 1% ferric oxide, lime, magnesia and alkalies. The P.C.E. of KORUNDAL is Cone 39 to 40, equivalent to 3389° to 3425° F.

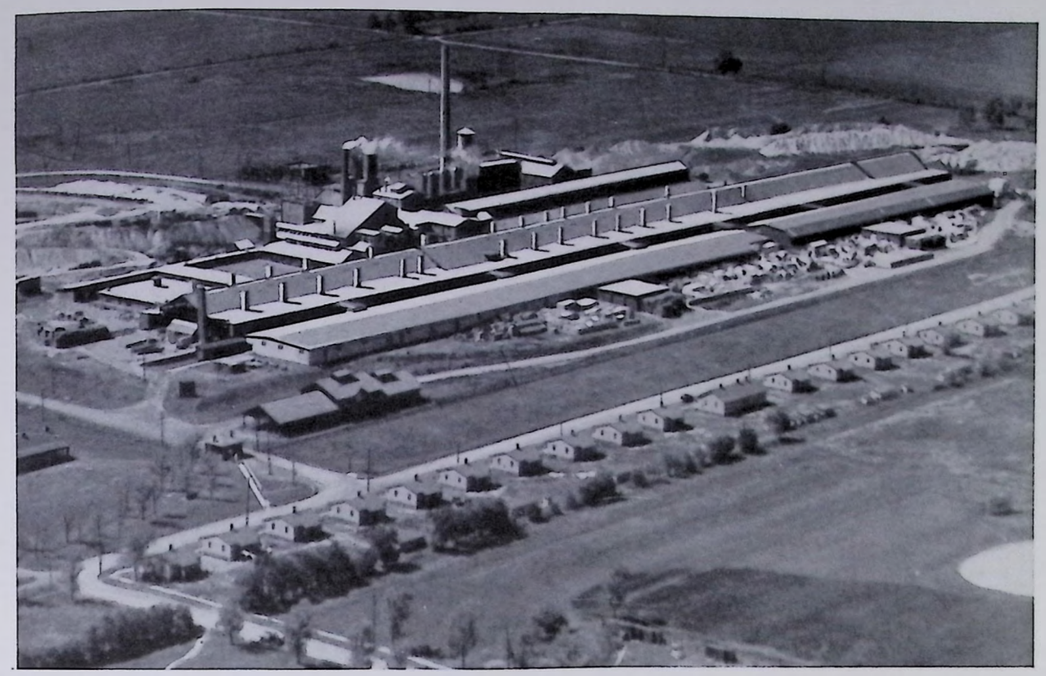
KORUNDAL is stable at very high temperatures because it consists mainly of the stable mineral corundum. High-alumina brick of lower alumina content contain less corundum and more mullite. Both of these minerals are highly resistant to the strongly corrosive action of alkalies and other fluxes at high temperatures. Of the two, corundum has the greater stability, since in the presence of alkalies mullite tends to decompose with the formation of corundum and alkali silicate minerals of lower refractoriness. KORUNDAL brick are stable in volume and exceptionally strong at high temperatures.

KORUNDAL brick are suitable for service under conditions of soaking heat, severe fluxing action, thermal shock, and extremely high temperature. They are used in piers, in supporting arches and in other constructions where heavy loads at high temperatures prevail. They give outstanding service in the jambs, port floors, port arches, tongue arches and checkers of glass tank furnaces, in the linings of aluminum remelting furnaces, and in the piers of furnaces of various types.

H-W CORUNDUM — 99% ALUMINA CLASS

H-W CORUNDUM brick consist entirely of corundum (crystalline alumina) in the purest form commercially available. The content of the basic fluxes lime, magnesia and alkalies totals less than 0.5%. Because of this high degree of purity the melting point is almost as high as that of pure corundum. In the cold condition H-W CORUNDUM brick are extremely strong, having a cold crushing strength of over 6000 pounds per square inch. They are exceptionally stable in volume at high temperatures, since in the process of manufacture, they are fired to temperatures in excess of 3000° F. in a special kiln designed for the purpose.

H-W CORUNDUM brick are well adapted to service at extremely high temperatures. They withstand pressure and are resistant to attack by highly alkaline and other basic fluxes. They may be used advantageously for operating conditions similar to those for which KORUNDAL is adapted, but of such a degree of severity that KORUNDAL is not entirely adequate.



Airplane View of Vandalia, Missouri, Plant, where High-Alumina Refractories are Made

BONDING MORTARS

In order to secure the fullest advantage from the use of Harbison-Walker high-alumina brick, they should be laid with adequately refractory mortar such as H-W SUPER-DUTY MORTAR, HARWACO BOND, THERMOLITH, ANKORITE, CORALITE BONDING MORTAR or KORUNDAL BONDING MORTAR. Data concerning these materials are given on pages 114 to 118.

RAMMING MIXTURE

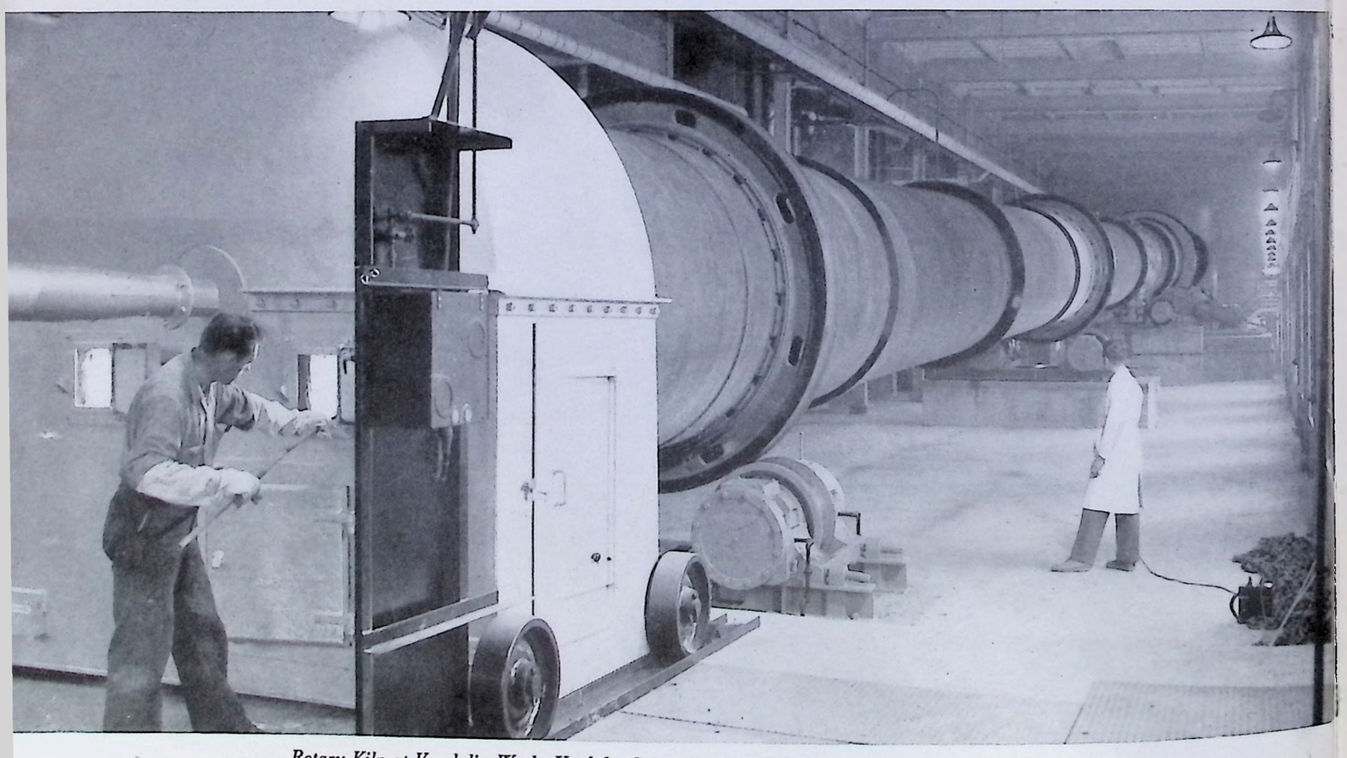
H-W KORUNDAL RAMMING MIXTURE, which is similar in composition to KORUNDAL brick, is used to form a monolithic refractory of great strength. It is discussed on page 122.

For Provision to be Made for Thermal Expansion — *See page 255*
For Weights of Refractory Brick — *See page 247*
For Amounts of Mortar Material Required for Laying Brick — *See page 247*
For Other Data on Mortar Materials — *See pages 111 – 118*
For Standard and Other Sizes — *See pages 29 – 48*

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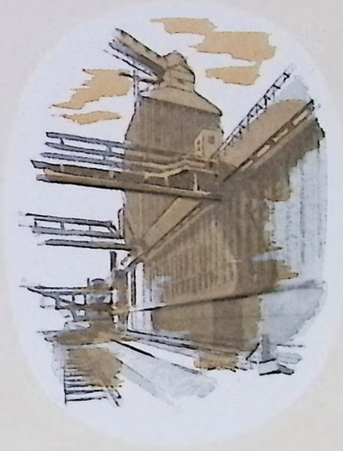


A Harbison-Walker Deposit of Missouri Diaspore Clay



Rotary Kiln at Vandalia Works Used for Calcination of High-Alumina Clays and Other Clays

SILICA REFRACTORIES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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SILICA REFRACTORIES

THE plants of Harbison-Walker at which silica brick are manufactured are situated in Alabama, Indiana, Pennsylvania and Texas, in close proximity to the consuming industries. The advantageous geographic distribution of these plants facilitates delivery to all points.

The raw material used in the manufacture of silica brick is taken from the company's own quarries. It consists of silica rock, either hand-selected or washed, of the proper types and of the highest commercial quality.

The brick are molded either by the power press, by the gravity machine, or by hand, depending upon the design of the sizes and shapes, and the service for which they are intended. The application of the power press to the manufacture of silica brick is an achievement of relatively recent years.

The green or unfired brick, immediately after being molded, are placed upon steel pallets and loaded upon drier cars. They are dried in tunnel driers and fired in periodic kilns or in continuous car-type tunnel kilns. In the firing process a definite time-temperature schedule is carefully maintained. This insures the production of strong, well-bonded brick, which, during firing, attain their normal permanent expansion of about 10 per cent by volume.

STAR

For more than half a century, STAR silica brick have been regarded as the standard of quality for this type of refractory. The properties responsible for the splendid reputation and excellent service of these brick are high refractoriness, rigidity under load at high temperatures, high resistance to spalling influence of rapid temperature change above 1200° F., high mechanical strength and resistance to abrasion, high resistance to corrosion by acid slags, uniformity of size and excellence of workmanship. The thermal conductivity of STAR is appreciably higher than that of fireclay brick.

STAR silica brick are extensively used in a wide variety of industrial furnaces. They are employed in the construction and maintenance of open-hearth and electric steel furnaces, by-product coke ovens, gas retorts, glass tanks, copper reverberatory furnaces, copper and nickel refining furnaces, wire-bar and anode furnaces, vertical shaft lime kilns, and various other furnaces. They are widely favored for the construction of roof arches. Modern manufacturing equipment and the large capacity of the company's plants make possible the most satisfactory handling of orders of any size.

VEGA

The super-duty silica brick VEGA was developed by Harbison-Walker to meet the demand for a silica refractory that would permit higher furnace temperatures, give longer life and reduce maintenance costs.

Silica brick in the cold condition contain several per cent of silicates in a body which is otherwise crystalline silica. Upon being heated to high temperatures, the silicates melt to form a liquid; as the temperature rises, the amount of liquid increases through solution of silica, at first very slowly and then more rapidly, especially above 2900° F. When relatively small amounts of liquid are present, the solid crystalline portion of a brick forms a rigid skeleton, with liquid merely between the solid particles, and the brick as a whole retains its rigidity even under load. With the larger amounts of liquid developed at higher temperatures, the bond is weakened, and the brick may lose its rigidity under load.

Since it is the amount of liquid present at high temperatures which causes the brick to lose strength, reduction in the amount of this liquid should be expected to raise the refractoriness of the brick. Studies made at Harbison-Walker's Research Laboratory revealed that the percentage of liquid formed at high temperatures in brick containing the usual 1.8 per cent to 3.5 per cent of lime, increases in direct ratio to the increase of alumina, titania and alkalies. Using available raw materials, it proved commercially possible to produce silica brick which in the load test at 50 pounds per square inch, would not crush until the temperature had risen 50° to 90° F. higher than that required for the crushing of the conventional silica brick. The product was given the brand name VEGA. Its unique quality is protected by United States patent, No. 2,351,204, granted June 13, 1944. The raw materials for VEGA are subjected to a rigorous testing procedure, so that the total of alumina, titania and alkalies does not exceed 0.5 per cent. To make this procedure possible, Harbison-Walker has established a spectroscopic testing laboratory, the first in the refractories industry.

The 50° to 90° F. higher refractoriness under load which characterizes VEGA gives it a distinct advantage in high temperature melting furnaces by permitting operation at higher temperatures. If no change is made in the operating temperature, the normal expectation is appreciably longer life of the refractory. In many cases, VEGA gives the needed increase in refractoriness required for open-hearth furnaces in which compressed air or oxygen is used for lancing or as an aid for combustion.

VEGA super-duty silica brick are used with equally satisfactory results in the roofs of electric steel furnaces, in the super-structure of glass tank furnaces, in the roofs of copper anode and wire-bar furnaces and in the roofs of copper reverberatory furnaces.

XX SILICA

A special type of silica refractory, XX SILICA, is made in Pennsylvania from a rock of high silica content known as Homewood Sandstone. Its combination of rigidity and high resistance to spalling and its tendency to become glazed at high temperatures, render XX SILICA advantageous for various specific uses, even though its refractoriness is not quite as high as that of STAR. It is well fitted for service in soaking pits, where strength under conditions of soaking heat and high resistance to spalling are important, but where the temperatures are not as high as those in open-hearth steel furnaces.

Under certain conditions XX SILICA brick are used to excellent advantage in shaft lime kilns. Their marked resistance to abrasion, their strength at the usual operating temperatures, and their resistance to reaction with lime, account for their successful use in the eyes over the arches and in other portions of the kilns.

Another application of XX SILICA brick is in piers where the usual high duty silica brick are at a disadvantage because of spalling conditions within the low temperature range. XX SILICA brick are also well suited for service in the crowns of beehive coke ovens.

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MORTAR MATERIALS

Mortar materials used for laying silica brick should have either a silica base or a chrome ore base. Among mortars with a silica base are H-W Star Silica Fire Clay, H-W Coke Oven Silica Fire Clay, Starbond, Firebond and Vega Bond. The last named, which was developed especially for use with Vega brick, represents the ultimate in refractoriness of silica mortar materials. As a bonding mortar with a chrome ore base, Harbison-Walker supplies Thermolith. All of these mortar materials are discussed on pages 114 to 118.

H-W GROUND SILICA GANISTER

Ground ganister is produced in various sizings for different uses. It is made from such quartzites as are used in making Star silica brick.

H-W Ground Silica Ganister, of the sizing especially suited for the various purposes, has been adopted as standard at many plants for building the monolithic bottoms of acid open-hearth and acid electric steel-melting furnaces. It is widely used also for the preparation of monolithic ladle linings in steel foundries. Usually a percentage of plastic bond clay furnished by Harbison-Walker is mixed with the ground ganister. When desired, the ground ganister is supplied mixed with the clay, ready for use.

While many side-blow converters in steel foundries are lined entirely with Star silica brick, others are lined wholly or in part with a mixture of H-W Ground Silica Ganister and refractory clay. A special blend with H-W Bond Clay B is used extensively.

SUGGESTIONS CONCERNING THE USE OF SILICA REFRACTORIES

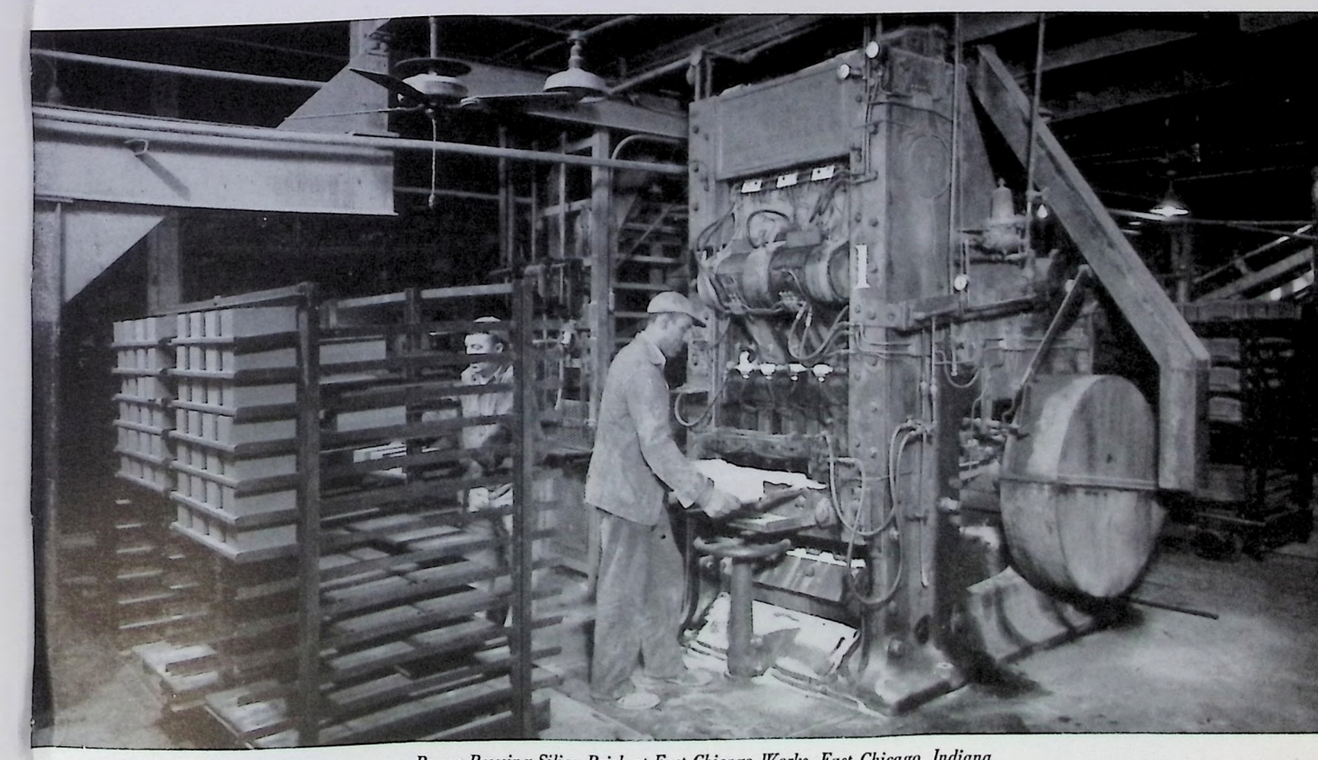
Silica brick should be stored in a dry place. Bonding mortar used for silica brick should be mixed with sufficient water to permit laying with dipped joints. Heating of the brickwork up to a dull red heat should be done slowly, to expel the moisture gradually, and to avoid spalling. To avoid too rapid heating of wall and arch surfaces, flame should not be allowed to come in contact with the brick during the early stages of heating. Provision for expansion of the brick is made at the rate of ⅛ to 3/16 inch per foot, depending upon the construction.

Cooling a silica brick down to a red heat may be accomplished fairly rapidly, provided that cold air is not allowed to impinge upon the brick at any time. Further cooling from a dull red heat to atmospheric temperatures must be done slowly and carefully to prevent spalling.

For Provision to be Made for Thermal Expansion	*See page 255*
For Weights of Refractory Brick	*See page 247*
For Amounts of Mortar Material Required for Laying Brick	*See page 247*
For Other Data on Mortar Materials	*See pages 111 – 118*
For Standard and Other Sizes	*See pages 29 – 48*

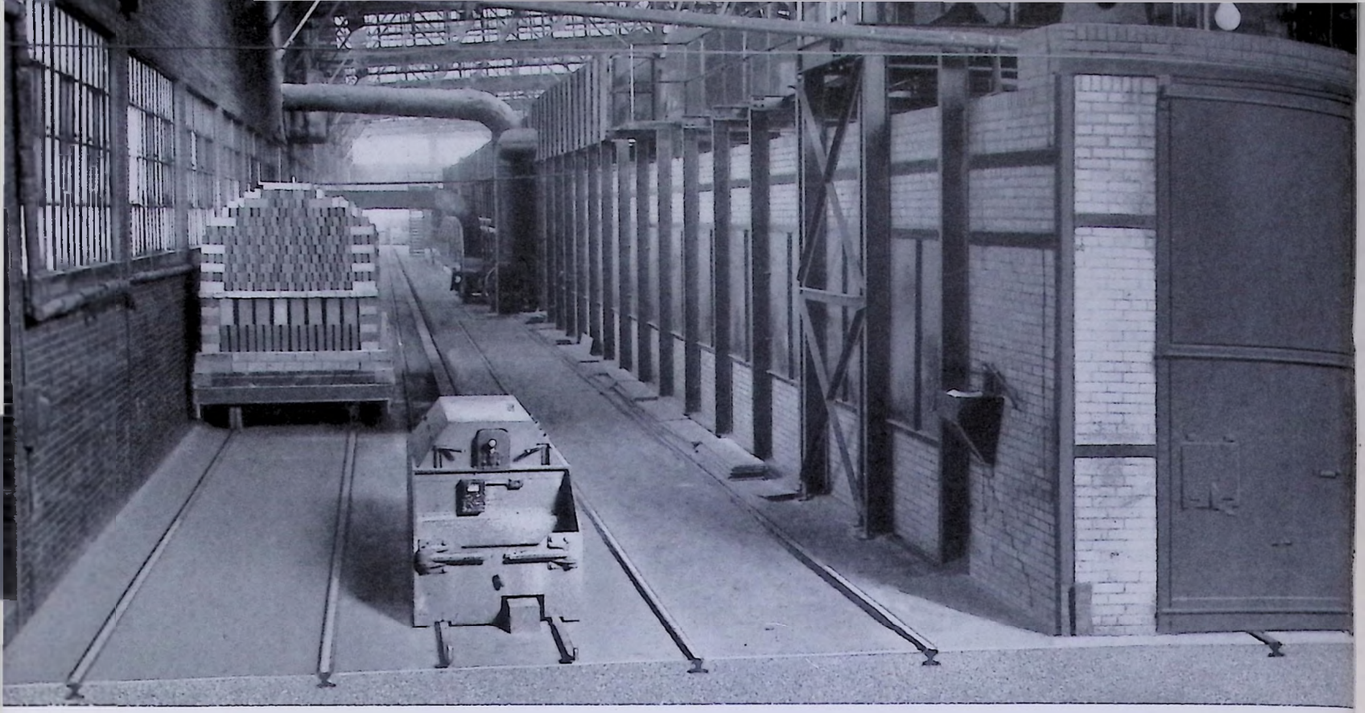


Plant for Beneficiating Quartzite, Mount Union, Pennsylvania



Power Pressing Silica Brick at East Chicago Works, East Chicago, Indiana

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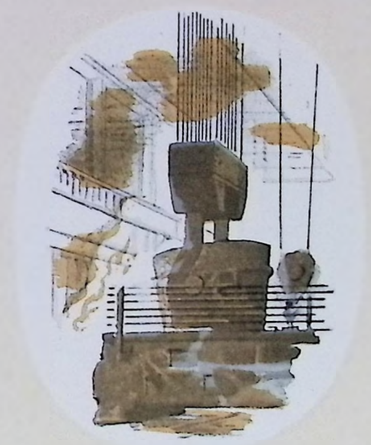


Continuous Tunnel Kiln for Burning Silica Brick at East Chicago Works, East Chicago, Indiana



Train of Tunnel Kiln Cars Ready for Unloading, East Chicago Works, East Chicago, Indiana

BASIC REFRACTORIES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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BASIC REFRACTORIES

THE properties and uses of magnesite, chrome and forsterite refractories are such that these materials are advantageously manufactured in the same plants. From the standpoint of their applications they are grouped together as "basic refractories". The distinction once made between basic and neutral refractories no longer applies, since many brick are made from blends of magnesia, which is strongly basic, with forsterite, which is moderately basic, or with chrome ore, the most nearly neutral of all the commonly used refractory materials.

The strongly basic chemical character of magnesite refractories, together with their extremely high temperature of fusion, renders them invaluable for use in contact with basic slags. Almost from the time when the basic open-hearth process for making steel was introduced down to the present, dead-burned magnesite has been employed as a hearth material for the basic open-hearth furnace. During this entire period, Harbison-Walker has specialized in the production of magnesite refractories.

Prior to 1939, the large deposits in Europe and in the state of Washington supplied nearly all of the magnesite used in the United States for refractory purposes. Just before the outbreak of World War II, a program of expansion and improvement had been initiated by the largest producer of domestic magnesite, the Northwest Magnesite Company, in which Harbison-Walker has a controlling interest. A new treatment plant at Chewelah, Washington, rendered possible the production of large quantities of magnesite of superior quality and an additional dead-burning plant increased the total kiln capacity by 85 per cent. Later a plant was constructed at Cape May, New Jersey, for the extraction of magnesia from sea-water and dolomite, and for production of dead-burned magnesite.

As a result of recent development and expansion, the Americas are now independent of the rest of the world for their future requirements of magnesite of all grades and for any amount. Harbison-Walker is in position to supply the most satisfactory magnesite products which can be manufactured.

The high refractoriness and unique character of chrome ore and chrome brick give them an important role as materials for furnace linings. Practically all of the chrome ore used in this country for the manufacture of refractories has been imported from Greece, Cuba, the Philippine Islands, Turkey and Rhodesia. The ores of greatest utility as refractories contain 30% to 40% Cr_2O_3, 15% to 30% Al_2O_3, and 15% to 20% MgO. The company's Research Department has made thorough studies of the properties of all the ores which are commercially available, and has developed methods of processing them for the production of superior refractory products.

The company's magnesite-chrome and chrome-magnesite brick, made from blends of dead-burned magnesite and chrome ore, are basic refractories of unexcelled quality.

The development of a commercial refractory material consisting mainly of the mineral forsterite ($2MgO \cdot SiO_2$) is an achievement of Harbison-Walker research. Prior to this development, magnesium silicates had not been used as high temperature refractories except on a small scale in Europe. Forsterite refractories have now become so strongly established that they are considered a necessity for various important furnace applications.

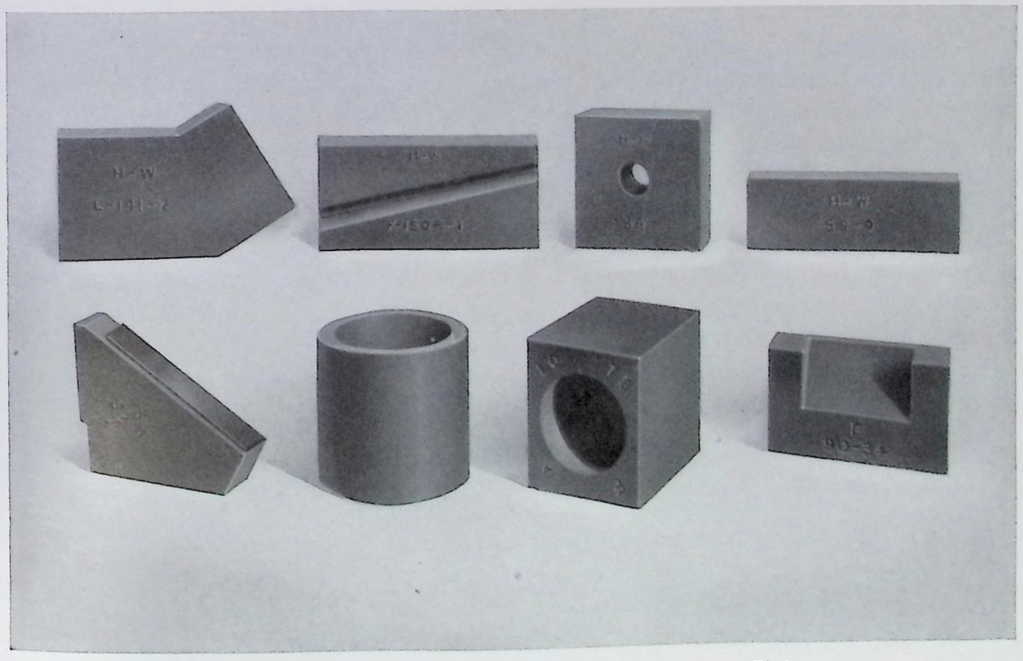
Manufacture: Basic brick, in general, are formed at high pressure in hydraulic or mechanical presses from ground, sized and blended raw materials—dead-burned magnesite, chrome ore, and olivine, with or without minor amounts of bonding agents. Some basic brick are bonded by firing; others are bonded chemically.

The brick to be bonded by firing are first dried in controlled-humidity driers, then placed in kilns and subjected to a soaking heat at a sufficiently high temperature to cause the grains to bond strongly together.

In manufacturing chemically bonded brick, the bonding constituents are blended with the ground materials before pressing, and the bond is developed in special controlled-humidity driers. In service at high temperatures, chemically bonded brick undergo changes as a result of which their characteristics approach and in some instances even surpass those of brick which have been fired at high temperatures.

The company's brands of basic brick include magnesite, chrome, chrome-magnesite and forsterite bonded by firing, and magnesite-chrome and chrome-magnesite brick bonded chemically, and METALKASE. The terms "chrome-magnesite" and "magnesite-chrome" refer to blends of chrome ore and magnesite; the constituent which predominates is named first.

For many years, the company manufactured basic refractories in a plant at Chester, Pennsylvania. The increased requirements for basic refractories, resulting from the growth of the metallurgical industries, led to the replacement of the Chester plant by a new and larger plant at Baltimore. This new plant was placed in operation late in 1947. In its design and construction, full advantage was taken of improvements in machinery and in manufacturing techniques. Equipment was provided for the manufacture of new products. Tunnel kilns of the most modern design were installed. Uniformity of quality is assured by rigid inspection, and by tests made in a well-equipped control laboratory.



Typical Basic Brick Shapes, Made at Harbison-Walker Baltimore Works

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BASIC BRICK

H-W MAGNESITE BRICK

H-W MAGNESITE brick are made from dead-burned magnesite containing about 88% magnesia and carefully controlled proportions of minor constituents. The brick are molded under heavy pressure, fired at high temperature and have great mechanical strength. The complexities of manufacture are such that it takes a highly trained organization to produce brick of consistently good quality and workmanship.

H-W MAGNESITE brick are recommended for use wherever a strongly basic refractory lining is required. They find application in the bottoms, the lower front and back walls, and the ports of basic open-hearth steel furnaces; in the lower side walls of soaking pits; in the bottoms of basic electric steel furnaces; in heating furnace bottoms; in copper converters, reverberatories, refining and melting furnaces.

H-W PERIKLASE BRICK

H-W PERIKLASE are fired magnesite brick containing 90% to 95% magnesia, mainly as periclase, and minor percentages of iron oxide and other oxides. Their excellent properties result from their high magnesia content, optimum grain sizing, the high pressure of molding and the high temperature at which they are fired. At high temperatures, their strength is greater and their shrinkage tendency is less than that of brick of lower magnesia content, and they have superior resistance to spalling.

H-W PERIKLASE brick may be used to advantage in exposed sections of front and back walls of open-hearth furnaces; in side walls of electric steel furnaces; in copper converters, particularly in the tuyere section; in the lower side walls and invert arch bottoms of copper refining furnaces, and in the linings of electric furnaces for the melting of copper; in the linings of lead softening, drossing and by-product furnaces; in bottoms of heating furnaces; and in the high temperature zone linings of some rotary kilns. In various types of high temperature furnaces, H-W PERIKLASE brick meet the need for refractories usable at temperatures considerably above 3000° F.

MAGNEX BRICK

MAGNEX is a chemically bonded magnesite-chrome brick. The grain sizing, the nature of the bond, and the high forming pressure impart strength, rigidity, and resistance to spalling. MAGNEX brick are recommended for use in exposed areas of brickwork where spalling may occur. In basic open-hearth steel furnaces, they find application in front and back walls.

In some copper and nickel reverberatory furnaces, MAGNEX brick are used for complete roofs of the suspended arch type; in others, they are used only at the hot ends, with the balance of the roof built of other refractories, usually silica brick. At several smelters the sprung arch roofs of copper reverberatory furnaces have shoulders of MAGNEX, extending 4 to 5 feet from the skews at each side of the furnace, with silica brick in the central section. MAGNEX brick are used also in the side walls of copper reverberatory furnaces, in the upper walls of copper wire bar and anode furnaces and in brass melting furnaces.

MAGNEX brick find wide application in the burning zones of rotary kilns used for making Portland cement, for calcining lime, for burning dolomite and for dead-burning magnesite.

THERMAG BRICK

Prior to the development of THERMAG, not any magnesite-chrome brick were available which possessed both the usual desirable properties of this type of refractory, and also the strength needed at high temperatures in service where resistance to abrasion and erosion are important.

THERMAG, a fired refractory, is well adapted for the linings of high-temperature zones of rotary cement kilns. Its high strength is maintained throughout the temperature gradient extending through the lining. Protective coatings are readily developed and firmly retained. As compared with other brick containing chrome ore, THERMAG is more resistant to the destructive influences which commonly prevail in the ports of basic open-hearth steel furnaces.

METALKASE BRICK

The practice of using steel casings or sheets around and between basic refractories was introduced by Harbison-Walker over thirty years ago. Since then, there have been various changes in the manner of applying the metal to the brick. The most advanced practice is that represented by METALKASE.

METALKASE are basic brick encased in soft steel containers, which usually cover three sides, but not the ends. (Illustrated on page 46.) The brick are chemically bonded, and molded under high pressure in heavy duty presses.

METALKASE have the high refractoriness and slag resisting qualities of basic brick, with superior resistance to spalling. In service, the metal at the exposed ends oxidizes and combines with the magnesia of the brick to form a magnesioferrite bond, producing a monolithic surface. Farther back in the wall the steel remains rigid and reinforces the brickwork.

In open-hearth front and back walls, METALKASE are giving several times the life of silica brick and are repeatedly demonstrating their superiority over other basic refractories. In end walls METALKASE often last for as much as two or even three furnace campaigns. Their use in skewbacks and in roof shoulders or panels not only increases the life of the roof but also results in longer life of front and back walls.

In side walls of some basic electric steel furnaces METALKASE have given double the life secured from other basic brick. They are also used advantageously for the lower side walls of soaking pits. In exposed walls and suspended roofs of copper reverberatory and refining furnaces, METALKASE are used advantageously.

METALKASE are manufactured in standard 9, 13½ and 18-inch straights and sizes, as well as in a wide variety of special shapes, including various suspended-roof shapes.

METALKASE ROUNDS consist of dead-burned grain magnesite packed solidly in round steel containers, open at the ends. The containers are 3 inches in diameter and 9, 13½ or 18 inches long. METALKASE ROUNDS are used to advantage in the bulkheads of basic open-hearth furnaces.

H-W CHROME BRICK

H-W CHROME brick are manufactured from chrome ores of the qualities which experience has shown to be the most suitable, and are fired at high temperatures in periodic or tunnel kilns. The properties of chrome brick upon which their utility mainly depends are high refractoriness and high resistance to the corrosive action of the usual metallurgical slags. The thermal conductivity of chrome brick is considerably lower than that of magnesite brick.

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H-W CHROME brick are used to advantage in basic open-hearth furnaces for facing the port blocks, in front walls and back walls at and below the slag line, and in furnace bottoms. In certain types of furnaces, such as soaking pits, heating, heat treating, forge and welding furnaces, the iron oxide scale formed has a strongly corrosive action upon both fireclay brick and silica brick. H-W CHROME brick serve to advantage in the portion of the furnace where this scale collects. Six or eight courses of chrome brick are often used with economy in the lower side walls of soaking pits.

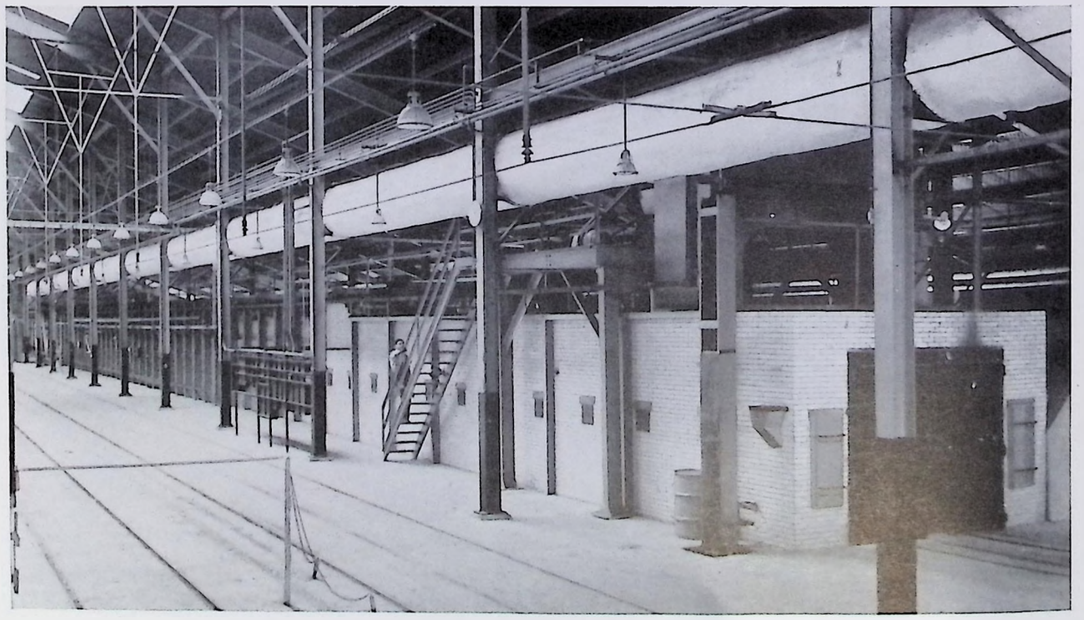
In the paper industry, the refractory linings of furnaces employed for the recovery of sodium salts are subjected to severe chemical attack. In many paper mills H-W CHROME brick laid with THERMOLITH have proved highly resistant to the destructive influences which prevail in these recovery furnaces.

Chrome refractories are sometimes used to separate other refractories, such as magnesite and fireclay brick, which may react chemically with each other at high temperatures.

CHROMEX BRICK

CHROMEX is a chemically bonded chrome-magnesite brick characterized by high mechanical strength, constancy of volume and freedom from shrinkage at high temperatures. Due to a texture imparted by the mix and the sizing of the grains, it has excellent resistance to spalling.

CHROMEX brick are recommended for use in the construction of walls in furnaces in which high operating temperatures prevail, as for example, in open-hearth front and back walls, bulkheads, end walls and ports. They are used in the copper industry in refining and secondary melting furnaces, and in the paper industry for lining recovery boilers and furnaces.



Continuous Tunnel Kiln for Firing Basic Refractories — Baltimore Works

CHROMEX B BRICK

CHROMEX B is a chrome-magnesite brick fired at an extremely high temperature. In its manufacture, application is made of all that has been learned through extensive research on means of securing the utmost stability in volume of chrome-magnesite brick at high temperatures and under heavy loads. Its change in volume in the reheat test at 3000° F. is negligible. It is strong at high temperatures, having approximately the same load carrying capacity as STAR silica brick. In addition, CHROMEX B has a very high degree of resistance to thermal shock — a remarkable property for high-fired basic brick.

The basic chemical character of CHROMEX B, and its combination of desirable physical properties, account for its successful application in back walls, front wall piers, end walls and sub-bottoms of basic open-hearth furnaces, as well as in the suspended roofs and supported walls employed in the construction of basic ends of open-hearth furnaces. CHROMEX B is used to great advantage also in the linings of basic electric steel furnaces, in soaking pits and in the bottoms of forge furnaces. A considerable proportion of the production of CHROMEX B finds application in non-ferrous metallurgy for the linings of copper converters, and of lead and brass reverberatory furnaces.

FORSTERITE BRICK

While forsterite brick are the newest of the major types of refractories, they are well established for use as furnace lining materials in many industries. Forsterite refractories were developed by Harbison-Walker research and their manufacture is protected by patents.

Outstanding characteristics of Harbison-Walker FORSTERITE brick are their stability of volume and strength at high temperatures. They show negligible shrinkage when heated to 3000° F. Their ability to support load at high temperatures has led to their use in furnace roofs. The thermal conductivity of FORSTERITE brick is lower than that of magnesite brick. Consequently, with FORSTERITE linings, the heat losses are lower and there is less danger of overheating metal parts than with magnesite linings.

In the glass industry, FORSTERITE has fulfilled the requirement for a refractory that must withstand high temperatures and attack by alkaline dusts and fumes. FORSTERITE brick are used in parts of the glass tank furnace where service conditions are extremely severe, as in ports, uptakes, regenerator walls and crowns, and air checkers. FORSTERITE brick are extremely resistant to the fluxing action of volatile alkalies and batch dust. FORSTERITE checker brick remain clean, and the checker openings do not readily clog.

Certain modifications of FORSTERITE brick have contributed to their increasing use. At many plants, they have given service second to that of no other refractory in the burning zones of rotary kilns used for dead-burning magnesite or for sintering refractory dolomite. FORSTERITE brick are used in the high temperature zone of rotary lime kilns, and lime sludge kilns. In sprung and suspended roofs of various metallurgical furnaces, FORSTERITE give excellent service. In sprung arch roofs of copper holding furnaces, they may last several times as long as conventional silica brick. FORSTERITE also find application in open-hearth steel furnaces, especially those which are gas-fired, in the construction of ports, uptakes, bulkheads, and corner walls.

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BASIC PRODUCTS OTHER THAN BRICK

H-W DEAD-BURNED GRAIN MAGNESITE

Dead-Burned grain magnesite for use in furnace bottoms is prepared by heating the raw material in rotary kilns at a sufficiently high temperature to effect complete shrinkage and to sinter the particles, thereby producing hard, dense nodules which are almost entirely inert to atmospheric moisture and carbon dioxide. The magnesia is converted largely into the crystalline or mineral form known as periclase.

H-W Washington Dead-Burned Grain Magnesite has the correct proportion of fluxing constituents to make it frit or set at the proper temperature in the bottoms of open-hearth and electric steel furnaces. The high content of periclase and relatively low content of lime give freedom from air-slaking in storage.

H-W Washington Dead-Burned Grain Magnesite may be mixed with 10% to 20% of basic open-hearth slag for use in making furnace bottoms, and for patching in open-hearth and electric steel furnaces. The durability of such bottoms has been definitely established over the past quarter of a century. Many of these furnace bottoms remain in service after so many years that the dates when they were originally burned-in have been long forgotten.

H-W Dead-Burned Magnesite, which is shipped either in bulk or in sacks, is supplied in the form of a mixture of grains ranging in size from about ⅝ of an inch in diameter to very fine particles. For the construction of open-hearth furnace bottoms, former practice favored the use of grains ranging from ½ inch diameter down, with only a minor portion finer than 28 mesh. The trend is now toward gradings containing enough of the finer sizes to fill the interstices between the larger grains and to give very dense packing.

H-W MAGNAMIX

H-W Magnamix is a magnesite ramming mixture which permits the installation of basic open-hearth and electric furnace bottoms complete to within 4 to 8 inches of their finished contours before the application of heat. Steel can be made within a very few days after construction of the hearth is begun, without the risk of overheating and consequent damage to other portions of the furnace structure, and with great saving in labor and in time. In contrast, the sintering-in of a complete open-hearth bottom with dead-burned magnesite and slag requires high temperatures and often causes a delay of as much as two or three weeks time.

H-W Magnamix contains approximately 80% magnesia, largely in the form of the mineral periclase, the durable constituent of magnesite furnace bottoms. H-W Magnamix is installed without the addition of slag and the high magnesia content is therefore not diluted. When properly rammed into place, an H-W Magnamix bottom contains about 130 pounds of periclase per cubic foot. This is an appreciably higher concentration than can be secured with dolomite mixtures, or with mixtures of dead-burned magnesite grains and furnace slag.

H-W Magnamix hearths are rapidly installed with unskilled labor. Complete open-hearth furnace bottoms have been placed at the rate of over two tons of H-W Magnamix per hour, with less than five man-hours of labor per ton of material. The installation of an open-hearth bottom with Magnamix may begin immediately upon completion of the sub-bottom, front wall, back wall, and roof, and proceed simultaneously with construction of ports and end walls, and repairs to regenerators.

H-W Magnamix is being used with outstanding success for maintaining and repairing the flats, banks and tapholes of basic bottoms. In hot patching, the dampened H-W Magnamix clings to the steepest banks and sinters rapidly to form a dense, durable patch of any required area and depth. The high refractoriness, the excellent working properties, and the uniformity in quality of H-W Magnamix are maintained through constant supervision and control.

H-W Magnamix is shipped dry in sacks of 100 pounds each. It is prepared for use by mixing with water to the consistency required.

H-W LUMP CHROME ORE

H-W Lump Chrome Ore is a carefully selected grade of the type which is best adapted for service as a refractory material. All of the ore used is imported, and to assure maintenance of uniform quality, it is carefully sampled and analyzed as received.

H-W Lump Chrome Ore is shipped either in bulk or in sacks, as desired by the purchaser.

H-W SPECIAL FURNACE CHROME

H-W Special Furnace Chrome, finely ground refractory chrome ore, has a wide field of usefulness. It serves not only for laying chrome brick, but also, under certain conditions, for laying silica or magnesite brick. It is employed for ramming around the tapholes of open-hearth furnaces; as a daubing material for the protection of the brickwork in back walls, front walls, ports, blocks and door-jambs of open-hearth furnaces; and as a daubing material in furnaces of other types. H-W Special Furnace Chrome is frequently applied by means of an air-gun.

BASIC MORTAR MATERIALS

H-W Furnace Magnesite is a finely ground dead-burned magnesite product used for laying magnesite brick, for patching and for building up steep banks such as those at the back wall of the open-hearth steel furnace. Further data will be found on page 115.

H-W Periklase Bonding Mortar is a dry air-setting cement which contributes to the stability of structures of any type of basic brick. Its high content of periclase imparts the desirable properties of extremely high refractoriness and resistance to basic slags. It is discussed on page 118.

Thermolith is a dry air-setting high temperature bonding mortar with a chrome ore base. The combination of desirable physical and chemical properties which it possesses — including high refractoriness, excellent bonding strength and resistance to attack by a wide variety of slags — gives it an extensive range of utility. It serves advantageously not only for laying basic brick, but for laying fireclay and high-alumina brick as well. A more complete description is given on page 117.

H-W Forsterite Bonding Mortar is an air-setting mortar material which consists largely of the mineral forsterite. It sets hard merely upon drying, and at high temperatures develops a strong ceramic bond. It is used mainly for laying Forsterite brick. (See also page 118.)

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BASIC RAMMING MIXTURES AND CASTABLES

H-W Periklase Batch is a basic ramming mixture which is shipped in dry form. Its properties and uses are discussed on page 122.

Thermolith Batch and Plastic Thermolith Batch are air-setting ramming materials with a chrome ore base. The former is shipped in dry form and the latter in wet plastic condition. Detailed information concerning them is given on page 121.

H-W Chrome Castable, a highly refractory castable material with a chrome ore base, is fully described on page 123.

SUGGESTIONS CONCERNING THE USE OF BASIC BRICK

Selection of the most serviceable basic refractories for any particular application depends upon the operating conditions, and may require analysis by a competent engineer of wide experience. Such studies are included in the service which the company renders to users of refractories.

At 2600° to 2700° F. magnesite and fireclay brick react chemically with each other, with the formation of a liquid slag. At 2800° to 2900° F. magnesite and silica brick react, with effects which are somewhat damaging to both. In high-temperature service, it is therefore good practice to separate magnesite refractories from fireclay brick, and frequently from silica brick, by a neutral course such as chrome brick or by a heavy joint of Thermolith.

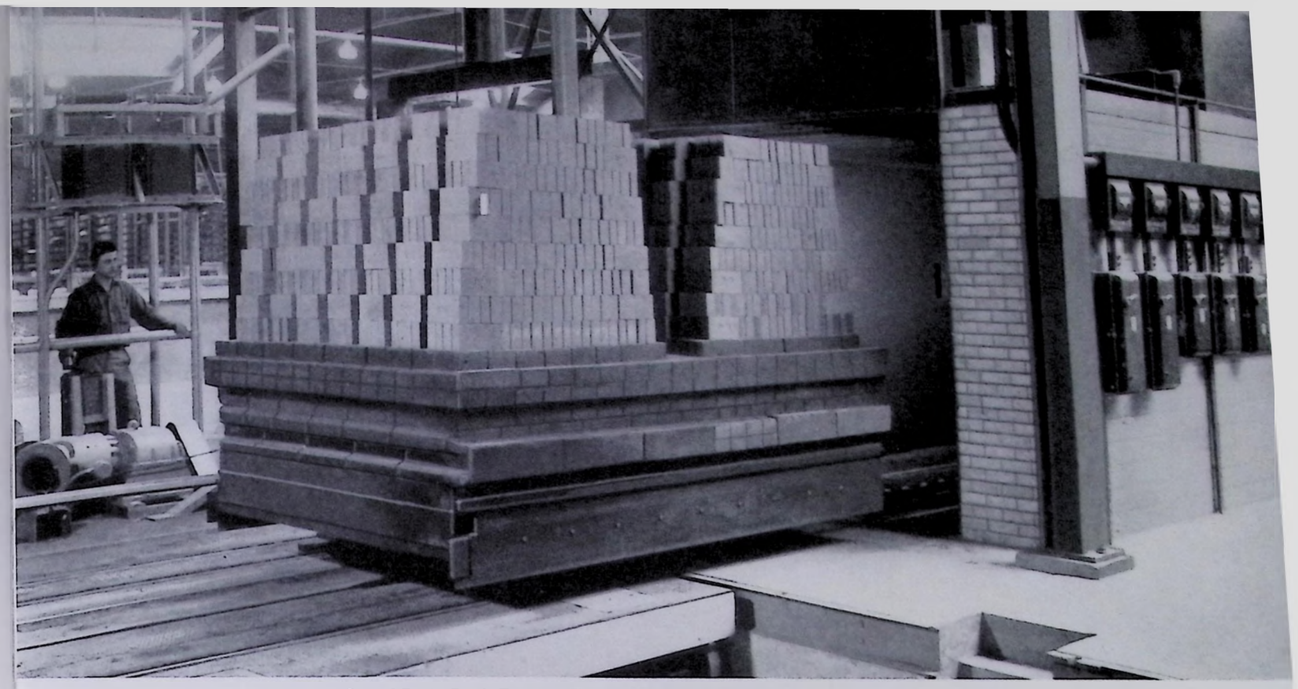
Dead-burned magnesite, H-W Magnamix, magnesite brick and chemically bonded brick containing free magnesia may slake when subjected to the action of steam. All basic materials should be stored in a dry place. This is especially important in the case of chemically bonded brick, since the bonding agents are somewhat soluble in water. It is good practice to avoid rapid heating or cooling of basic brick.

Magnesite and magnesite-chrome brick may be laid with H-W Furnace Magnesite, H-W Periklase Bonding Mortar, H-W Special Furnace Chrome, or Thermolith.

Chrome and chrome-magnesite brick may be laid with H-W Special Furnace Chrome or Thermolith, and Forsterite brick with H-W Forsterite Bonding Mortar or Thermolith.

In laying Metalkase as headers, 18 of the rounds or 12 of the 9-inch straights are required per square foot of wall. Metalkase straights and keys are laid dry or with furnace chrome, and frequently with an additional steel holding plate. The rounds are laid with H-W Furnace Magnesite or with H-W Special Furnace Chrome, barely moist enough to be worked with a trowel. The amount required per 1000 pieces is 900 pounds for the 9-inch rounds, 1350 pounds for the 13½-inch rounds, and 1800 pounds for the 18-inch rounds.

For Provision to be Made for Thermal Expansion	*See page 255*
For Weights of Refractory Brick	*See page 247*
For Amounts of Mortar Material Required for Laying Brick	*See page 247*
For Other Data on Mortar Materials	*See pages 111–118*
For Standard and Other Sizes	*See pages 29 – 48*

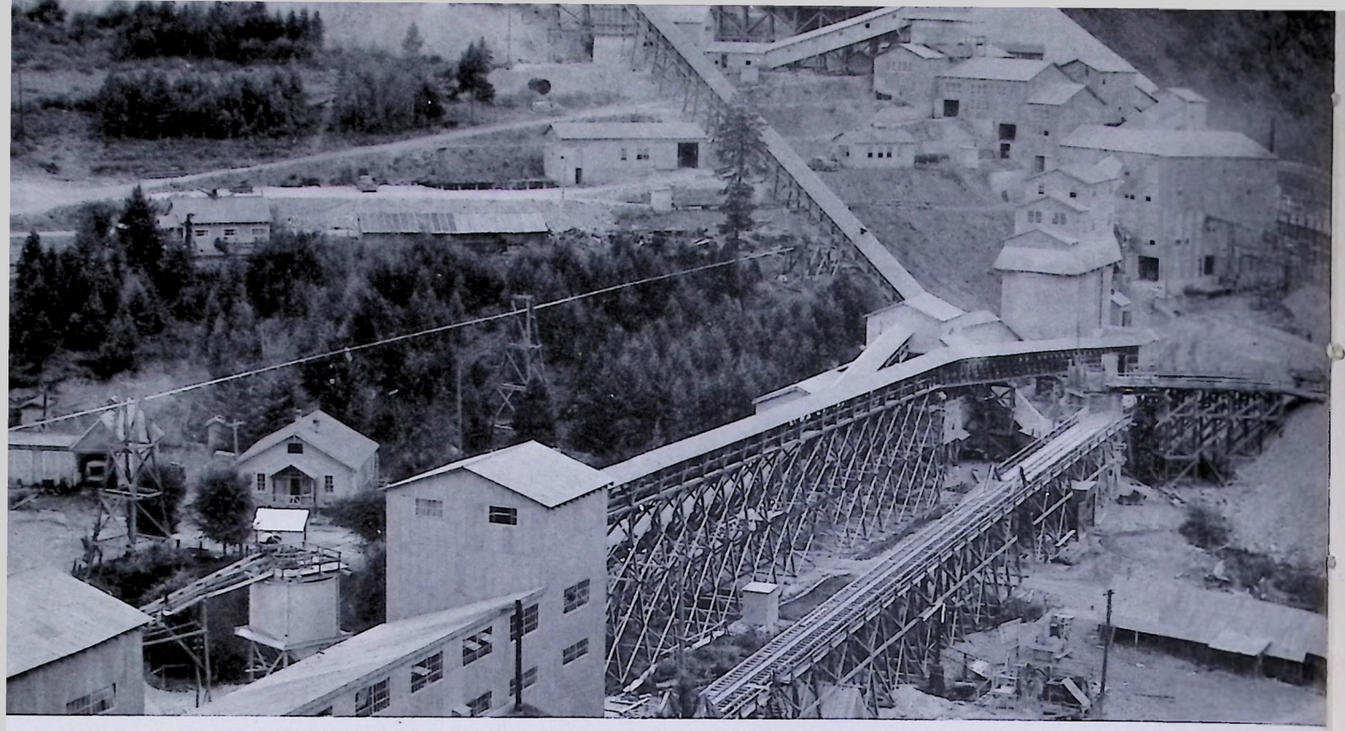


Car of Basic Brick Entering Tunnel Kiln — Baltimore Works, Baltimore, Maryland

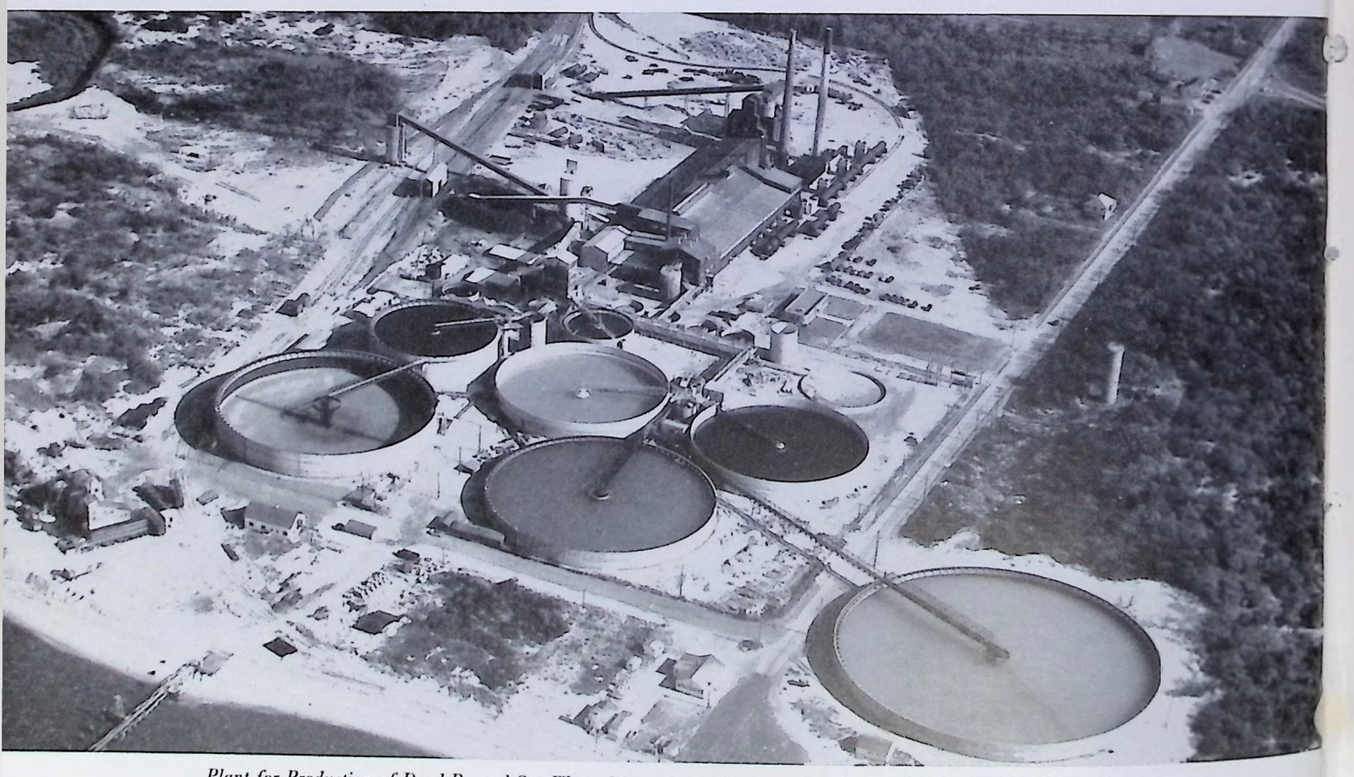


Stocks of Basic Brick Stored on Pallets — Baltimore Works, Baltimore, Maryland

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Plant for Beneficiation of Crude Magnesite — Northwest Magnesite Co., Chewelah, Washington



Plant for Production of Dead-Burned Sea-Water Magnesite — Northwest Magnesite Co., Cape May, New Jersey

SPECIAL CLAYS



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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BONDING CLAYS

H-W ATHENS PLASTIC CLAY

H-W Athens Plastic Clay is a bonding clay of the siliceous type obtained from deposits near Athens, Texas. It is very plastic and has excellent bonding properties. It is open-burning and when fired has excellent resistance to thermal spalling. Its low content of impurities and its relatively high content of free silica impart mechanical strength and rigidity at high temperatures. H-W Athens Plastic Clay is used with outstanding results in the manufacture of zinc retorts and saggers, and of setting tile which are subjected to transverse loads.

H-W BOND CLAY B (WEATHERED)

H-W Bond Clay B possesses a remarkable combination of desirable properties, including high plasticity, strong bond when merely air dried, high strength after firing, high fusion point, moderate shrinkage, and exceptional uniformity. It is mined from an unusually large deposit, the extent and quality of which have been determined by thorough core drilling. A steady, uniform output for many years to come is assured.

Like most plastic clays of high fusion point, H-W Bond Clay B is in comparatively hard lump form as mined. While plasticity and good bonding qualities are acquired merely upon grinding and tempering with water, these properties are not developed to the fullest extent except by weathering. H-W Bond Clay B is weathered for at least one year, to disintegrate and slake the lumps, to make the clay more plastic, and to develop its bonding strength. A series of stock piles provides a uniform and adequate supply.

Finely ground H-W Weathered Bond Clay B gives exceptional service when used for laying high duty fireclay brick; for mixing with ground silica ganister or with ground calcined clay in making monolithic bottoms and linings; for mixing with calcined grog to be used in making repairs to furnace linings by spraying; and for laying bungs and for daubing in malleable iron furnaces. When thoroughly mixed with water, H-W Weathered Bond Clay B passes almost entirely into suspension, forming a slurry which can be supplied to brick masons in an elevated structure, such as a blast furnace lining, by means of a plunger pump.

H-W CRUCIBLE CLAY

In the preparation of H-W Crucible Clay, thoroughly weathered clay is finely ground, pugged and stored for many months in a sweating room. It is then passed through a combination pug mill and auger machine. This treatment develops the plasticity and bonding strength to the utmost degree.

H-W Crucible Clay is used in the manufacture of various products which require clay of high refractoriness as well as of high plasticity and bonding power, as for example, refractory graphite products. It is shipped in dobie form, either wet or dry, or finely ground, as may be desired.

H-W D CLAY

H-W D Clay is a white burning siliceous kaolin with an extremely low flux content. It is produced from a large deposit in central Pennsylvania. Selective mining assures quality control and uniformity of product.

H-W D Clay is used as the open-burning constituent in sagger batches. It is also advantageously employed in potteries as a constituent of various ceramic bodies. H-W D Clay is well adapted for use in monolithic bodies and for any other purpose requiring clay of extremely low shrinkage and high refractoriness. It is supplied either unground or ground to the degree of fineness desired.

H-W FOUNDRY CLAY

H-W Foundry Clay is a plastic bond clay which is well adapted for patching and daubing in cupolas and malleable iron furnaces, and for general foundry use. The shrinkage of H-W Foundry Clay at high temperatures is very low. Consequently, it does not tend to peel or separate from brickwork. When heated it becomes hard and strong and at furnace operating temperatures readily acquires a glazed surface, resistant to penetration by slags.

H-W GEORGIA KAOLIN

H-W Georgia Kaolin possesses high refractoriness and great plasticity. It is mined by the open pit method. Careful selection insures a product of uniform quality. It is furnished either in lump form or ground to desired size for use in refractory products and ceramic bodies.

H-W MISSOURI PLASTIC CLAY

H-W Missouri Plastic Clay is a refractory bond clay obtained from deposits operated by the company near Fulton, Missouri. It has high plasticity and excellent working properties and it develops high strength after drying and firing. H-W Missouri Plastic Clay is well adapted for use in the manufacture of zinc retorts and condensers and of saggers. It also finds use in other applications where high bonding strength is of importance.

H-W MOLDSAND BOND

H-W Moldsand Bond is a finely ground extremely plastic bonding clay of high refractoriness. As described on page 182, it is especially adapted to the making of synthetic mixtures with clean sand or with Calamo and as a rejuvenating agent for molding sand in foundries which are equipped with chaser mills or mullers.

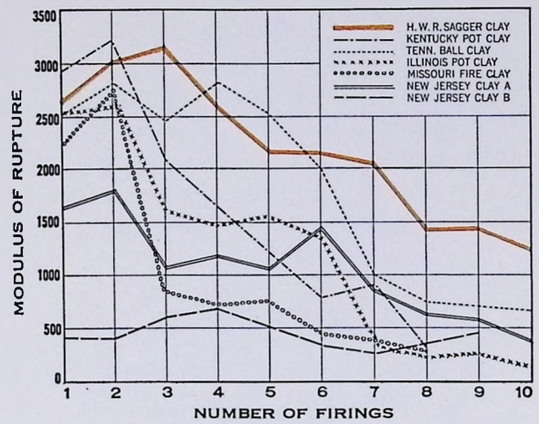
The minute particles of the ground bond clay become much more finely divided when tempered with water; consequently, homogeneous clay-sand mixtures are easily prepared. Because of its high refractoriness, Moldsand Bond does not fuse at metal pouring temperatures. The most desirable degree of cohesiveness and permeability can be secured by adding suitable amounts of Moldsand Bond to the molding sand.

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H-W SAGGER CLAY

Long sagger life and low sagger costs are in no small measure dependent upon the use of clays of uniformly high quality. H-W Sagger Clay is a standard constituent of the batch at many potteries; its use has reduced the important item of sagger costs.

The clay as shipped is in proper condition for mixing and pugging. The batch containing it is easily worked. The saggers dry very readily and are extremely strong, both before and after firing. One of the important properties of H-W Sagger Clay is its ability to withstand repeated firings with very slight loss of strength, as shown in the following chart.



Modulus of rupture of various clays after successive firings of bars consisting of 50% clay and 50% grog. Note the superiority of H-W Sagger Clay

CALCINED CLAYS

H-W CALCINED CLAY DOBIES

H-W Calcined Missouri Clay Dobies and H-W Calcined Texas Clay Dobies are prepared from high grade refractory clays from the company's extensive deposits. The raw clays are ground, thoroughly mixed with water in a pug mill, extruded from an auger machine in the form of a column, and cut into rectangular blocks or dobies. These are fired in kilns to the same temperature as that employed in the manufacture of highly refractory fireclay brick. The calcined dobies are of uniform hardness and of homogeneous texture, and are fully shrunk during the firing process. They are of high density and strength, and when ground, break with a splintery fracture and with the production of a minimum of fines. Their most general application is in the manufacture of zinc retorts and condensers, and of clay products used by the glass industry. They are used also for the preparation of siege clays. H-W Calcined Clay Dobies, made in Missouri and Texas, are supplied either without further processing or ground to any degree of fineness which may be desired.

H-W CALCINED FLINT CLAY

The stability of many refractory products made of fireclay is dependent upon the character and amount of grog used in the batch. In refractories intended for use where they are required to withstand severe service conditions, the grog must be of superior quality. Highly refractory flint clays possess the characteristics necessary for such grog.

H-W Calcined Missouri Flint Clay is a selected clay of high refractoriness which has been calcined in a rotary kiln. It is of extremely uniform burn, and of high density. It ranges in size from pieces of approximately 2½ inches in diameter to particles of ⅛-inch size, including a small proportion of fines. It is also furnished ground to specification.

H-W Calcined Pennsylvania Flint Clay is prepared from lumps of highly refractory clay obtained from the company's mines in central Pennsylvania. Uniformity in quality is assured by careful hand selection. The temperature of calcination is sufficiently high to effect practically complete shrinkage. When crushed, the calcined clay breaks down into angular fragments, so desirable in mixes used in the manufacture of clay bodies which must be mechanically strong and well bonded.

H-W Calcined Flint Clays, from Missouri and Pennsylvania, are used in the manufacture of refractory blocks for the glass industry and in the manufacture of zinc retorts and condensers. They also serve admirably as the grog constituent in monolithic linings and patching mixtures, and as the grog component of saggers and various other refractory bodies such as plastics and castables.

H-W CALCINED KAOLIN

H-W Calcined Kaolin is obtained through calcination of selected high grade material at high temperature in a rotary kiln. It is of hard burn and of high density. The calcines range in size from a maximum diameter of 2½ inches down to ⅛ inch, including a small percentage of finer particles. The high refractoriness and density of H-W Calcined Kaolin adapt it for use in ramming mixtures, refractory concrete, saggers and other refractory products.

H-W HIGH DUTY CALCINED CLAY

H-W High Duty Calcined Clay is manufactured from refractory clays that have been burned at high temperatures to eliminate the shrinkage. It is supplied in various standard grinds, or in special sizings as may be required for particular applications. H-W High Duty Calcined Clay is used in the preparation of ramming mixtures, saggers, zinc retorts, and as the grog constituent in a wide variety of other refractory products.

Modern Refractory Practice: 3rd Edition (1950)
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SOME RECOMMENDED USES FOR H-W SPECIAL CLAYS

Application	Materials
Air Gun Mixes	H-W BOND CLAY B H-W CALCINED CLAYS
Ceramic Bodies	H-W BOND CLAY B H-W D CLAY H-W GEORGIA KAOLIN H-W CALCINED FLINT CLAY H-W CALCINED GEORGIA KAOLIN
Cupolas (Patching and Daubing)	H-W FOUNDRY CLAY
Foundry Service	
General Patching and Daubing	H-W FOUNDRY CLAY
Synthetic Molding Mixtures	H-W MOLDSAND BOND
Ganister Mixes	H-W BOND CLAY B (WITH H-W GROUND GANISTER)
Glass House Refractories	H-W BOND CLAY B H-W CRUCIBLE CLAY H-W CALCINED FLINT CLAY
Graphite Products	H-W CRUCIBLE CLAY H-W CALCINED CLAYS
Malleable Furnaces	
For Laying Bungs and Daubing Mixtures	H-W BOND CLAY B
Monolithic Linings	H-W BOND CLAY B H-W D CLAY H-W CALCINED CLAYS H-W BOND CLAY B (WITH H-W GROUND GANISTER)
Mortar for Laying Brick	H-W BOND CLAY B
Saggers	H-W SAGGER CLAY H-W D CLAY H-W ATHENS PLASTIC CLAY H-W MISSOURI PLASTIC CLAY H-W CALCINED CLAYS
Zinc Condensers	H-W MISSOURI PLASTIC CLAY H-W CALCINED CLAYS
Zinc Retorts	H-W MISSOURI PLASTIC CLAY H-W ATHENS PLASTIC CLAY H-W CALCINED CLAYS

MORTAR MATERIALS



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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MORTAR MATERIALS

Masonry built of refractory brick consists of many relatively small units, laid together to conform to a definite, prescribed plan or design. The strength of the masonry depends upon the strength of the individual units, the manner in which they are laid together and the nature of the mortar material used in the joints. The purpose of the mortar is to fill the joints, and to bond the individual brick together; it should protect the joints from attack by slag, and provide resistance to infiltration of cold air and to the outward flow of gases.

Users of refractories now realize that poorly made joints, or joints filled with improper material, may greatly shorten the life of a refractory structure; and usually they select the mortar material as carefully as the brick with which it is to be used.

Refractory mortar materials are divided into two general classes:

1. Hot-setting bonding mortars.
2. Air-setting bonding mortars.

Included in each of these groups are materials of various compositions, each of which has a definite field of application.

The compositions of all Harbison-Walker mortar materials and the methods of preparation have been developed through laboratory investigations, in which consideration has been given to the particular combination of properties each bonding mortar should possess. Among the factors included are workability, plasticity, water retention, fineness of grind, drying and firing shrinkages, chemical composition, refractoriness, cold and hot bonding strengths, vitrification temperature, and resistance to the action of fluxes and gases.

The requirements which a bonding mortar must meet in service are often extremely exacting, and require a nicely adjusted balance of properties. For economy and convenience in laying, a mortar should have good working properties when mixed to either putty-like or cream-like consistency. With excellent workability and water retention over a range of consistencies, a mortar can be used for dipped or troweled joints, as a surface coating for walls, or for patching. The mortar should not shrink excessively upon drying or heating, nor should it overfire and become vesicular at high temperatures. The thermal expansion of the mortar should be approximately the same as that of the brick, or temperature changes will affect the bond between brick and mortar, and cause surface coatings to crack or peel. The refractoriness must be sufficiently high so that the mortar will not melt or flow from joints at furnace operating temperatures. However, if strong joints are needed, the mortar material must be affected sufficiently by the heat to develop a ceramic bond, and the bonding strength must be adequate.

In some cases, there must be sufficient chemical reaction between brick and mortar to develop a strong bond between them, but in no case may the chemical reaction be sufficient to damage the brick. In many types of service, it is essential that the joint material be highly resistant to chemical attack by the furnace charge, slag, dust, volatilized fluxes or gases; and for certain uses it is important that the mortar material should not discolor nor otherwise contaminate the material being processed in the furnace. Bonding mortars which do not develop a strong bond are often desirable for use in laying brick in walls which are subjected to soaking heat, such as the flue-walls in carbon-baking furnaces. Mortars of this kind permit movement of the brickwork as expansion and contraction occur due to heating and cooling.

HOT-SETTING BONDING MORTARS

The distinguishing characteristic of a hot-setting bonding mortar is that it develops a strong bond only at furnace temperatures. The bonding temperature usually lies between 2000° and 2500° F., depending upon the composition.

A hot-setting bonding mortar consists of finely ground crude or calcined refractory material, or a mixture of these. The mortar is usually similar in composition and properties to the brick with which it is to be used.

Materials of this type usually have excellent working properties. They are prepared for use by mixing them with a sufficient amount of water to give the desired consistency. The brick are laid with either troweled or dipped joints, as may be desired. Usually thin joints are best.

Harbison-Walker fine ground fire clays are shipped either in bulk or in sacks. All other Harbison-Walker hot-setting bonding mortars are shipped in sacks.

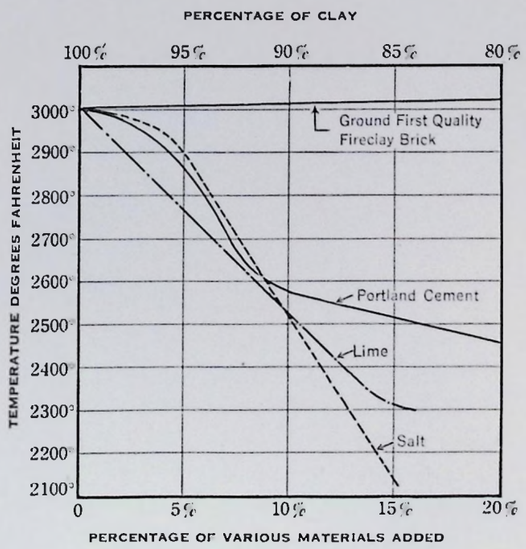
H-W FINE GROUND FIRE CLAYS

Finely ground fire clay is generally used for laying fireclay brick. For dipped joints, the mortar material is thoroughly mixed with water to form a thin paste.

The addition of Portland cement, lime, asbestos, salt or other foreign materials to finely ground fire clay, to be used as mortar material for brick entering into high temperature operation, is not to be recommended. Such materials, even in small proportions, may have a marked effect in decreasing the refractoriness of the mortar. This fact is illustrated in the accompanying figure, which shows the effect of certain materials on the melting point of a plastic fire clay. Fluxing agents added to fireclay mortar not only decrease its refractoriness, but also render it more vulnerable to attack by slags.

Fireclay brick of superior quality should never be laid with inferior fire clay. Such material may shrink excessively at even moderate temperatures. At higher operating temperatures, it may swell and soften sufficiently to flow from the joints. Very impure clays at high temperatures will react chemically with the brick, and cause serious damage.

In each manufacturing district, Harbison-Walker prepares finely ground fire clays which are especially adapted for use as mortar materials for laying H-W fireclay brick of the various brands produced in the district.



Fusion Temperatures of Mixtures of a Plastic Fire Clay and other Materials

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H-W SPECIAL MORTAR MIXTURE

H-W Special Mortar Mixture consists of a blend of raw and calcined clays. The raw clay component is very plastic, and develops high bonding strength at moderate furnace temperatures. The calcined clay component is a very refractory fire clay which has been completely shrunk by firing at a high temperature. H-W Special Mortar Mixture is appreciably more refractory than are the fine-ground fire clays generally used for laying high duty fireclay brick, and its shrinkage at high temperatures is negligible.

H-W Special Mortar Mixture is supplied for laying either high duty fireclay brick or super-duty fireclay brick for service in which full or solid joints with minimum shrinkage are especially desirable, and in which an exceedingly strong bond is not an essential requirement. It is especially adapted for high temperature service where temperature fluctuations are extreme. Since it does not bond the brick rigidly together, it permits them to expand or contract freely when changes in temperature occur.

H-W SUPER-DUTY MORTAR

H-W Super-Duty Mortar is a hot-setting mortar material, designed for use in laying super-duty fireclay brick. It consists of calcined flint clay and highly refractory bonding clays, blended in proper proportions to give the most desirable combination of physical properties. This material has superior working qualities, and can be used for either dipped or troweled joints. It develops a strong ceramic bond at furnace temperatures, has negligible shrinkage and is highly refractory. It is shipped in sacks containing 100 pounds.

Alamo, Boone, and Dean Super-Duty Mortars serve well for laying either super-duty or high duty fireclay brick, and in special applications for laying high-alumina brick.

ANKORITE

In order to secure the full benefit from the superior properties of H-W high-alumina brick, it is necessary to lay them with the proper mortar material. Ankorite bonding mortar is made for this particular purpose. It is a blend of finely ground calcined and uncalcined diaspore clays. The proportion of calcined diaspore in Ankorite is such that its drying and burning shrinkages are negligible. When mixed with water, it has excellent working properties, and develops a strong bond at furnace operating temperatures. It is recommended for use in laying and coating high-alumina brick of the 50%, 60%, 70% and 80% alumina classes.

H-W STAR SILICA FIRE CLAY

H-W Star Silica Fire Clay is a highly refractory mortar material especially suited for laying silica brick. It consists of a mixture of finely ground silica material and a highly siliceous plastic clay. It readily enters into suspension when mixed with water; it has excellent working properties, and it can be spread easily and smoothly with a trowel.

H-W Star Silica Fire Clay, of the standard composition, fulfills all of the usual requirements for mortar material employed in laying silica brick. Its refractoriness is high, and it forms a strong ceramic bond. Several modifications are furnished for service requiring a mortar which possesses one or more particular properties developed to a maximum degree.

H-W COKE OVEN SILICA FIRE CLAY

H-W Coke Oven Silica Fire Clay is somewhat more refractory than the usual silica fire clays. While it is made especially for laying silica brick in coke ovens, it is used also in glass tanks and other furnaces. It consists of a mixture of finely ground silica material and highly siliceous plastic fire clay, blended in such proportions as to secure high refractoriness and excellent plasticity and working properties. H-W Coke Oven Silica Fire Clay can be worked easily with a trowel, and can also be used satisfactorily for dipped joints. It develops a strong ceramic bond when heated to furnace operating temperatures.

STARBOND

Starbond is a hot-setting bonding mortar, of higher silica and lower alumina contents than the standard types of silica cement. It is approximately equal in refractoriness to Star silica brick. It contains a plasticizing agent which imparts exceptional plasticity and working properties, and is used for troweled or dipped joints.

Advantage is taken of the superior physical and chemical properties of Starbond, by using it for laying silica brick in constructions where the refractories are subject to severe corrosion or to other extremely severe operating conditions. Starbond is shipped in paper sacks of 100 pounds net weight.

VEGA BOND

The ultimate in silica cements is attained in Vega Bond. This may be classified accurately as a super-duty silica cement, as it was developed especially for use with Vega super-duty silica brick, and it corresponds in chemical composition and refractoriness to Vega brick.

As mixed with water for use, Vega Bond develops a high degree of plasticity. When mixed to a creamy consistency, it is especially well suited for laying silica brick with thin but full joints. When mixed to a thicker consistency, it serves for laying brick with relatively thick joints, as required for leveling up courses. Vega Bond is used economically for laying Star silica brick for service under severe operating conditions, as for example, where slag attack is an important factor in the service conditions to which the brickwork is subjected.

H-W FURNACE MAGNESITE

H-W Furnace Magnesite consists of finely ground dead-burned magnesite. While prepared especially for laying magnesite brick, it also finds useful application for patching, and in mixtures with granular magnesite material it serves for the construction of rammed linings and monolithic hearths. It is also used in mixtures for patching and surface coating by application with the various types of air guns.

The use of water with furnace magnesite in the preparation of mortar to be used for laying magnesite brick is not best practice, unless great care is taken in drying thoroughly. Water glass, or linseed oil in proportions ranging from 5 per cent to 15 per cent by volume, may be employed. Hot tar is frequently preferred for mixing with furnace magnesite and grains to be used for patching or for rammed linings.

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H-W SPECIAL FURNACE CHROME

H-W Special Furnace Chrome is prepared from carefully selected chrome ores of high refractoriness. It is used to advantage for laying chrome brick, and in many instances for laying silica or magnesite brick. It forms joints which are resistant to attack by a wide range of furnace slags and other fluxing agents. It is used as a daubing material for the protection of brickwork in various types of furnaces, as for example in center walls of soaking pits.

H-W Special Furnace Chrome is shipped in paper sacks, or in cloth sacks, as desired.

AIR-SETTING BONDING MORTARS

For many purposes, hot-setting bonding mortars do not meet the requirements of modern furnace practice. At moderate temperatures, a hot-setting bonding mortar acts merely as a filler between the brick. If the joints are thick, the mortar may be blown out by rapidly moving furnace gases, or removed by abrasive action. Not until a temperature of 2000° F. or higher is reached do the average hot-setting bonding mortars develop sufficient strength to bond the brickwork firmly together. When the normal operating temperatures are less than this, a true bond is not formed. Moreover, at high temperatures a hot-setting mortar bonds the brick only so far into the joint as the temperature of ceramic set reaches — usually not more than an inch or two. Slags easily penetrate porous joints and attack the brick on the four faces as well as on the exposed end.

Bonding mortars of the air-setting type are now used for laying all types of standard refractory brick, especially in those portions of industrial furnace masonry where the operating conditions are most severe.

Harbison-Walker air-setting bonding mortars are recommended for service in which a strong bond over a wide range of temperatures is desirable. These mortars are prepared from suitable refractory materials, by proper selection and combination. Chemical binders impart air-setting properties, and maintain the strength of the bond up to the temperature at which the ceramic bond takes effect. Air-setting mortars take a rigid cold set, have a firm bond at all temperatures and form mechanically strong joints with high resistance to abrasion and erosion. Their porosities and permeabilities are low and they are highly refractory. They bond the wall the whole way through — from the hot to the cold surface.

FIREBOND

Firebond is a high temperature cement of the siliceous type, which is shipped dry. It can be quickly prepared for use by mixing it with just enough water to form a mortar of the desired consistency for either dipped or troweled joints. An excess of water is to be avoided, to assure retention of the lightest particles. Firebond has excellent working properties. It sets as it dries, forming a strong bond which is maintained at furnace operating temperatures. It is resistant to the corrosive action of siliceous slags, and retards slag penetration at joints.

Firebond is recommended for laying fireclay or silica brick. When applied as a coating to the inner wall surfaces of furnaces, it materially reduces leakage of gases and infiltration of air.

Firebond is shipped in air-tight steel drums of 200 pounds net weight.

HARWACO BOND

Harwaco Bond is an air-setting high temperature bonding mortar which is shipped in wet form ready-mixed for use. Its essential component is calcined diaspore clay of high alumina content. It is considerably more refractory than any bonding material with a fireclay base.

Harwaco Bond, as shipped, contains just the proper amount of liquid to make it suitable for the average troweled joint. Experience in the use of this mortar has proved the importance of its workability. While Harwaco Bond resists settling in the drums, increased smoothness may be obtained by thorough mixing. This can normally be accomplished without removing the mortar from the drum. Unused portions of the mortar which remain in the drum will retain their full working qualities if the cover is kept tightly sealed.

Harwaco Bond is exceptionally plastic. It can be worked with a trowel as long as necessary, even on a porous brick, without drying out. With the addition of water, it can be brought to the desired consistency either for dipped joints or for surface coating.

Harwaco Bond is recommended for use as a daubing mixture and for laying fireclay, superduty fireclay, or high-alumina brick. Its high refractoriness renders it advantageous for applications where extremely high temperatures prevail. Because of its high bonding strength it is also well adapted for moderate duty service. When applied as a thin coating to the inner surfaces of furnace walls Harwaco Bond materially reduces gas leakage and air infiltration. It is shipped in air-tight steel drums of 25, 50, 100 and 200 pounds net weight.

THERMOLITH

Thermolith is a dry high temperature cement having a chrome ore base. It is mixed with water to produce an air-setting mortar of exceptional merit. Because of its nearly neutral chemical character it forms joints which are extremely resistant to chemical corrosion by a wide variety of slags. Its high bonding strength and high refractoriness adapt it for service as a bonding material in applications covering a wide range of temperatures.

Thermolith can be easily prepared for use by mixing it thoroughly with a sufficient amount of water to form a thick mortar for troweled joints, or a slightly thinner mortar for dipped joints. An excess of water should be avoided, to insure uniform consistency of the mortar. For surface coatings, Thermolith is usually applied by means of an air gun.

Thermolith is so highly refractory that it may be used to form heavy troweled joints when such joints are needed. It begins to set soon after being spread, forming firmly bonded joints, and the strong bond is maintained throughout the range of furnace temperatures. It bonds the wall the whole way through, from hot face to cold face, and the joints become the strongest parts of the masonry.

Thermolith is recommended for use in laying basic brick of all types, fireclay brick, high-alumina brick and silica brick; or as a neutral layer between brick which tend to react with each other at high temperatures. It also serves to advantage as a bond for daubing mixtures used in making repairs to damaged brickwork. Thermolith is shipped in air-tight steel drums of 200 pounds net weight.

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CORALITE BONDING MORTAR

CORALITE BONDING MORTAR is a wet air-setting high temperature cement with a high-alumina base. It consists essentially of the same materials as those used in the manufacture of CORALITE brick. In addition it contains a chemical bonding agent which imparts high strength. CORALITE BONDING MORTAR is used advantageously for laying brick of the 60%, 70% and 80% alumina classes, especially in service where the brickwork is exposed to attack by corrosive slag. It is readily thinned to suitable consistency for dipped joints by adding water and mixing. Shipment is made in air-tight steel drums of 200 pounds net weight.

KORUNDAL BONDING MORTAR

KORUNDAL BONDING MORTAR was developed especially for use with KORUNDAL brick. One of its most significant properties is extremely high refractoriness, imparted by its alumina content of more than 85 per cent. It is used to great advantage with all classes of high-alumina brick in applications where slagging conditions are extremely severe or temperatures are unusually high, and should always be used for laying KORUNDAL brick. KORUNDAL BONDING MORTAR is an air-setting mortar material shipped dry in steel drums of 100 pounds net weight.

H-W PERIKLASE BONDING MORTAR

H-W PERIKLASE BONDING MORTAR, a basic high temperature cement of exceptionally high magnesia content, is ideally suited for laying H-W PERIKLASE brick. However, it may be used successfully in all applications where a chemically basic mortar is required.

H-W PERIKLASE BONDING MORTAR is extremely refractory, and has excellent bonding strength at all temperatures. It is a dry mortar material and needs only to be mixed with water to prepare it for use. It is shipped in air-tight steel drums of 175 pounds net weight.

H-W FORSTERITE BONDING MORTAR

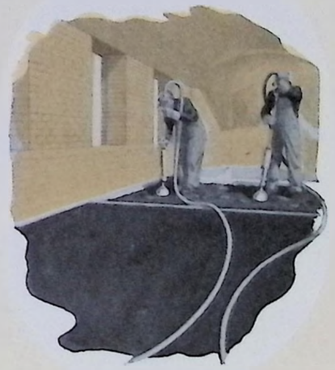
H-W FORSTERITE BONDING MORTAR was developed primarily for use with H-W FORSTERITE brick, and its composition is substantially the same as that of the brick. Bonding agents are blended with the mortar material for the purpose of imparting strong air-setting properties and a strong ceramic bond. The high bonding strength is maintained throughout the entire range of temperatures at which H-W FORSTERITE brick are used.

This mortar is shipped in dry form in steel drums of 175 pounds net weight.

SELECTION OF HIGH TEMPERATURE CEMENTS

Choice of a bonding mortar for any specific application depends upon both the type of refractory brick to be bonded and the operating conditions to which the brick are to be exposed. Service conditions vary so widely in different furnaces and usually in different parts of the same furnace that many kinds of brick and bonding mortars are needed. The correct choice of brick and mortars will be assured by consultation with a Harbison-Walker representative.

PLASTIC FIRE BRICK RAMMING MIXTURES AND CASTABLES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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H-W PLASTIC FIRE BRICK

H-W Plastic Fire Brick is a hot-setting refractory of proper plastic consistency for use without further preparation. This material is manufactured from carefully selected calcined and bond clays of the highest quality. Uniformity is assured by close laboratory control.

H-W Plastic Fire Brick is used for monolithic furnace linings and is especially adaptable for making quick, economical emergency repairs. It forms a solid, one-piece refractory surface free from joints.

It is easily rammed to any shape or contour. By its use, the necessity of waiting for manufacture and delivery of special shapes when urgently needed may be avoided.

It does not require special experience for installation. With a few simple tools, the average plant maintenance crew can make repairs.

It resists destructive spalling and slagging influences of furnace operation.

It is packed in strong, easy-to-handle, moisture-proof paper cartons containing 100 pounds net weight, and in steel drums containing 200 pounds net weight.

The high refractoriness of H-W Plastic Fire Brick and the ease with which it can be rammed into place make it suitable for many important applications, among which are boiler settings, oil still settings, oil burner installations, heating furnaces, forge furnaces, annealing ovens and furnaces, small brass melting furnaces, coke oven ascension pipes, cupolas, ladles, lehrs, incinerators, bake ovens, burner blocks, furnace door linings and domestic fireplaces.

H-W Plastic Fire Brick is available in two grades: H-W Standard Plastic Fire Brick for moderate and high duty service, and H-W Super-Plastic Fire Brick for more severe operating conditions.

H-W Standard Plastic Fire Brick is equivalent to high duty fireclay brick in refractoriness, and, in general, is used successfully under conditions for which fireclay refractories of this class are adequate.

H-W Super-Plastic Fire Brick is recommended for conditions beyond the limits of standard plastic fire brick. Manufactured from highest quality calcined flint clays and plastic clays, it serves the purposes for which appreciably higher refractoriness is necessary.

For estimating purposes, approximately 135 pounds of H-W Standard Plastic, or 137 pounds of H-W Super-Plastic Fire Brick are required per cubic foot of construction.



RAMMING MIXTURES

During recent years, ramming mixtures of various types and compositions have found increased favor for use in forming monolithic furnace hearths and furnace linings. Based upon a thorough knowledge of the requirements, Harbison-Walker has developed ramming mixtures which have become established as standard in many industrial plants.

H-W MAGNAMIX

H-W Magnamix is an air-setting ramming mixture which consists mainly of dead-burned Washington magnesite, and contains approximately 80 per cent magnesia. It is used for building the bottoms of basic open-hearth furnaces, and electric steel and ferro-alloy furnaces, and for maintaining and repairing the banks and tap-holes of basic hearths.

When H-W Magnamix is used for building the bottoms of basic open-hearth and electric steel furnaces, the refractories in walls and roof are spared the severe treatment which attends the sintering-in of dead-burned grain magnesite mixture in successive layers.

More complete information concerning H-W Magnamix is given on page 100.

THERMOLITH BATCH (DRY)

Thermolith Batch is a self-bonding ramming mixture with a chrome ore base. The addition of water is necessary to develop bonding properties and to prepare it for application.

Thermolith Batch is highly refractory and resistant to chemical attack by slags. It does not shrink appreciably in service, and it withstands the spalling influences of rapid changes in temperatures. By its use in the bottoms of forge furnaces and heating furnaces of various types, low installation and maintenance costs are attained. It is applied advantageously for facing and patching brickwork. It is especially well suited for application with an air gun.

Thermolith Batch is shipped in dry form in steel drums of 200 pounds net weight.

PLASTIC THERMOLITH BATCH

Plastic Thermolith Batch is a ramming mixture which consists of carefully graded sizes of refractory chrome ore, with added plasticizing and bonding agents. It is easily applied and upon air drying sets to form a dense, well bonded, monolithic refractory.

Because of the great strength developed merely upon drying, it is usually unnecessary to "burn-in" a lining or hearth of Plastic Thermolith Batch before proceeding with normal furnace operation. When heat is applied, its density increases to such an extent that it actually become denser than commercially fired chrome brick. This property, together with its nearly neutral chemical character, makes Plastic Thermolith Batch an admirable material for use in the construction of furnace bottoms where the corrosive action of ash, slag or scale is a destructive factor. For the monolithic portions of recovery furnaces in the kraft paper industry, Plastic Thermolith Batch is regarded as a standard refractory.

Plastic Thermolith Batch is shipped in drums of 200 pounds net weight.

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H-W PERIKLASE BATCH

H-W Periklase Batch is a ramming material with a magnesia base. It is shipped in dry form in steel drums of 200 pounds net weight. It consists of a mixture of carefully graded sizes of ground dead-burned magnesite of low iron content, with which minor amounts of other materials have been blended to render the batch plastic and workable and to make it self-bonding when water is added in its preparation for use. It can be applied easily and when tamped into place, it sets upon air drying to form a dense, well bonded monolithic refractory having many of the excellent properties of H-W Periklase brick.

H-W KORUNDAL RAMMING MIXTURE

H-W Korundal Ramming Mixture is similar in composition to Korundal brick, a refractory which consists mainly of corundum. It is used for patching, for making rammed-in shapes such as burner blocks, and for monolithic linings. Thus it is possible to secure the advantages of Korundal quality even when time does not permit the manufacture of special shapes, or when the design of the shapes desired is such that it is impracticable to make them.

H-W Korundal Ramming Mixture is shipped in dry form in steel drums of 100 and 200 pounds net weight. When mixed with water, rammed into place and dried, it forms a dense homogeneous refractory of exceptional refractoriness and of good strength.

H-W CASTABLES

H-W Castables are refractories which are mixed and poured like concrete. They are shipped in dry form, and when mixed with water to the desired consistency are poured or tamped into place, or applied by means of an air gun. H-W Castables take a strong hydraulic set at room temperatures, and good strength is maintained until the ceramic bond is developed as the temperature is increased. Thus, they may be used at any temperature up to their service limit.

H-W Castables are especially suited for furnace linings of irregular dimensions, for patching brickwork, and for casting special shapes which are needed in a hurry. Cutting of brick to fit is unnecessary if the service is such that castables can be employed.

H-W Castables are carefully blended so that they are amply refractory, show negligible shrinkage in service, have low coefficients of thermal expansion, and are resistant to both spalling and abrasion.

CLAY-BASE CASTABLES

Three grades of refractory clay-base castables are supplied:

H-W Super-Castable, for use at temperatures up to 2700° F.

H-W Standard Castable, for use at temperatures up to 2400° F.

H-W 56 Light-Weight Castable, for use at temperatures up to 2000° F., and H-W 85 Light-Weight Castable, for use at temperatures up to 2200° F., where light weight or low thermal conductivity is desired.

After installation, the standard and super-castables are generally referred to as "refractory concrete", and the light-weight castable as "insulating concrete".

H-W Super-Castable is recommended for applications where operating conditions are beyond the limits of standard castables. It is especially adapted for making special shapes of super-duty quality when needed promptly.

H-W Super-Castable is shipped dry in sacks of 100 pounds, net weight. For pouring consistency, approximately 17 per cent water by weight, or 2.0 gallons per 100 pounds of dry material is used. Approximately 120 pounds are required per cubic foot of finished construction.

H-W Standard Castable is especially convenient and economical for pouring special shapes. It is shipped dry in sacks containing 25 pounds or 100 pounds each, net weight. For pouring, approximately 20 per cent water by weight, or 2.4 gallons per 100 pounds of dry castable is used. For tamping, slightly less water is required. A cubic foot of finished construction requires approximately 110 pounds.

H-W Light-Weight Castables combine the desirable properties of refractoriness with excellent insulating value and light weight. By their use, heat losses from furnace walls are materially reduced.

H-W 56 Light-Weight Castable weighs only 56 pounds per cubic foot when cast into place and heated to furnace temperatures. It is shipped dry in sacks which for convenience contain just enough material for one cubic foot of furnace volume — 56 pounds. H-W 85 Light-Weight Castable weighs about 85 pounds per cubic foot in place, and is shipped in dry form in sacks containing 100 pounds net weight. Both materials have excellent workability, and can be applied either with a trowel or by means of an air gun. For pouring or casting, they are mixed with about 45 per cent of water by weight, or 5.4 gallons of water per hundred pounds of castable. At operating temperatures, they have excellent strength and stability of volume. Their thermal conductivities are approximately proportional to their bulk densities.

BASIC CASTABLE

H-W Chrome Castable is a highly refractory castable material which consists essentially of a mixture of carefully sized chrome ore particles and chemical bonding agents. It forms a smooth-casting refractory concrete with utility to temperatures above 3000° F.

When mixed with water, H-W Chrome Castable may be poured as a concrete, it may be rammed or troweled into place, or it may be applied by means of an air gun. In twenty-four hours time, it takes a strong set and forms a well bonded mass. When heat is applied, it develops a ceramic bond without change in volume. Its use is especially advantageous in furnace linings subjected to attack by basic slags or fluxes. Approximately 185 pounds of H-W Chrome Castable are required per cubic foot of construction.

TYPICAL USES OF H-W CASTABLES

Annealing furnace door linings, walls and bottoms; car tops; roof slabs for pit furnaces. Billet heating furnaces — door linings and wall repairs. Boiler furnace baffles and door linings; ash pit linings; rear arches of H.R.T. boilers. Coke oven door linings. Incinerator linings. Oil Still furnace floor slabs and burner ports. Rod Mill and Sheet Mill furnaces — door linings, walls, and bottoms. Stoker installations. Gas burners; oil burners. Precast shapes.

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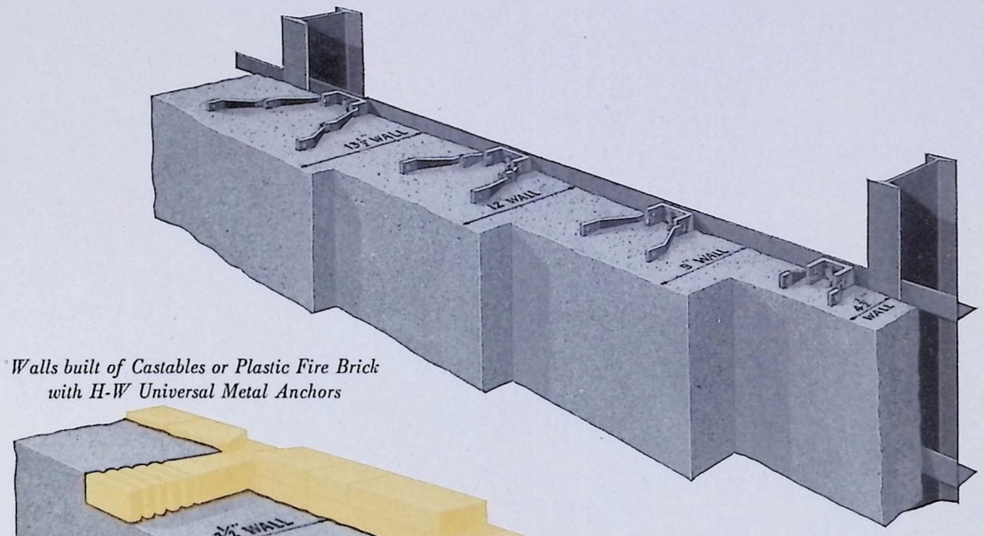
H-W UNIVERSAL ANCHORS

FOR SUPPORTING WALLS MADE OF PLASTIC FIRE BRICK OR CASTABLES

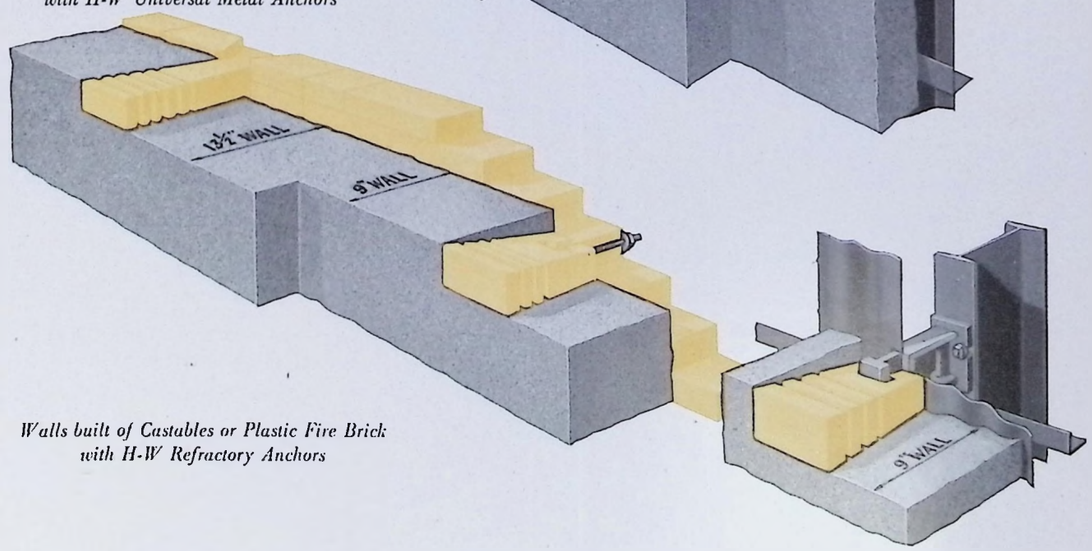
Metal Anchors: The Harbison-Walker metal anchor assembly, for use in walls constructed of plastic fire brick or castable materials, is illustrated in the accompanying figures. Each anchor consists of a base plate and attachable links. The base plate, which is bolted to a steel angle, is made of cast iron, while the links may be made of cast iron or of alloys capable of withstanding high temperatures.

The anchor assembly is very flexible in its application and may be used for any thickness of wall above 2 inches (the depth of the base plate) merely by variation in the number of links used, and in the angle at which they are set. The design permits a free movement of the links within the wall, as expansion or contraction occurs.

Refractory Anchors: Harbison-Walker Refractory Anchors are designed for use where the temperatures are so high that metal anchors cannot be used. They are strong brick shapes made of high duty fireclay material.



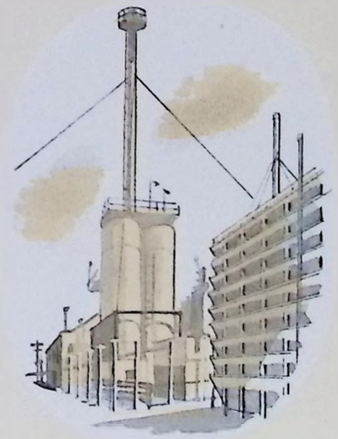
Walls built of Castables or Plastic Fire Brick with H-W Universal Metal Anchors



Walls built of Castables or Plastic Fire Brick with H-W Refractory Anchors

ACID-PROOF BRICK AND TILE

FOR ACID AND CHEMICAL RESISTANT STRUCTURES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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ACID-PROOF BRICK AND TILE

DURO — MADE IN PENNSYLVANIA

DURO Acid-Proof brick and tile are dense, vitreous, non-absorbent, and strongly resistant to the action of solvents. Unlike ordinary vitrified brick and chemical stoneware, DURO is manufactured from materials of extremely low flux content. The very low porosity and the non-absorbent quality of DURO are imparted by the method of manufacture and by the high temperature of firing. Standard shapes which can be formed by machine methods are rendered highly impervious by being molded at high pressure under a high vacuum.

DURO brick and tile are so dense and non-absorbent that any penetration by acids or corrosive chemicals is exceedingly slight. The care exercised in their manufacture insures the excellent workmanship which is so highly desirable in securing uniform joints when the brick are laid.

During the firing of DURO, the material of which it is composed is converted very largely into stable minerals which are insoluble in acids and various corrosive acid chemical solutions, and very resistant to the action of moderately concentrated alkaline solutions. The mineral constitution of DURO, and its close vitreous texture, render it highly insoluble in mineral acids (except hydrofluoric acid), and organic acids of any degree of concentration at practically all working temperatures.

The refractoriness of DURO is unusually high for acid-resisting material. It is well adapted for service in processes employing temperatures as high as 2300° F. in conjunction with nascent gases and acid fumes. It has exceptionally high mechanical strength.

The type of cement used for laying DURO brick is dependent upon the kind of service for which the brick are intended. For relatively low temperature service, as in floors and pickling tanks, DURO brick are generally bonded with sulphur compound cements, which are poured into place while in a molten condition. Cements of a resinol base are used in special applications at relatively low temperatures. DURO brick used in contact with concentrated acids, and at somewhat higher operating temperatures, are preferably laid with an acid-proof cement of the plastic type which sets hard upon drying.

When DURO brick are used at comparatively high temperatures in linings which must resist the action of acid or other corrosive fumes, as for example in stack linings, they are sometimes laid with HARWACO BOND.

The sizes of DURO brick generally used in the construction of acid storage tanks, acid towers, acid tower packing, and for acid equipment in general, are standard straights and other sizes of the 9″ x 4½″ x 2½″ series, listed on page 30, and the DURO liner or packing tile (12″ x 6″ x 1½″). DURO sizes in the 9″ x 4½″ x 3″ series of sizes, listed on page 32, are supplied when desired.

DURO brick and tile weigh approximately 140 to 145 pounds per cubic foot.

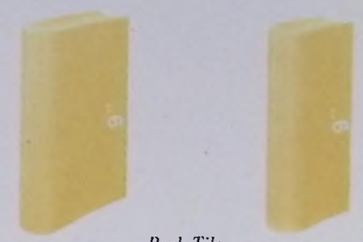
W-ACID — MADE IN ALABAMA

W-ACID brick are the counterpart of DURO in their physical and chemical properties and are used for the same purposes as DURO. At many points, especially throughout the South, their delivered cost is lower than that of DURO because of lower transportation costs.

UNIVERSAL CIRCLE BRICK AND BOOK TILE



Universal Circle Brick

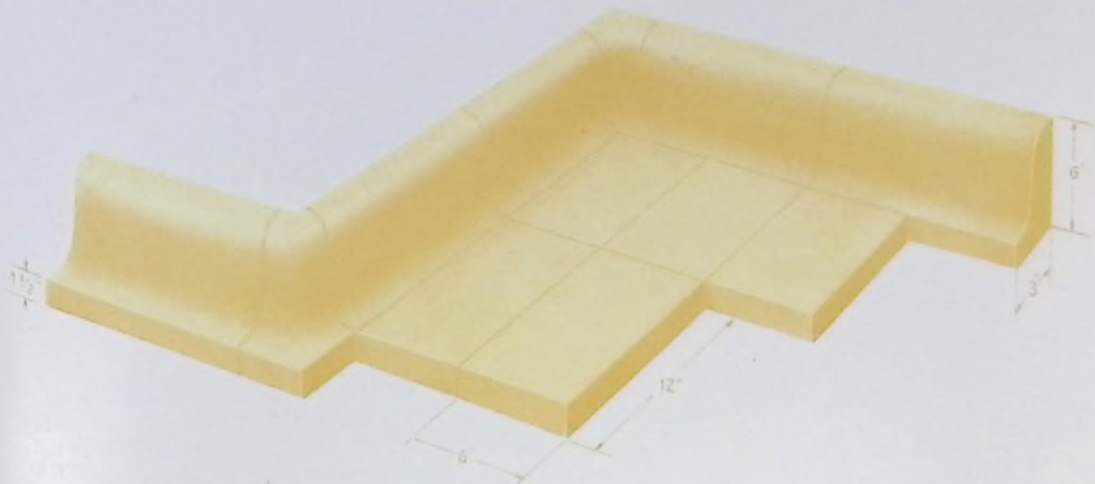


Book Tile

DURO and W-ACID Universal Circle Brick, with effective dimensions of 9″ x 4½″ x 2½″, are used to build 4½-inch linings in vertical tanks or stacks having any diameter from 2′ 0″ to 30′ 0″. This is possible because of the unique design of the ends of the brick, which provides both flexibility and tightness of joints. Use of the Universal Circle Brick is especially advantageous in plants having tanks of different diameters, since the one size will fit all tanks. DURO Book Tile, of similar design, are furnished for thinner linings. DURO Universal Circle Brick and Book Tile are machine made. They are extremely dense and have superior workmanship. The brick can be laid with thin joints, and with a minimum amount of cement.

ACID-PROOF FLOOR CONSTRUCTION

In many plants acid solutions come into contact with the floors. In others, the floors are subject to hard wear, and to continual dampness. For both of these conditions DURO and W-ACID floor construction is widely used. The floors are usually laid with standard tile 12″ x 6″ x 1½″ or 9″ x 4½″ x 1½″. However, standard 9″ x 4½″ x 2½″ straights are preferable for floors which are subjected to heavy moving loads. The special shapes which surround the floor are known as Cove Base; Cove Base, Interior Angle; and Cove Base, Exterior Angle.



Acid-proof Floor Construction

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HEXAGONAL PACKING TILE

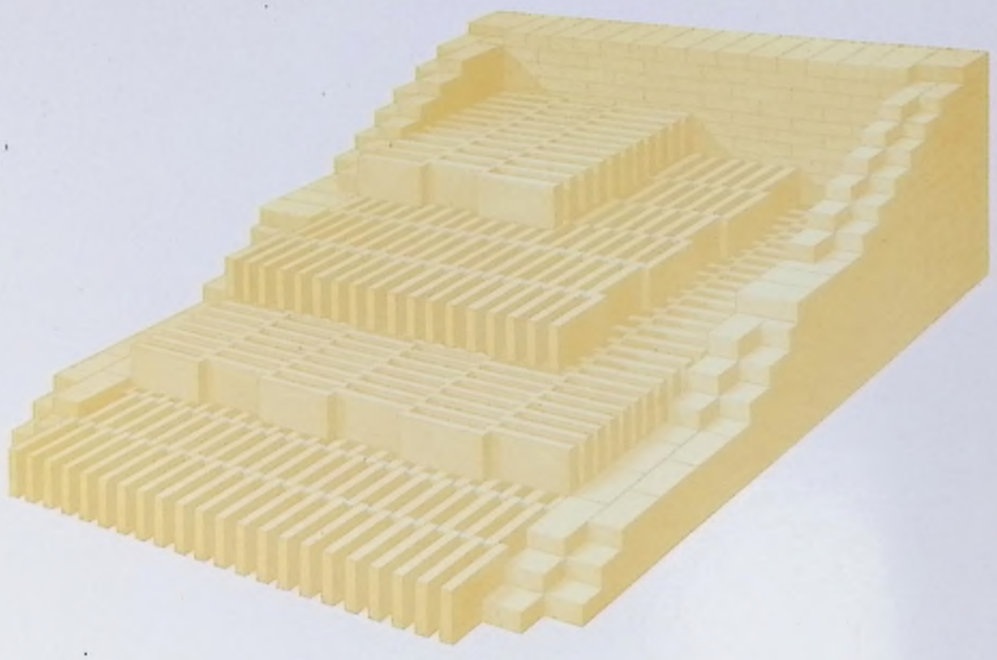


DURO Hexagonal Packing Tile are so designed that the openings within a tile and those between tile have approximately the same area. Uniform distribution of gas and liquid is thus promoted. Each tile is provided with six outer legs and one center leg, insuring substantial construction. The tile are aligned vertically in installation and can be used in both rectangular and circular towers.

RECTANGULAR PACKING TILE

DURO and W-ACID Packing Tile, 12″ x 6″ x 1½″, are exceedingly durable and highly efficient as packing for acid towers. They afford great exposed surface area, and the sharp edges cause a break in the flow of the liquid, insuring maximum contact between liquid and gases. Since by far the greater portion of the contact faces are vertical, channeling effects in the circulation are practically eliminated, and the operation of the tower is rendered highly efficient.

Various tile having dimensions larger than 12″ x 6″ x 1½″ are also used in some cases to provide larger openings required to prevent clogging by dust from gases.



Arrangement of Packing Tile in Acid Tower

PACKING RINGS



Tower Packing Partition Ring Diameter 3″, Length 3″



Tower Packing Partition Ring Diameter 4″, Length 4″



Tower Packing Partition Ring Diameter 6″, Length 6″

DURO and W-ACID tower packing partition rings are made from exactly the same materials as those used in the manufacture of the corresponding acid-proof brick. They are dense and vitreous throughout, have superior resistance to chemical attack and maximum surface area per cubic foot of packing.

Packing rings are manufactured in various sizes, such as 3″ x 3″, 4″ x 4″, and 6″ x 6″. The 6-inch rings are provided with cross recesses at one end as shown in the illustration. This feature brings about equalization of gas pressure, prevents channeling of the gas, and permits uniform distribution of the washing liquid. Thus, maximum contact between gas and liquid are maintained throughout the tower or scrubber.

Packing rings of greater length than 6 inches are manufactured for certain purposes. For some applications, straight cylinders without partitions are used.

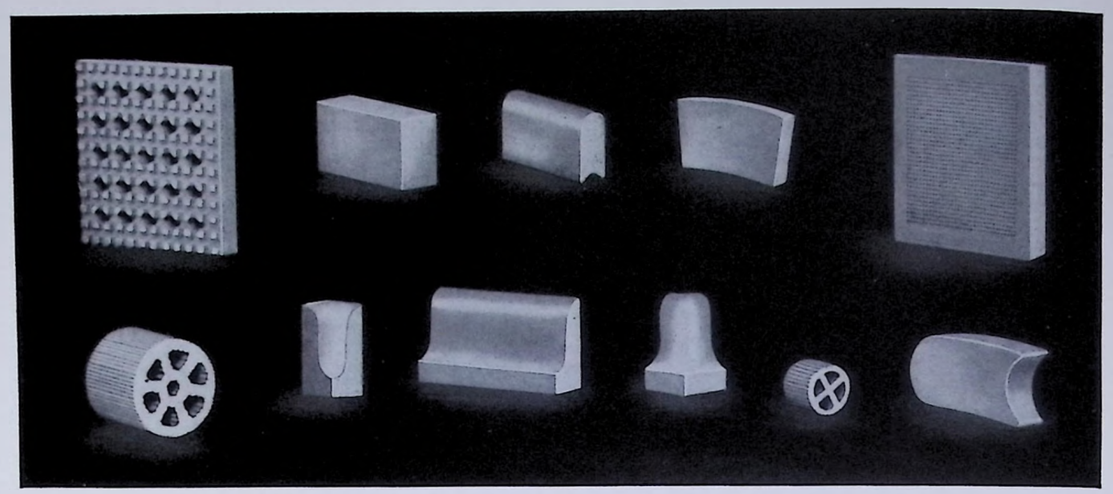
The surfaces of DURO and W-ACID packing rings may be either smooth or corrugated as desired. The corrugations increase the exposed area, and thus render more effective the contact between the gas and the liquid.

Packing rings are easily and rapidly laid in either circular or rectangular towers. When they are nested together, the areas of the openings between rings are approximately equal to that of the openings within the rings themselves. In placing successive rows, no effort need be made to line up the rings vertically, because the equalizing cross recesses greatly reduce gas channeling, and also retard clogging of the openings.

Data Concerning Packing Rings Illustrated Above

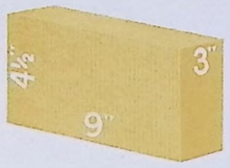
	3″ x 3″ Ring No. 263	4″ x 4″ Ring No. 515	6″ x 6″ Ring No. 403
Number of Partitions	4	4	6
Number of Rings per Cubic Foot of Packing	74	31.2	9.24
Exposed Area per Cubic Foot of Packing	45.6 Sq. Ft.	29.0 Sq. Ft.	27.4 Sq. Ft.
Approximate Weight of Rings per Cubic Foot of Packing	67 lbs.	69 lbs.	75 lbs.
Net Volume of Solid Material per Cubic Foot of Packing	804 Cu. In.	824 Cu. In.	890 Cu. In.
Open Space	53.5%	52.3%	48.5%

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A Group of Duro Shapes

SCORED BRICK



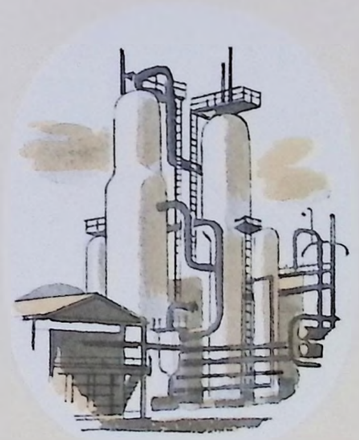
Scored 9″ Straight Brick
9″ x 4½″ x 3″

For tank linings and other acid-proof constructions, DURO Standard 9″ x 4½″ x 3″ Straight Brick are supplied with any of the faces scored as desired to form stronger joints with certain types of cements. Faces of the brick which will be exposed to the corrosive influences of acids are not scored.

SOME APPLICATIONS OF DURO AND W-ACID BRICK

Absorbing Towers
Accumulators for Paper Mills
Acid Cooler Linings
Acid Fan Casings
Acid Filters
Acid Mixing Tanks
Acid Room Floors
Acid Storage Tanks
All-masonry Acid Towers
Blow Pit Linings
Chlorinators
Concentrating Towers
Concentrator Pan Settings
Cottrell Precipitators
Dipping Vats
Electrolytic Tanks
Filter Linings for Purifying Acid
Floors, Acid Room (except hydrofluoric)
Floors, Dairy
Floors, Rayon Plants
Flues for Conducting Acid Gases and Fumes
Gay-Lussac Towers
Glover Towers
Insulators for Electrolytic Cells
Launder Linings
Leaching Tank Linings
Linings for Bottoms of Lead Acid Chambers
Linings of Chutes for Handling Hot Acids
Magnesium Cells
Mixing Tanks
Nitric Acid Retort Linings
Phosphoric Acid Hydrators
Phosphoric Acid Towers
Pickling Tanks
Picric Acid Filter Linings
Picric Acid Nitrator Linings
Purifying Towers
Scrubbers for Blast Furnace Gas
Scrubbers for Producer Gas
Sumps and Drains in Chemical Plants
Stacks for Smelters and Acid Plants
Tanks for Storage of Acid
Tower Packing

INSULATING REFRACTORIES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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INSULATING REFRACTORIES

HARBISON-WALKER BRANDS OF INSULATING FIRE BRICK

Brand	Maximum Allowable Temperature at Hot Face
H-W 16	1600° F.
H-W 20	2000° F.
H-W 23	2300° F.
H-W 26	2600° F.
H-W 28	2800° F.
H-W 444	2900° F.

THE primary function of furnaces built of refractory materials is to confine and utilize heat energy. The quantity of heat which passes through furnace walls, to be dissipated into the surrounding air, often constitutes a considerable proportion of the total heat input. Such heat losses may be reduced greatly by the application of insulating fire brick to the outer faces of the refractory walls.

Low heat storage capacity is a fundamental requirement for furnaces operated intermittently, such as those used for annealing metals, which must respond sharply to desired temperature changes. Low heat storage capacity is obtained by use of insulating fire brick for the construction of entire walls and roofs.

Harbison-Walker insulating fire brick are used as backing for the more dense refractory brick of various types, and also under certain conditions, as inner linings exposed directly to furnace atmospheres. In these brick a balance has been obtained between the important properties of strength and thermal efficiency. Lightness of weight, which is essential to high insulating value and to low capacity for heat storage, has been attained to the greatest degree consistent with the mechanical strength necessary for handling, shipment and service.

All Harbison-Walker brands of insulating fire brick except H-W 16 may be used for the inner linings of furnaces where they are directly exposed to furnace gases at temperatures not exceeding their maximum temperature limits. However, insulating fire brick as a class are not suitable for inner linings where they would be in contact with slag or molten metals, or subjected to appreciable abrasion.

H-W 16 is made with a special light-weight aggregate; H-W 20, H-W 23, H-W 26 are fired products having a fireclay base; H-W 28 is a fired brick with a high-alumina base; and H-W 444 is a light-weight silica brick.

All Harbison-Walker insulating fire brick except H-W 444 are highly resistant to spalling over the entire range of temperatures for which they are applicable. H-W 444 brick have relatively low resistance to thermal spalling below 600° F., but are highly resistant above 600° F.

For insulating and refractory linings of industrial furnaces, many combinations of insulating fire brick and refractory fire brick are possible. Harbison-Walker, with complete lines of both types of brick, can furnish the correct combination for any service requirement.

Freedom from excessive shrinkage within the recommended temperature limits is an important property of the Harbison-Walker brands.

A program of testing at every stage of manufacture, conducted in works control laboratories, assures uniformity of quality.

SELECTION OF INSULATING FIRE BRICK

WHEN insulating fire brick are used as backing, the interface temperature between the refractory lining and the insulation is an important factor in the choice of the refractory, and a determining factor in the choice of the insulating material. When the insulating fire brick are used as inner linings, the maximum operating temperature of the furnace is the major factor governing the choice of the brand.

Obviously, the insulating fire brick selected for backing up a firebrick wall must be sufficiently refractory to withstand the temperature at the interface between the refractory and the insulating backing. If the refractory may be expected to be worn away gradually by slag attack or abrasion, its final safe working thickness should be estimated as a basis for determining the maximum interface temperature.

An insulated wall built of fireclay brick has a higher mean temperature than an uninsulated wall which is of equal thickness and exposed to the same hot-face temperature. Brick of higher refractoriness may therefore be required for the wall which is insulated.

Economy in Heat: Conservation of fuel is one of the most important reasons for applying insulation to the refractory linings of industrial furnaces. The heat required to bring a furnace to the operating temperature is lost when the brickwork is allowed to cool. In the case of intermittently operated furnaces, this heat loss is of great significance in the economy of the process, and may be of even greater importance than the amount of heat necessary to maintain the required temperature during periods of operation. The use of insulating fire brick instead of dense fireclay brick reduces not only the amount of heat lost by radiation, but also that which is stored in the brickwork, and which is lost when the furnace cools.

Economy in Time: The time required to bring a cold furnace to operating temperature depends not only upon the rate of firing, but also upon the rate at which heat penetrates into the brickwork and upon the heat storage capacity of the furnace lining. Insulating fire brick can be heated quickly to furnace operating temperatures, and their capacity for the storage of heat is relatively low. Through the use of insulating fire brick in place of dense fireclay brick, the time of heating may be shortened 80 per cent to 90 per cent, with a 60 per cent to 70 per cent reduction in the amount of heat stored in the brickwork.

Economy in Space: For furnaces in which the refractory linings are not subjected to wear, the use of insulating fire brick in place of dense fireclay brick makes thinner walls practicable. For example, a 4½-inch wall of H-W 20 insulating fire brick has almost as great insulating value as a 27-inch wall of dense fireclay brick.

When furnaces are thoroughly insulated, less clearance is required between and around them for the comfort of the workmen. The saving in space may be of added importance if space is at a premium.

Economy in Weight: Through the use of insulating fire brick the weight of a furnace lining may be reduced 60 per cent to 70 per cent. Because of this reduction in weight, the foundations may be of lighter construction, and the buckstays, tie rods, and other furnace binding may be of lighter weight. When insulating fire brick are used for the linings of furnace doors, the door frames and counter balance mechanisms may be of lighter construction. The use of insulating fire brick makes possible the design of portable annealing furnace covers with weights well within the load limits of crane facilities.

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PROPERTIES OF H-W INSULATING FIRE BRICK

	H-W 16	H-W 20	H-W 23	H-W 26	H-W 28	H-W 444
Maximum temperature limit, ° F.	1600	2000	2300	2600	2800	2900
Approximate weight per 9″ x 4½″ x 2½″ Straight, in pounds	1.9	2.0	2.4	2.9	3.3	3.4
Approximate weight per cubic foot, in pounds	32	34	41	50	56	58
Cold crushing strength, in pounds per square inch	75-100	150-175	175-200	225-250	250-275	165-180
Approximate relative insulating value, with fireclay brick = 1	7.	6.	4.	3.5	3.	3.

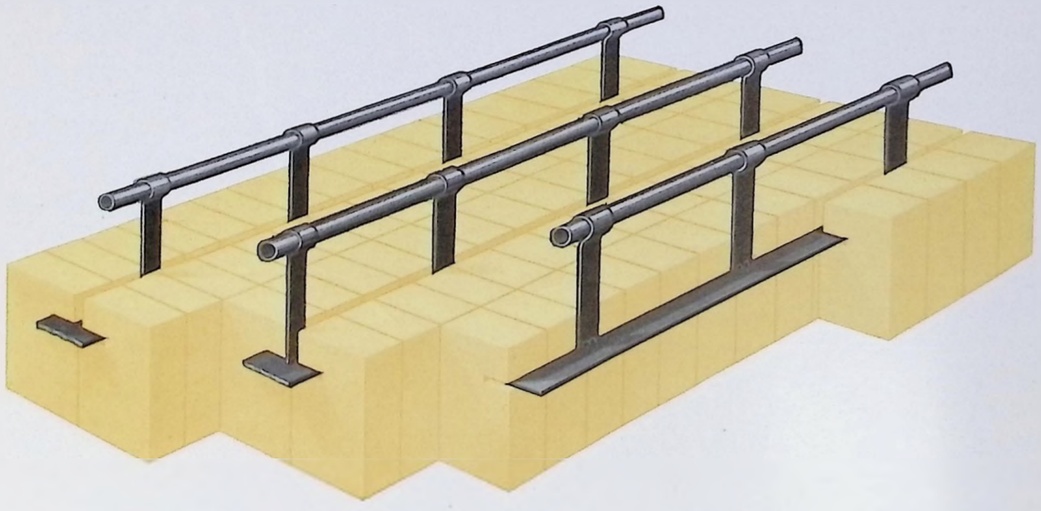
SIZES

Harbison-Walker insulating fire brick are manufactured both in standard sizes, and in a wide variety of special shapes.

Insulating fire brick in general are molded in the form of rectangular blocks or billets, which are fired and then cut to specified dimensions. Brick of the arch, wedge, or key types are cut to any desired taper. Consequently either a ring or an arch of a given radius may be constructed with brick of one size only.

Insulating fire brick are shipped in heavy cardboard cartons which contain 25 standard 9″ x 4½″ x 2½″ straights, or approximately the same volume of other standard 9-inch sizes.

Brand	Standard Sizes
H-W 16	9″ x 4½″ x 2½″ straight
H-W 20, H-W 23	9″ x 4½″ x 2½″ straight and corresponding series of sizes, as shown on pages 30 and 31.
H-W 26, H-W 28	9″ x 4½″ x 3″ straight and corresponding series of sizes, as shown on pages 32 and 33.
H-W 444	9″ x 4½″ x 2½″ straight.



Flat Suspended Arch Built of Insulating Fire Brick

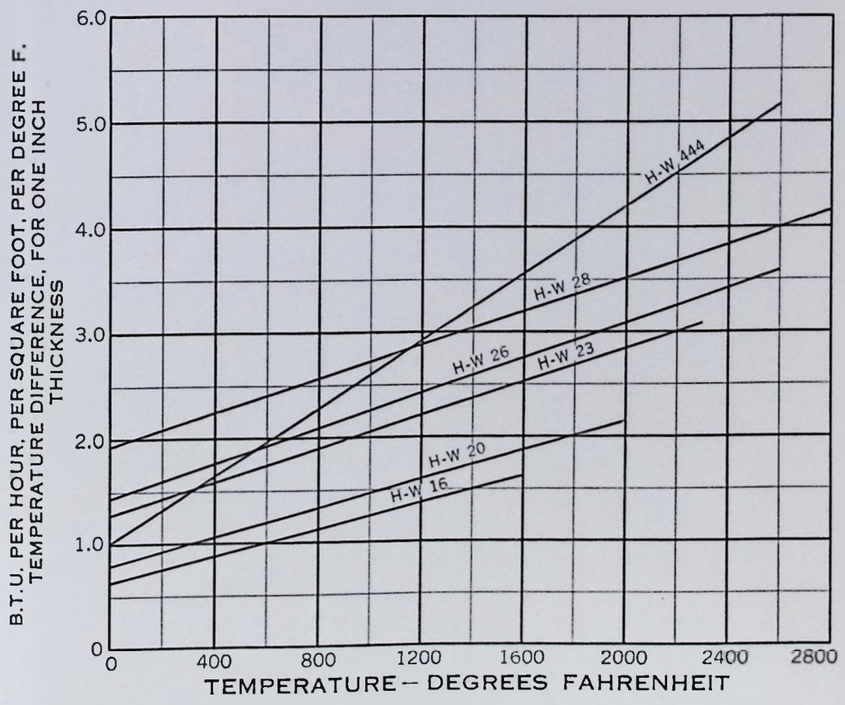
THERMAL DATA

The approximate thermal conductivities of H-W insulating fire brick are given below. Other thermal data are given in a separate booklet in which Harbison-Walker insulating fire brick are more fully described. The data given include the theoretical heat losses by conduction through furnace walls for various hot-face temperatures, and also the heat storage capacities. The data apply to walls of various thicknesses, and constructed of various combinations of dense fire brick and insulating fire brick. The booklet will be mailed upon request.

APPROXIMATE THERMAL CONDUCTIVITIES OF INSULATING FIRE BRICK

B.t.u. per Hour, per Square Foot per Degree F. Temperature Difference, for One Inch Thickness

	Temperature — Degrees F.														
	0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
H-W 16	0.62	0.74	0.87	0.99	1.12	1.24	1.37	1.49	1.62						
H-W 20	0.80	0.93	1.07	1.20	1.34	1.47	1.61	1.74	1.88	2.01	2.15				
H-W 23	1.28	1.44	1.59	1.75	1.91	2.06	2.22	2.38	2.53	2.69	2.85	3.00			
H-W 26	1.45	1.62	1.78	1.95	2.11	2.28	2.44	2.61	2.77	2.94	3.10	3.27	3.43	3.60	
H-W 28	1.93	2.09	2.25	2.41	2.57	2.73	2.89	3.05	3.21	3.37	3.53	3.69	3.85	4.01	4.17
H-W 444	0.98	1.30	1.63	1.95	2.28	2.60	2.93	3.25	3.58	3.90	4.23	4.55	4.88	5.20	5.53



Approximate Thermal Conductivities of Insulating Fire Brick

H-W MORTARS FOR INSULATING FIRE BRICK

Insulating fire brick are laid with mortar having properties compatible with those of the brick. When exposed directly to flame or to products of combustion, the brick are advantageously brush-coated on the exposed surfaces with a mortar which does not crack or peel.

H-W 20 BONDING MORTAR is recommended for laying H-W 16 and H-W 20 brick with dipped joints. It is shipped dry in sacks of 100 pounds net weight. One hundred and fifty to two hundred pounds of this mortar, when mixed with water to a creamy consistency, are sufficient for laying one thousand brick. H-W 20 BONDING MORTAR adheres firmly upon drying, and because it is hot-setting develops its maximum strength after exposure to heat.

H-W 26 BONDING MORTAR is supplied for laying H-W 23, H-W 26, and H-W 28 brick, and for brush-coating the surfaces of the brick if they are to be exposed to flame or furnace atmospheres. It is shipped dry in sacks of 100 pounds net weight and requires only the addition of water to bring it to the desired consistency for dipped or troweled joints or for brush-coating. Two hundred to two hundred and fifty pounds of mortar are generally required for laying and coating a thousand brick. H-W 26 BONDING MORTAR is hot-setting and requires heat to develop its maximum strength.

H-W 444 BONDING MORTAR is recommended for laying H-W 444 brick. It is dry hot-setting high temperature cement, which is prepared for use by the addition of water and thorough mixing. It is shipped dry in sacks of 100 pounds net weight. About 300 pounds are needed for laying and coating a thousand brick.

HARWACO BOND is used advantageously for laying H-W 16, H-W 20, H-W 23, H-W 26 and H-W 28 brick, and for brush-coating exposed surfaces for service in which an air-setting bonding mortar is desired. It is shipped wet in steel drums of 200 pounds net weight. It is applied liberally to the dry brick and the surplus is removed with a trowel, leaving only enough mortar for a $\frac{1}{16}$-inch joint. HARWACO BOND is also applied as a surface coating not over $\frac{1}{16}$ inch thick. Approximately 400 pounds are required to lay and coat 1,000 brick.

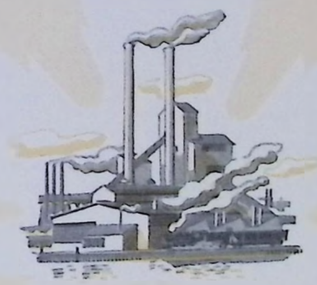
LIGHT-WEIGHT CASTABLES

H-W LIGHT-WEIGHT CASTABLES are insulating refractories which may be mixed and poured like concrete. They are shipped in dry form, and when mixed with water to the desired consistency, are poured or tamped into place, or applied by means of an air gun, forming joint-free surfaces. For pouring or casting, they are mixed with about 45 per cent of water by weight, or 5.4 gallons of water per hundred pounds of castable. They have excellent workability, and after application take a strong hydraulic set at room temperatures. Adequate strength is maintained until the ceramic bond is developed as the temperature is increased.

H-W 56 LIGHT-WEIGHT CASTABLE weighs only 56 pounds per cubic foot when cast into place and heated to furnace temperatures. It is shipped dry in sacks which contain 56 pounds of material — just the right amount for one cubic foot of furnace volume. Its insulating value is about three times that of an equal thickness of fireclay brick. It can be applied as a coating to either cold or hot furnace walls.

H-W 85 LIGHT-WEIGHT CASTABLE weighs about 85 pounds per cubic foot in place, and its insulating value is about two times that of fireclay brick. It is shipped in dry form in sacks containing 200 pounds net weight.

REFRACTORIES MADE IN CANADA



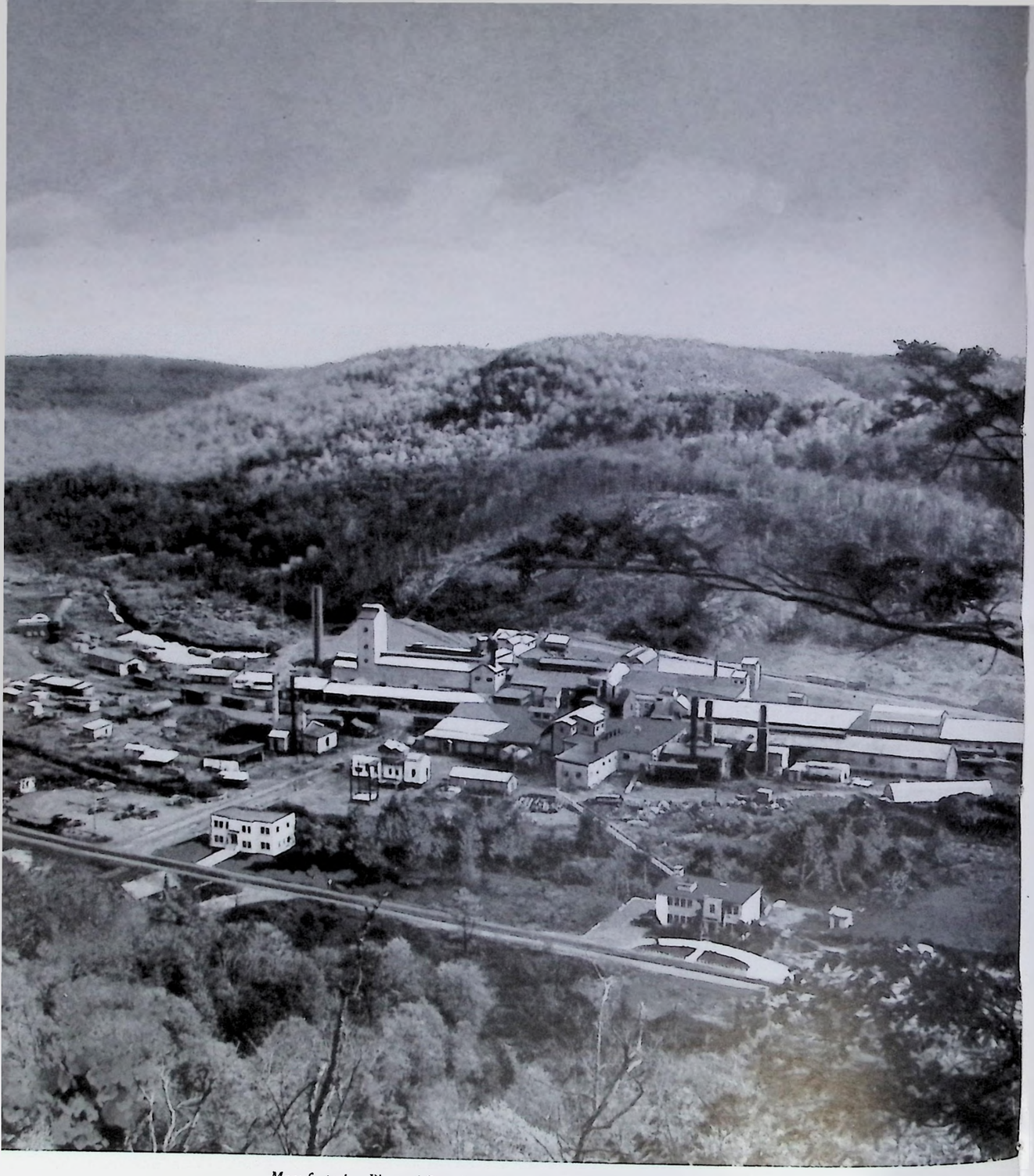
PRODUCTS OF

CANADIAN REFRACTORIES LIMITED

MONTREAL, QUEBEC

A SUBSIDIARY OF HARBISON-WALKER REFRACTORIES COMPANY

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Manufacturing Plant of Canadian Refractories Limited at Kilmar, Quebec

REFRACTORIES MADE IN CANADA

Until relatively recent years, Canada was almost wholly dependent upon imported refractories for its metallurgical and other industries. Today, Canadian Refractories Limited can supply basic refractories in any desired quantities from its plant at Kilmar, Quebec.

Although the deposits of magnesite at Kilmar had been known for some years prior to World War I, no development had taken place before that time. The Canadian magnesite is of a different type from that which had been imported, and methods of processing it for use as a refractory had not then been developed.

In 1925, the National Research Council of Canada, in cooperation with the Canadian Bureau of Mines, embarked upon a comprehensive research program on the technical problems involved in the commercial utilization of Kilmar magnesite. The research included a study of raw materials, manufacturing methods and finished products. Until 1943, the company worked very closely with these organizations and in that year opened its own research laboratory at Kilmar, where the investigations have been continued independently and greatly expanded. For many years the road to success was by no means obvious. However, the products developed by research — the refractories being manufactured at Kilmar today and shipped to the world's markets — testify how successful the program has been.

Canadian Refractories Limited has built up resourceful and highly competent research, operating and sales organizations which are thoroughly informed on the needs of industry. Active prosecution of research continues to be a primary policy of the company.

Exhaustive investigations demonstrated the fact that the composition of the Kilmar magnesite is such as to lead to the production of refractories having unique chemical and physical properties, which render their use particularly advantageous for specific applications in various large-scale operations. An entirely new group of refractories was developed for the domestic market, and the service obtained from these new materials was such that a substantial export market developed.

These special refractories have since been supplemented by other products of high magnesia content, manufactured in part from brucite of high purity produced in Canada. The Kilmar magnesite and Canadian brucite, together with imported chrome ores and other domestic and foreign raw materials, form the basis for a manufacturing operation in which a wide range of refractory products is made. The company manufactures dead-burned grain magnesite, basic brick, ramming mixtures, castables and refractory cements, comprising in all more than fifty different products. These products are marketed not only in the United States and Canada, but also in many other countries in all continents.

In acquiring a controlling interest in Canadian Refractories Limited, the Harbison-Walker Refractories Company demonstrated its faith in the future of Canadian industries and its

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appreciation of the quality of CRL products. The way was thus cleared for the exchange of technical information to the advantage of the many consumers of the refractories manufactured by both companies. The progressive policies of Canadian Refractories Limited were continued and the program of expansion of the Kilmar plant, which had been under way for several years, was accelerated.

The mine and plant are located 70 miles northwest of Montreal. Thorough prospecting by diamond drilling has developed sufficient reserves of raw material to last many years. Stoping is carried out on various levels down to a depth of 700 feet from the surface. At the surface, the rock is fed to a heavy-media separation plant for beneficiation, before being transported to the nearby manufacturing plant. At that point, various additions may be made, depending upon the product to be manufactured. The magnesite, with its additions, is dead-burned in a rotary kiln 245 feet long, at temperatures up to 3300° F. After crushing and sizing, certain dead-burned products are shipped for use in furnace bottoms; others are further processed in the Kilmar plant for the manufacture of a wide variety of other products.

Both hard-burned and chemically bonded brick are manufactured in a plant which is entirely modern. The brick are formed in power presses under extremely high pressures. The plant is provided with oil-fired tunnel and periodic kilns.

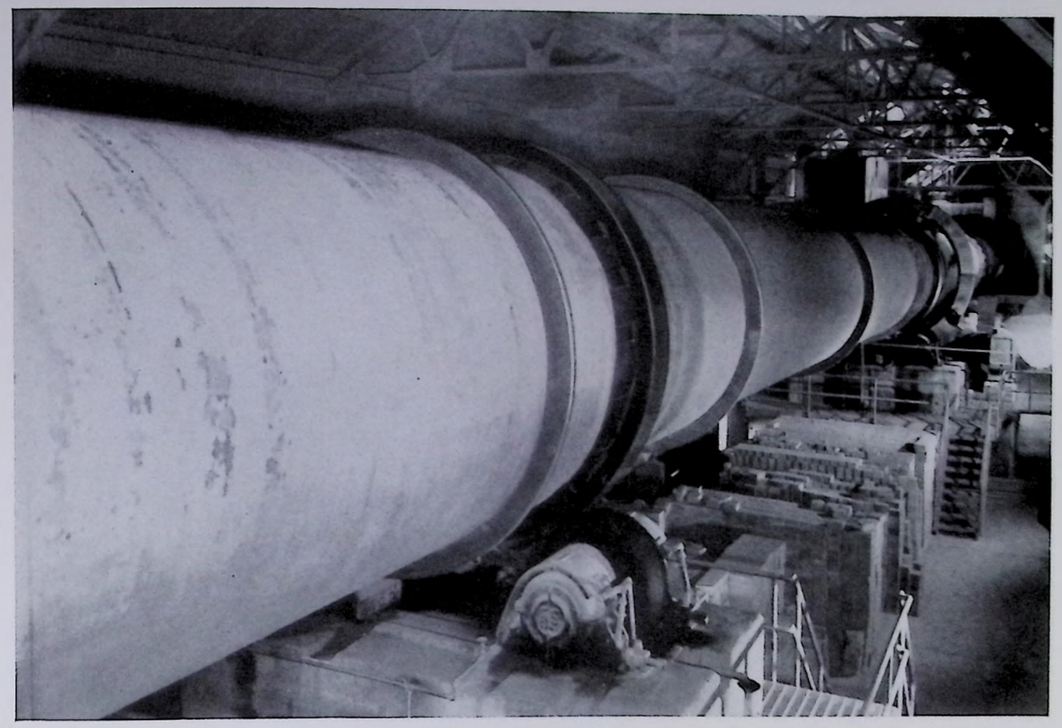
Quality control is exercised through every step of mining and manufacture. Both the feed to the rotary kiln and the dead-burned granular products from the kiln are sampled and tested at frequent intervals. The brick in process and after completion of manufacture are subjected to control tests in the laboratory. Automatic sampling of brick aggregates, followed by physical tests and chemical analyses, insures uniformity of quality. Physical tests of the brick include determination of density, porosity and strength. Cements, castables and ramming mixes are tested for plasticity, setting properties, refractoriness and bonding strength.

The brick manufactured at Kilmar are shipped in railroad cars, either in cartons or loose and well packed with heavy paper. Brick for export are shipped on skids or in cartons.

Canadian Refractories Limited maintains a complete engineering service to assist the user in the selection and application of refractory materials. The company is in position to supply all Harbison-Walker products.

BASIC BRICK

Canadian Refractories Limited produces a complete range of basic brick manufactured from dead-burned magnesite, from chrome ore, and from combinations of these materials. They include magnesite, magnesite-chrome, chrome-magnesite, and chrome brick, equivalent to the brick of such types manufactured in the United States and in Europe. The company's brands of brick include CRL Brucite, CRL Metalkase, CRL Chrome and CRL Chrome-Magnesite. In addition, the company produces a magnesite brick of unique composition — Magnecon. **CRL Burned Brucite** is a hard-burned magnesite brick having a high magnesia content, and containing no chrome ore. It is comparable in composition and in properties with H-W Magnesite brand. Some of the more important uses are for linings of copper refining furnaces, secondary non-ferrous metal furnaces, aluminum melting furnaces, and copper converters. **CRL Chemically Bonded Brucite** brick, of high magnesia content, are comparable with



Rotary Kiln used for Dead-Burning Basic Products, Kilmar, Quebec

Magnex brick manufactured by Harbison-Walker. In the copper industry they are used in the linings of reverberatory and refining furnaces; in the steel industry, they serve for the linings of metal mixers.

CRL Metalkase are chemically bonded magnesite brick encased in steel sheets. In service, the steel oxidizes at the hot ends and combines with the magnesia to form a bond consisting of the refractory mineral magnesioferrite. The spalling resistance of the brick is thereby increased. At the cooler ends of the brick, the steel casings add strength and stability. CRL Metalkase brick are recommended for use in applications where basic refractories are required and where both high refractoriness and high resistance to spalling are important properties. They are used in suspended roofs of open-hearth steel and nickel reverberatory furnaces, in the roofs and upper side walls of copper reverberatory and refining furnaces, in the linings of electric steel melting furnaces above the slag line, and in the bulkheads, back walls, front walls, skews, and roof panels of basic open-hearth steel furnaces.

CRL Chrome brick are hard-burned and correspond closely to H-W Chrome brick in chemical composition and in physical properties. They are used in soaking pits, in the subhearths of various types of furnaces, in aluminum remelting furnaces, in recovery units of kraft paper mills, and in the working hearths of forge furnaces where uniform heat distribution is required. They are also used as a parting course between magnesite and silica brick.

CRL Chrome-Magnesite brick are supplied in two modifications: burned brick, which correspond to Harbison-Walker brand Chromex B,

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and chemically bonded brick which correspond to CHROMEX. Both are made from blends of chrome ore and dead-burned magnesite, with optimum particle sizing, and both are molded at very high pressure. They are of accurate dimensions and excellent workmanship, mechanically strong, resistant to thermal shock, and highly stable in volume at high temperatures. The burned brick are fired at extremely high temperatures, to develop a strong crystalline groundmass of forsterite as a bond for the grains of chrome spinel, thus achieving the capacity to support load at maximum temperatures. CRL CHROME-MAGNESITE brick are recommended for the walls, ports, and suspended roofs of basic open-hearth furnaces; for the roofs of electric melting furnaces, for the walls of copper refining furnaces, and for the linings of copper and copper-nickel converters. The choice between the burned and the chemically bonded brick depends upon the particular application.

CRL Magnecon brick, which are made from Kilmar magnesite, have unique properties and are in every sense a product of research. While they are not designed for use under conditions of exceptionally high temperature or heavy load, for which other CRL brick are recommended, their high degree of spalling resistance, their relatively low thermal conductivity, and their unusual resistance to attack by basic materials at moderate temperatures have led to their use in a wide range of applications.

CRL MAGNECON brick are unusually resistant to chemical attack by Portland cement clinker. They have achieved the widest success in many countries for lining the burning zone of rotary cement kilns, and are well known internationally for their excellent suitability for this exacting service. Their outstanding ability to take a coating quickly, and to hold the coating when the kiln is cooled, permits the maximum output of cement at low cost for the refractories. The relatively low thermal conductivity of CRL MAGNECON brick adds in no small measure to their advantages for this service. CRL MAGNECON brick are manufactured in many sizes and shapes. The size most commonly used in rotary kiln linings is the 6-inch arch shape, which forms linings 6 inches thick. Wedge brick, which form linings 9 inches thick, are sometimes used. Liners of different taper are supplied to fit kilns of different diameters.

CRL MAGNECON brick serve advantageously for the linings of furnaces in which the slag is high in lime, or in which basic dusts come into contact with the refractories. They are used with excellent results for the end walls, front walls, and sloping back walls of basic open-hearth furnaces, and for the linings of both large and small electric steel furnaces.

CRL MAGNECON brick at moderate temperatures are resistant to iron scale and to slags high in iron oxide formed in various furnace operations. They are highly recommended for construction of the hearths of forge furnaces, reheating furnaces, and billet heating furnaces, for the settings of boiler furnaces fired with coal having ash high in iron oxide, and for parts of the linings of soaking pits and metal mixers in basic open-hearth steel plants. They are used successfully in calcium carbide furnaces, copper and silver refining furnaces, in aluminum remelting furnaces, and in secondary lead, brass, and copper furnaces.

CRL MAGNECON brick give excellent service in various furnace operations where they are exposed to contact with lime, with dolomite, or with alkaline dust or fumes. They are used to advantage in the hot zone linings of rotary lime and dolomite kilns and in the walls, arches, and checkers of glass tank regenerators.

BASIC REFRACTORIES OTHER THAN BRICK

CRL Magnifrit, or BASIFIRM, as it is known in countries other than Canada and the United States, is a quick-setting basic clinker, specially made from Kilmar magnesite for use in furnace hearths. Careful selection of the magnesite rock, and proper choice of materials added to facilitate dead-burning, insure the production of clinker having high ultimate refractoriness and the proper flux content for burning-in monolithic hearths. The rigidly controlled grain sizing of CRL MAGNIFRIT contributes to high density of the hearths and long life in service. CRL MAGNIFRIT has been used for many years for the permanent bottoms of open-hearth steel furnaces, and is a standard refractory for the resurfacing and daily maintenance of the bottoms and banks of open-hearth and electric steel furnaces. Shipments are made in bulk or in bags as desired.

CRL Ramix is the original air-setting magnesia ramming mixture used for the bottoms of basic open-hearth and electric steel melting furnaces, largely superseding the "burned-in" bottoms. By its development, the construction of basic steel furnace hearths was virtually revolutionized.

CRL RAMIX is a product of intensive research carried out in Canada over a period of years. It has as its major constituent a special hydration-resistant clinker made from Kilmar magnesite, carefully sized to facilitate ramming, and to form monolithic hearths of high density. It contains several chemical bonding agents, each serving a special purpose, and together providing exceptionally high strength throughout the entire thickness of the hearths. It is possible to install the greater part of the hearth of an open-hearth furnace, and in many cases the entire hearth, merely by ramming the RAMIX into place as a monolith of the desired thickness and contour. Because of its exceptional resistance to hydration, CRL RAMIX hearths do not slake during the drying period or during furnace shut-downs. The long and costly delays incident to the burning-in of furnace hearths can be avoided by its use. Its high density and low porosity minimize metal and slag penetration, and reduce subsequent cost of maintenance as well as lost time. In the installation of electric furnace bottoms, CRL RAMIX completely eliminates the necessity for burning-in the bottoms with the arc, and all its attendant hazards.

CRL RAMIX is used also for the maintenance of bottoms and banks. The rate at which it sets greatly exceeds that of conventional grain magnesite, and by its use, hot or cold repairs can be made in a minimum of time. For use in copper and nickel reverberatory furnaces, CRL RAMIX is rammed into metal containers, which in service are supported in such manner that they form the upper part of the side walls. CRL RAMIX is used to form the tap holes of basic open-hearth furnaces and for various other applications. It is shipped dry in bags of 100 pounds net weight and requires only the addition of water and thorough mixing to prepare it for use.

CRL 695 Plastic, originally developed for the United States market, is a highly refractory magnesite-chrome ramming mixture of the most advantageous grain sizing. It is shipped in dry form in bags of 100 pounds net weight and is prepared for use by the addition of water and thorough mixing. It sets quickly to form a hard dense mass, and when heated acquires a glazed surface which is almost impervious to attack by slag or metal. CRL 695 PLASTIC was developed for use in forming the tap holes of basic open-hearth furnaces, either by conven-

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tional ramming methods or by means of an air gun. When used on the slopes of open-hearth furnaces it effectively protects them from silica drip and foamy slags. It may be used advantageously for patching the front and back walls and for repairing floors and uptakes of the ports. It also serves well for repairing the bases of soaking pits, the hearths of billet heating furnaces, and sections of metal mixers.

CRL 695 PLASTIC has long been a standard refractory in many foundries for use in lining ladles up to 5 tons capacity, employed for handling manganese and other alloy steels. It is readily rammed into place behind forms as a basic lining which insures freedom from nonmetallic inclusions in the molten steel.

OTHER CRL SPECIALTIES

Canadian Refractories Limited manufactures a wide range of refractory specialties — cements, plastic ramming mixes and castables — in chrome, magnesia, alumina, mullite, silica, fireclay and insulating materials, from both domestic and imported raw materials. Many specialties are custom-made to meet the diverse and exacting needs of industry. These products are backed by years of skill in chemical and mineral formulation in the laboratories of Canadian Refractories Limited.

Silica No. 40 Cement is the pioneer in the class of special clay-free silica bonding mortars. Its noteworthy properties are excellent plasticity and water retention, and high refractoriness. Its use for laying the super-duty silica brick VEGA and conventional silica brick such as STAR contributes to the resistance of these brick to spalling and slagging in lime kilns and glass tank furnaces, and in steel and various other metallurgical furnaces.

CRL Chrome Cements are prepared from selected ores blended with additives to obtain unusual properties. SPECIAL CRL GROUND CHROME ORES, well suited for furnace maintenance, are used merely by mixing with water and applying by hand or by spraying with an air gun.

Other CRL specialties — MAGNIFRIT CEMENT, MAGSET CEMENT and CRL SILLIMANITE products, including mullite brick, are well known in the metallurgical field. DUROCRETE FIRECLAY CASTABLE and DUROPATCH FIRECLAY PLASTIC are leaders among refractories used in boiler furnace installations. Other multibond cements used for laying brickwork exposed to high temperature and extremely severe conditions are compounded expressly to give the properties of high water retention, and high strength both cold and hot. These high-temperature bonding mortars include KYANEX, HARWACO BOND, and others.

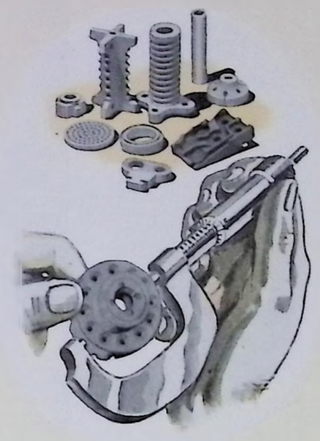
HARBISON-WALKER PRODUCTS

The services of Canadian Refractories Limited are available to every user of refractories in Canada in connection with all Harbison-Walker products. Stocks of various Harbison-Walker alumina-silica and silica refractories are carried in warehouses at Montreal and Hamilton.

H-W BRANDS EXTENSIVELY USED IN CANADA

High-Alumina Brick—ANCHOR, ALUSITE **Super-Duty Fireclay Brick**—ALAMO, VARNON, DEAN
High Duty Fireclay Brick—WALSH XX, FRANKLIN CROWN, WOODLAND, H-W 18, H-W H & B
Silica Brick—VEGA, STAR **Acid-Proof Brick**—DURO

PRECISION CERAMIC PRODUCTS



PRODUCTS OF
THE LOUTHAN MANUFACTURING CO.
EAST LIVERPOOL, OHIO

A SUBSIDIARY OF HARBISON-WALKER REFRACTORIES COMPANY

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PRECISION CERAMIC PRODUCTS

Electrical Porcelain Insulations	**Cordierite Refractory Porcelain**
Kiln Furniture for Tile and Pottery Ware	**Potters' Supplies**
Precision Refractories for Special Purposes	**Refractory Shapes for Foundry Molds**
Porous Refractories for Radiant Heaters and Domestic Furnaces	**Ceramic Shapes for Chemical Equipment and Acid Towers**

THE Louthan Manufacturing Company, a subsidiary of Harbison-Walker, has been engaged in the manufacture of precision ceramic products for special applications for approximately half a century. In the Louthan plant at East Liverpool, Ohio, all operations — blending, forming, drying, glazing, firing, inspecting — are carried out under one roof, in a building seven hundred feet long.

The raw materials include kyanite, china clay, ball clay, pyrophyllite, talc, feldspar, calcined clays, zircon, and burn-out materials. By blending these raw materials in proper proportions, many ceramic body compositions are obtained, each with a special field of application. Kyanite bodies are used for most kiln furniture, while ball clay and other bodies find application for potters' supplies. Steatite, vitrified porcelain and cordierite refractory porcelain bodies are employed in the manufacture of electrical porcelain (ceramic insulations). Porous refractory bodies serve for parts of gas, oil and coal heating appliances. Zircon bodies are used for a variety of special applications, such as combustion boats, and raschig rings for chemical processes. Ceramic shapes for a wide variety of applications are made in the various bodies which are particularly well suited for unusual combinations of conditions.

Most of the dies required for forming the ware, much of which is extremely intricate in design, are made in the company's own machine shop. The size tolerances permitted for these dies are extremely close.

Powered screw presses, automatic punch presses, hydraulic presses, extrusion machines, and hand-operated presses are available to form the shapes, which vary greatly in size and in complexity. The bulk of the ware is dried in two stages in modern infra-red dryers; some of the smallest pieces, which are formed in hand presses, are air dried. The unburned ware is loaded into saggers, placed on pallets, and transported to the kilns by lift trucks.

At the kilns the saggers are placed on the kiln cars. Firing is done in circular continuous tunnel kilns. The kilns are gas-fired, but can be converted promptly to oil-firing whenever necessary. The temperature of firing is controlled within 10° F. by electrical pyrometric equipment. Every piece of the finished products is inspected before packing in cartons or in strong wooden barrels for shipment.

The laboratory staff not only engages in scientific determination of body compositions for specific requirements, but also is responsible for control in every step of the manufacturing procedure.

ELECTRICAL PORCELAIN INSULATIONS

LOUTHAN's electrical porcelain insulations are outstanding for accuracy of dimensions and long service life. The properties desired for any particular service are attained by careful gradation of grain sizes, by the process of forming (either dry pressing or extrusion), by high forming pressures, by careful finishing and controlled drying, and by prolonged firing at high temperatures in circular tunnel kilns.

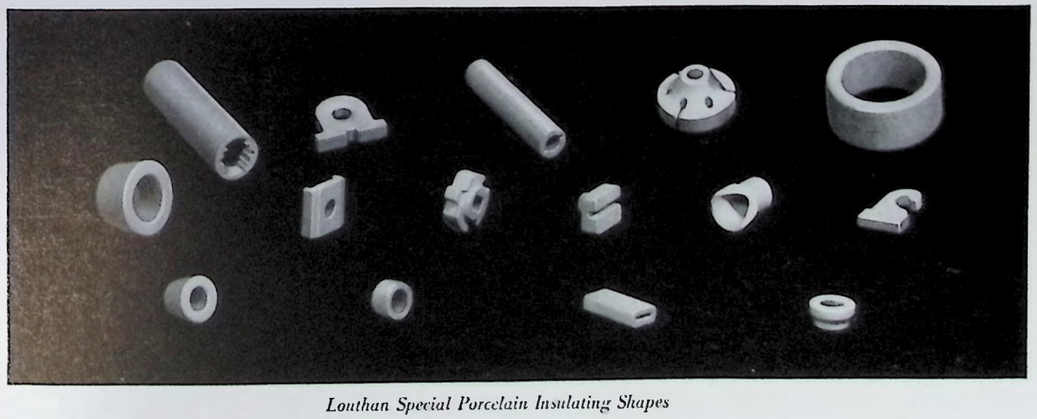
LOUTHAN insulating materials are scientifically formulated for the manufacture of products which will endure. LOUTHAN's engineers and laboratory staff cooperate with the users in the selection of the proper insulations for specific needs.

Insulators are made in the form of simple or intricate shapes, of almost any size, and to minimum tolerances. All are high-fired, with uniformity and precision assured. Most LOUTHAN insulating products are magnesium-aluminum-silicate porcelains having either a steatite or a cordierite base. They are designed primarily for low tension applications; that is, for 440 volts or less.

All electrical porcelain made by LOUTHAN may be used at temperatures up to about 2200° F. It is produced in either glazed or unglazed form. Standard items are available immediately from stock, and special shapes can usually be shipped within two weeks time after the buyer's approval of samples.

Louthan Steatite Porcelain is a vitrified product, with unusually high mechanical strength, a low loss factor at high frequencies, and relatively high dielectric strength. The absorption is zero for all ware except some small automatically pressed parts for electrical heating appliances, which have 4 per cent absorption. Since drying and firing shrinkages are closely controlled, close tolerances are maintained on the fired dimensions. Steatite porcelain is used both for high-frequency and for low-frequency applications. It is less resistant to thermal shock than is vitrified porcelain or cordierite porcelain.

LOUTHAN STEATITE PORCELAIN is used with excellent results for resistor tubes, mercury switch-tubes, and for electronic and radio insulator shapes which must have high strength and low loss characteristics, but which do not require extremely high resistance to thermal shock. The high frequencies of modern television sets necessitate the use of low-loss electrical insulations. The requirements are fully met by LOUTHAN STEATITE PORCELAIN.

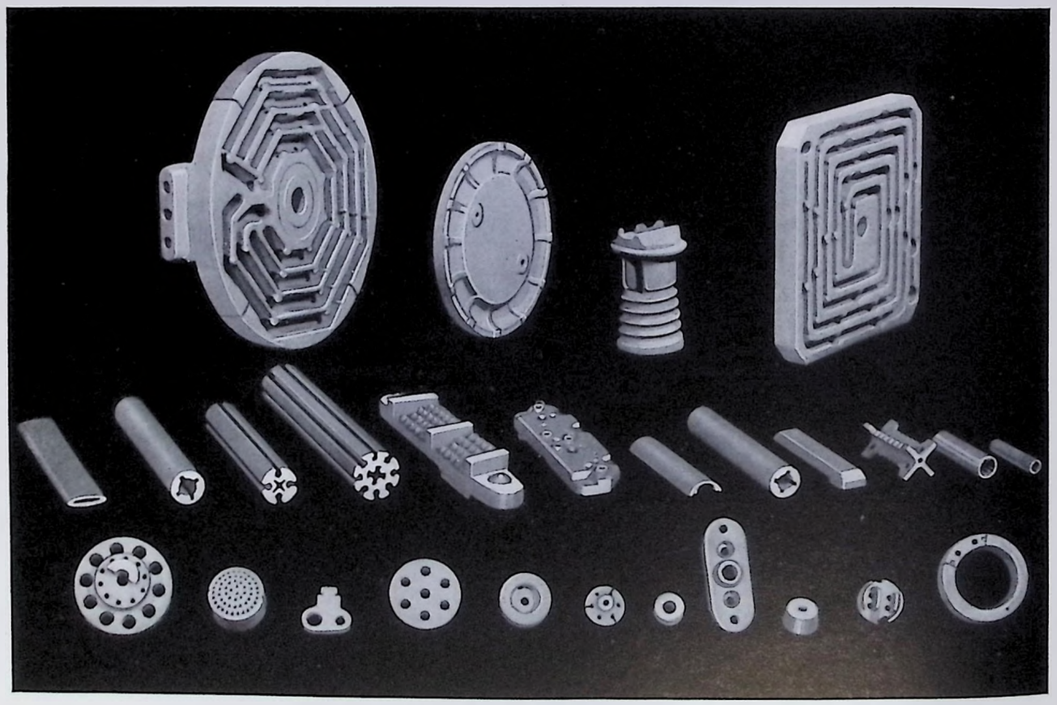


Louthan Special Porcelain Insulating Shapes

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Louthan Vitrified Electrical Porcelain differs from steatite porcelain in that it contains feldspar instead of talc. Its resistance to thermal shock is greater than that of steatite, but less than that of cordierite porcelain. For service in which exceptionally high strength and close size tolerances are not required, vitrified electrical porcelain is preferred to steatite porcelain because of its lower cost. It is recommended for terminal block shapes to be used with 60-cycle current in applications which require relatively high dielectric strength and zero absorption. LOUTHAN VITRIFIED ELECTRICAL PORCELAIN is supplied in either white or gray color, as desired.

Louthan Cordierite Refractory Porcelain is outstanding for its high resistance to thermal shock. Its electrical properties are excellent. Its modulus of rupture is sufficiently high, and its absorption about 15 per cent. It is designed for a frequency of 60 cycles and is recommended for all applications in which both high resistance to thermal shock and excellent electrical insulating properties are required, especially at the operating temperatures of electrical appliances.



Louthan Special Porcelain Insulating Shapes

SOME USES OF LOUTHAN PORCELAIN INSULATIONS

Heating appliances: electrical, gas and oil-fired.
Switch and control parts for radio, electronic and television control.
Terminals and bushings of transformers, and motor controls.

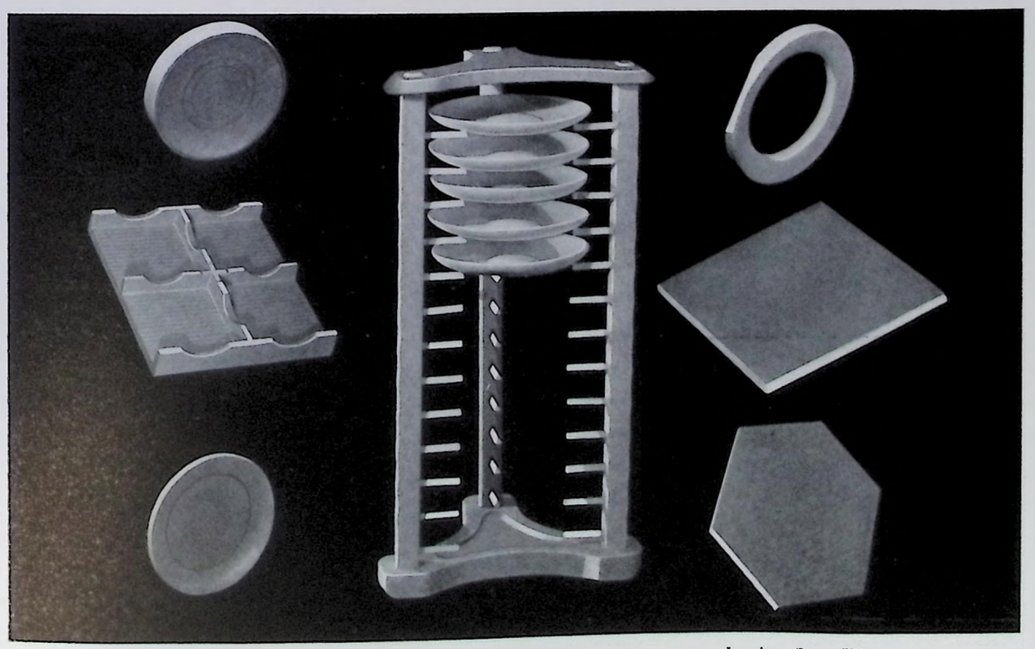
KILN FURNITURE

Nearly all LOUTHAN kiln furniture is made of a high-fired kyanite body. The shapes are precision formed, properly aligned and true to specified dimensions. They are clean and smooth, mechanically strong and highly resistant to thermal shock. They retain their alignment and dimensions throughout repeated firings, without dunting, sagging or warping.

LOUTHAN kiln furniture setters and other shapes are produced in a wide range of standard sizes. Special sizes and shapes are made as required. LOUTHAN SETTERS FOR DINNERWARE provide a practical and effective means of preventing warpage of ware in the green room and in the kilns. These setters have the clean smooth surfaces so necessary for the placement of dinnerware. LOUTHAN SETTERS FOR DINNERWARE are round or oval in form, and are provided in a wide variety of sizes and shapes, including standard setters, flat top setters, deep well and glost setters.

Improved Louthan Sandless Setter Rings are light and compact, and require a minimum of space both for storage and for setting in the kilns. Since they are sandless, placing costs are low, stable settings are assured, and warpage losses are kept at a minimum.

Louthan Firing Racks provide a simplified means of placing glost and decorated ware, without the use of saggers and with maximum kiln economy. The racks are built-up units and the component parts require but a fraction of the storage space needed for saggers. Their skeleton construction permits uniform distribution of heat directly to the ware. LOUTHAN FIRING RACKS insure economy in placing, as well as greater kiln capacity and less fuel consumption than when saggers are used.



Louthan Setter Tile *Louthan Firing Rack* *Louthan Setter Tile*

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The assembly of a LOUTHAN FIRING RACK is simple and can be completed in a few seconds. The method by which the posts are attached to the bottom plate by means of a sand seal was developed by LOUTHAN. In loading the racks, the ware is placed from the top down, insuring clean ware. The racks are manufactured in many variations of size and shape, to accommodate a wide variety of ware.

Louthan High-Fire Square and Rectangular Tile Setters are formed on heavy duty mechanical presses. They are straight and true to dimensions, and remain so on repeated firing. They provide the clean, smooth placing surfaces required for firing floor and wall tile.

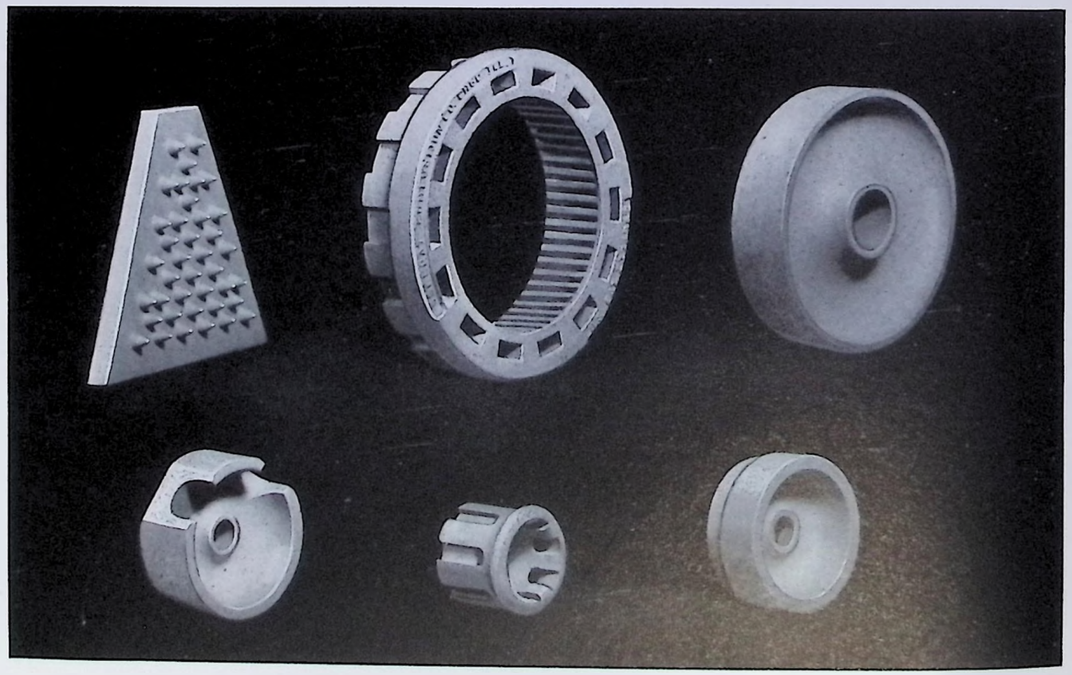
Louthan High-Fire Tubular Setter Pins are produced by the extrusion process in hardened steel dies, and have clean, smooth, hard surfaces. They have exceptionally high mechanical strength and resistance to spalling, and do not bend under normal loading.

Potters' Supplies: LOUTHAN manufactures a complete line of potters' supplies, including placing pins, thimbles, spurs and stilts.

POROUS REFRACTORY SPECIALTIES

Gas heater back walls and radiants, portable units, and special shapes for various parts of domestic heating furnaces are manufactured from porous refractory bodies, and withstand exceedingly rapid temperature changes without breaking or spalling. This type of refractory is especially adapted for gas conversion burners, and for burner tubes and baffles in gas, coal and oil-fired heating furnaces which are subjected to widely fluctuating temperatures.

Special refractory shapes for foundry service are regularly made.



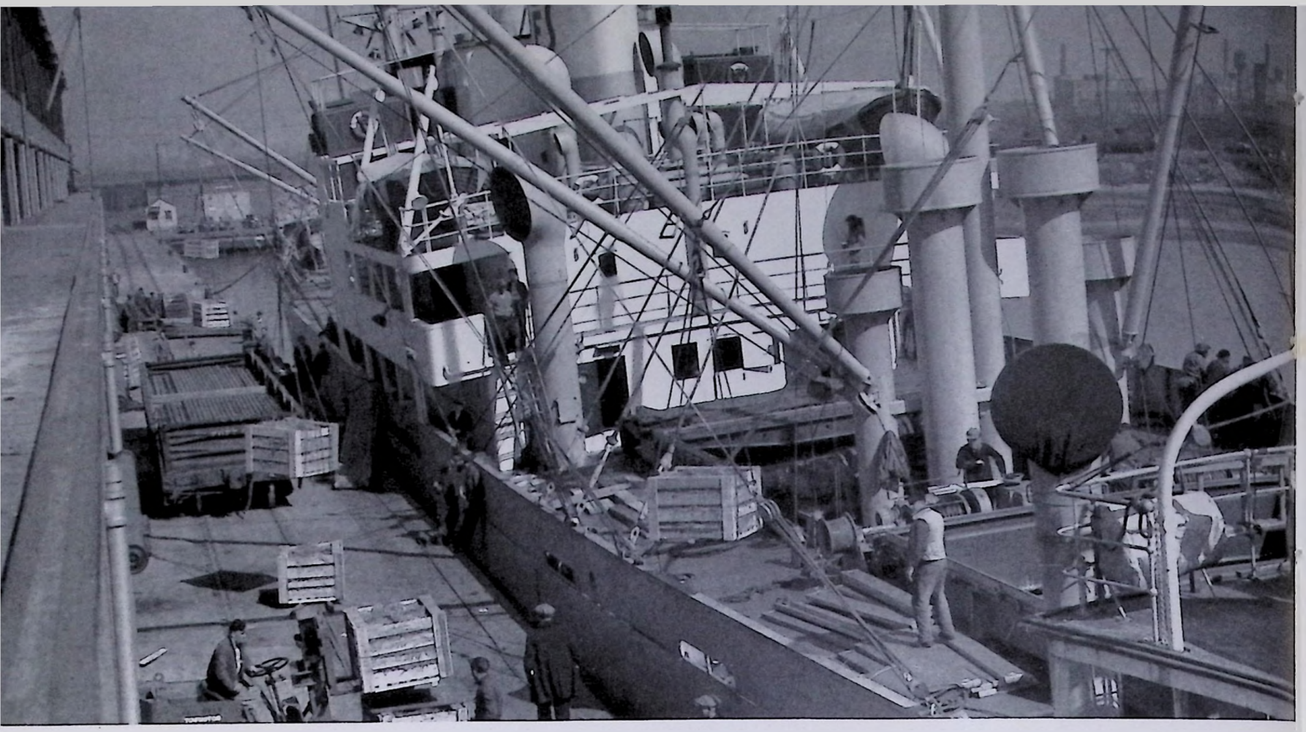
Porous Refractory Special Shapes

EXPORT DEPARTMENT



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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800 Tons of Blast Furnace Brick Being Loaded for Shipment to Brazil



A Large Export Order Awaiting Shipment at Baltimore, Maryland

AGENCY OFFICES

OUTSIDE CONTINENTAL UNITED STATES

CANADA

British Columbia	*Vancouver*
Manitoba	*Winnipeg*
Ontario	*Fort William, Hamilton, Port Arthur, Waterloo*
Quebec	*Montreal*

MEXICO

Northern	*San Antonio, Texas*
Southern	*Mexico D. F.*
Western	*Mazatlan*

CENTRAL AMERICA

Costa Rica	*San Jose*
El Salvador	*San Salvador*
Guatemala	*Guatemala*
Nicaragua	*Managua*
Panama	*Panama*

WEST INDIES

British West Indies	*Georgetown, British Guiana*
Cuba	*Havana*
Puerto Rico	*San Juan*
Trinidad	*Georgetown, British Guiana*

SOUTH AMERICA

Argentina	*Buenos Aires*
British Guiana	*Georgetown*
Brazil	*Rio de Janeiro, Sao Paulo*
Chile	*Santiago*
Colombia	*Barranquilla, Bogota, Cali, Medellin, Cartagena*
Ecuador	*Guayaquil*
Peru	*Lima*
Uruguay	*Montevideo*
Venezuela	*Barcelona, Caracas, Maracaibo*

PACIFIC ISLANDS

Hawaii	*Honolulu*
Philippines	*Manila*

EUROPE

Belgium	*Brussels*
Denmark	*Copenhagen*
Finland	*Helsingfors*
France	*Paris*
Great Britain and Ireland	*London*
Holland	*Brussels, Belgium*
Luxembourg	*Brussels, Belgium*
Greece	*Athens*
Italy	*Milan*
Norway	*Oslo*
Portugal	*Brussels, Belgium*
Spain	*Brussels, Belgium*
Sweden	*Goteborg*
Switzerland	*Zurich*
Turkey	*Istanbul*

ASIA

China	*Hankow, Hong Kong, Shanghai*
Ceylon	*Colombo*
India	*Bombay, Calcutta, Madras*
Iran	*Tehran*
Israeli	*Haifa*
Pakistan	*Karachi*
Siam	*Bangkok*

AFRICA

Egypt	*Cairo*

HARBISON-WALKER REFRACTORIES COMPANY

EXPORT SALES OFFICE

68 William Street New York 5, New York, U. S. A.

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EXPORT DEPARTMENT

For many years, Harbison-Walker has exported thousands of tons of refractory products annually to all parts of the world. Through long experience, it is equipped to handle promptly and accurately the many details connected with export shipments, in accordance with the customs requirements of the various countries.

With brick manufacturing plants in eight states — Alabama, Indiana, Kentucky, Maryland, Missouri, Ohio, Pennsylvania and Texas — the company has exceptional facilities for making foreign shipments either by all-rail service to Canada, Mexico or Cuba, or by combined rail and water service to foreign ports.

Harbison-Walker products meet the requirements of every kind of service, as they include practically the entire range of commercial refractories — fireclay, high-alumina, silica and basic brick, insulating fire brick, acid-proof brick, mortar materials of all classes, special clays, plastic fire brick, castables and hearth materials. The company's products are used extensively throughout the world, in boiler furnaces, in blast furnaces, in open hearth (Siemens-Martin) steel furnaces, in electric steel and alloy furnaces, in smelting and refining furnaces used in the metallurgy of copper, lead, tin, aluminum and magnesium, in vertical shaft kilns, in rotary kilns used for making cement, for burning lime, for sintering or for drying, in locomotive fire boxes, and in many other types of furnaces.

SUGGESTIONS REGARDING ORDERS FOR REFRACTORIES

When ordering, it is well to anticipate requirements as much as possible to insure desired deliveries. Orders for standard sizes of brick will be most clearly expressed when they include both the names of the brick sizes desired, and their complete dimensions either in millimeters or in inches, as they are given on pages 161 to 166. When orders are placed by cable, the sizes desired can be clearly and economically expressed by using the code words given on pages 161 to 166. These code words serve only to identify the sizes, and do not include the kind of brick or brand name.

Operators and engineers will find the brick tables on pages 381 to 422 helpful in determining the sizes and quantities needed. With initial orders for special shapes, the purchaser is requested to send sketches or drawings. On subsequent orders for the same shapes, it is sufficient to give Harbison-Walker's shape and drawing numbers, and to refer to the previous order for the same material. When ordering brick, sufficient mortar of the proper kind and quality should be included for laying them.

The purchaser is requested also to supply the following information:

1. The kind of packing preferred for brick—whether crates, skids, or cartons.
2. Complete and accurate description of each item, in the form required by customs regulations of the importing country. This information is necessary for making proper export declaration.
3. Full instructions regarding marking and numbering of packages, crates, skids, or cartons.
4. The kind and amount of insurance desired. Unless otherwise instructed, Harbison-Walker will arrange for insurance in accordance with its established practice.

PACKING H-W REFRACTORIES FOR EXPORT SHIPMENTS

Refractory brick for export shipments must be well packed in strong containers to prevent damage enroute. Shipments must be of the lowest possible tare weights consistent with safety, to avoid excessive costs for transportation. Based upon these considerations the company has adopted three types of containers, including (1) strong wooden crates, (2) strong wooden skids and (3) heavy paper cartons. Illustrations of these containers are shown on pages 157, 158 and 159.

The crates are made in two Standard Sizes, one holding 54 standard 9″ x 4½″ x 2½″ straight brick each, and the other holding 36 brick each. The larger crates serve for the shipment of fireclay, high-alumina, silica or acid-proof brick; the smaller crates are used for the heavier magnesite, chrome, and forsterite brick and for some brands of high-alumina brick. The gross weights per crate for the different types of brick vary from 360 to 590 pounds.

The skids provide a means for the safe shipment of large packages of heavy weight with the minimum amounts of labor and expense for packing. A single skid will hold up to 500 standard 9″ x 4½″ x 2½″ straight brick or their equivalent, with gross weights of 3220 to 5450 pounds, depending upon the type of brick. Skids are adapted for ocean shipment when adequate mechanical lifting equipment is available at transfer points and at destination.

The cartons used for packing fireclay, high-alumina, silica and basic brick are of such dimensions that they will contain 10 standard 9-inch brick each of the 2½-Inch Series (9″ x 4½″ x 2½″), or approximately the same volume of other 9-inch sizes. They are securely bound with strap iron, to prevent damage in transit or through handling. A full carton weighs 62 to 132 pounds, depending upon the type of brick which it contains. The tare is low, being only about 2 pounds per carton.

Cartons used for packing insulating fire brick will contain 25 Standard 9-inch brick each of the 2½-Inch Series, or approximately the same volume of other 9-inch sizes. The gross weight is approximately 50 to 90 pounds, and the tare is 3 pounds per carton.

The cartons are advantageous for the shipment of small lots; they occupy minimum space; when packed, they are relatively light in weight; and they are of a convenient size for transportation by mule train. However, cartons are not suitable for use where they may get wet in transit or in storage.

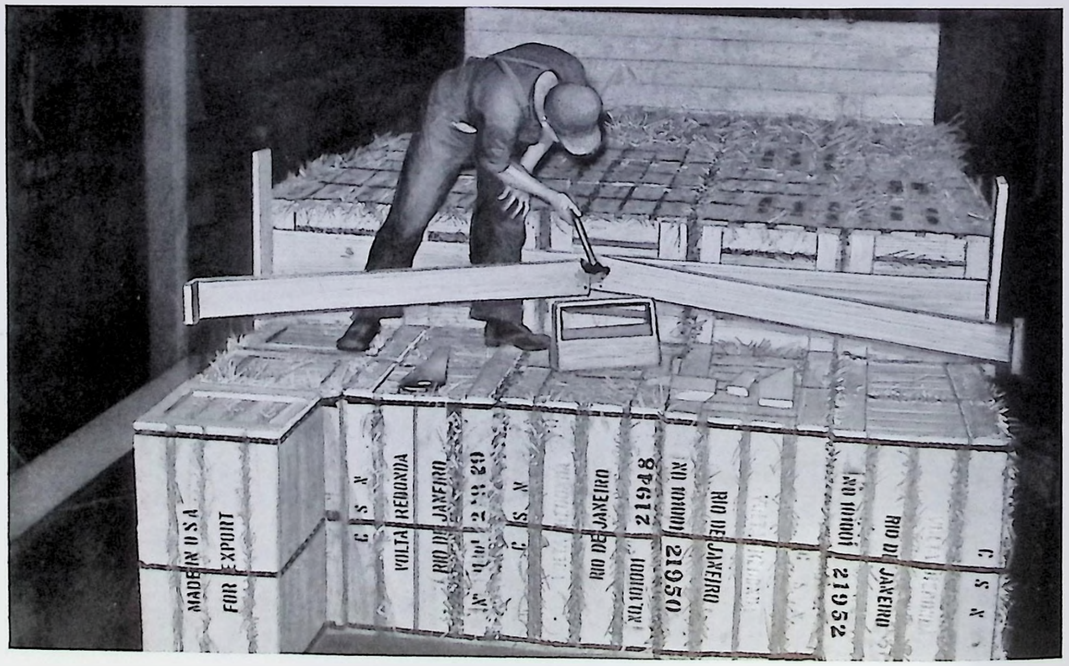
When required, brick are packed in especially strong wooden boxes which with their contents weigh 750 to 1200 pounds each. These boxes are used when shipping conditions are unusually severe, or when the brick shapes are of such dimensions that they cannot be packed satisfactorily in crates or on skids.

Most high temperature cements are shipped in steel drums. Bulk materials such as ground fire clay, dead-burned magnesite, Magnamix or special furnace chrome are shipped in suitable sacks or in wooden barrels. The barrels are advantageous for shipment of materials such as lump chrome ore, which might tear sacking materials. They are also used for other products when preferred by purchaser, or when required by customs regulations.

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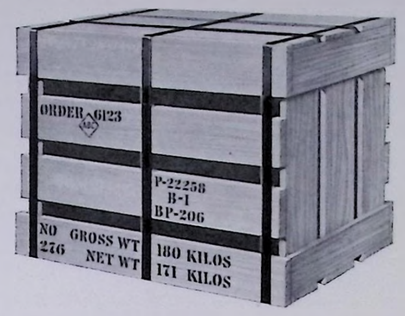


Packing Refractories for Export



Bracing Crates of Brick in Railroad Car for Transportation to Seaport

VOLUMES AND WEIGHTS OF REFRACTORIES PACKED FOR SHIPMENT



H-W STANDARD EXPORT CRATE
Made in Two Sizes

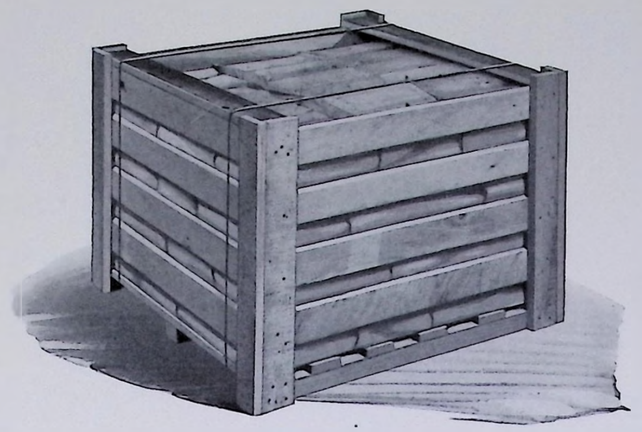
Size A holds 54 Standard 9″ x 4½″ x 2½″ Straights
Size B holds 36 Standard 9″ x 4½″ x 2½″ Straights

H-W STANDARD EXPORT CRATES

Crate	Approximate Size		Approximate Volume		Approximate Tare Weight	
	Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
A	27 x 21 x 16	686 x 533 x 406	5.25	.15	35	15.9
B	27 x 20 x 11	686 x 508 x 279	3.44	.10	25	11.3

Type of Brick	9″ x 4½″ x 2½″ Straights Per Crate	Approximate Net Weight Per Crate		Approximate Gross Weight Per Crate		Crate to be Used
		Pounds	Kilos	Pounds	Kilos	
Fireclay (Aluminous) High, intermediate and low duty	54	380–445	170–200	415–480	190–220	A
Super-duty	54	430–485	195–220	465–520	210–235	A
Fireclay (Siliceous)	54	355–380	160–170	390–415	175–190	A
High Alumina 50, 60 and 70% Alumina	54	405–475	185–215	440–510	200–230	A
80 and 90% Alumina	54	470–535	215–250	505–590	230–270	A
Silica	54	325–360	145–165	360–395	165–180	A
Magnesite and Magnesite-Chrome	36	360–415	165–190	385–440	175–200	B
Metalkase	36	415–470	190–215	440–495	200–225	B
Chrome and Chrome-Magnesite	36	395–430	180–195	420–455	190–205	B

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H-W STANDARD EXPORT SKID
Made in Two Sizes

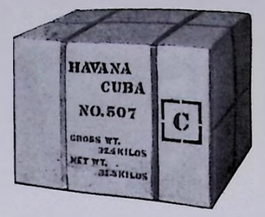
Size A holds 500 Standard 9" x 4½" x 2½" Straights
Size B holds 300 Standard 9" x 4½" x 2½" Straights

H-W STANDARD EXPORT SKIDS

Skid	Approximate Size		Approximate Volume		Approximate Tare Weight	
	Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
A	51 x 41 x 38	1295 x 1041 x 965	46.0	1.30	300	136
B	42 x 41 x 31	1067 x 1041 x 787	30.9	0.87	220	100

Type of Brick	9" x 4½" x 2½" Straights Per Skid	Approximate Net Weight Per Skid		Approximate Gross Weight Per Skid		Skid to be Used
		Pounds	Kilos	Pounds	Kilos	
Fireclay (Aluminous) High, intermediate and low duty	500	3500–4100	1590–1860	3800–4400	1725–1995	A
Super-duty	500	4000–4500	1815–2040	4300–4800	1950–2175	A
Fireclay (Siliceous)	500	3300–3500	1495–1590	3600–3800	1635–1725	A
High-Alumina 50, 60 and 70% Alumina	500	3750–4400	1700–1995	4050–4700	1835–2130	A
80 and 90% Alumina	500	4300–5150	1950–2335	4600–5450	2085–2470	A
Silica	500	3000–3350	1360–1520	3300–3650	1495–1655	A
Magnesite and Magnesite-Chrome	300	3000–3450	1360–1565	3220–3670	1460–1665	B
Metalkase	300	3360–3900	1525–1770	3580–4120	1625–1870	B
Chrome and Chrome-Magnesite	300	3300–3600	1495–1635	3520–3820	1595–1735	B

H-W STANDARD EXPORT CARTONS
Made in Two Sizes





Size A — *Contains 10 Standard 9" x 4½" x 2½" Refractory Brick*

Size B — *Contains 25 Standard 9" x 4½" x 2½" Insulating Fire Brick*

H-W STANDARD EXPORT CARTONS

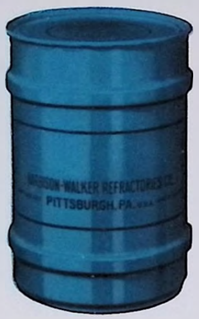
Carton	Approximate Size		Approximate Volume		Approximate Tare Weight	
	Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
A	13 x 9 x 9	330 x 229 x 229	0.61	.017	2	0.91
B	23¾ x 13 x 9½	603 x 330 x 241	1.70	.048	3	1.36

Type of Brick	9" x 4½" x 2½" Straights Per Carton	Approximate Net Weight Per Carton		Approximate Gross Weight Per Carton		Carton to be Used
		Pounds	Kilos	Pounds	Kilos	
Fireclay (Aluminous) High, Intermediate and Low Duty	10	70–80	32–36	72–82	33–37	A
Super-Duty	10	80–90	36–41	82–92	37–42	A
Fireclay (Siliceous)	10	65–70	29–32	67–72	30–33	A
High-Alumina 50, 60 and 70% Alumina	10	75–90	34–41	77–92	35–42	A
80 and 90% Alumina	10	85–105	39–48	87–107	39–49	A
Silica	10	60–65	27–29	62–67	28–30	A
Magnesite and Magnesite-Chrome	10	100–115	45–52	102–117	46–53	A
Metalkase	10	115–130	52–59	117–132	53–60	A
Chrome and Chrome-Magnesite	10	110–120	50–54	112–122	51–55	A
Insulating Fire Brick						
H-W 16	25	47.5–50.0	22–23	50.5–53.0	23–24	B
H-W 20	25	50.0–55.0	23–25	53.0–58.0	24–26	B
H-W 23	25	60.0–65.0	27–29	63.0–68.0	29–31	B
H-W 26	25	70.0–75.0	32–34	73.0–78.0	33–35	B
H-W 28	25	82.5–87.5	37–40	85.5–90.5	39–41	B

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H-W STANDARD EXPORT DRUMS

Drum	Approximate Size				Approximate Shipping Volume		Approximate Tare Weight	
	Outside Diameter		Height		Cubic Feet	Cubic Meters	Pounds	Kilos
	Inches	Millimeters	Inches	Millimeters				
A	16⅞	428.6	14¾	374.7	2.43	.069	12	5.4
B	16⅞	428.6	22½	571.5	3.71	.105	15	6.8
C	16⅝	422.3	9	228.6	1.44	.041	8	3.6



H-W Standard Export Drums are made in Three Sizes, A, B and C

Material	Approximate Net Weight Per Drum		Approximate Gross Weight Per Drum		Drum
	Pounds	Kilos	Pounds	Kilos	
Firebond	200	90.7	215	97.5	B
Harwaco Bond	200	90.7	215	97.5	A
Thermolith	200	90.7	212	96.2	A
Coralite Bonding Mortar	200	90.7	212	96.2	A
Korundal Bonding Mortar	100	45.4	108	49.0	C
Periklase Bonding Mortar	175	79.4	187	84.8	A
Forsterite Bonding Mortar	175	79.4	187	84.8	A

H-W STANDARD EXPORT SACK



H-W Standard Export Sack for Fire Clay

Material	Approximate Size		Approximate Shipping Volume		Approximate Tare Weight	
	Inches	Millimeters	Cubic Feet	Cubic Meters	Pounds	Kilos
Fire Clay and Silica Fire Clay	24 x 16 x 7	610 x 406 x 178	1.56	.044	1	.45

Material	Net Weight Per Sack		Gross Weight Per Sack	
	Pounds	Kilos	Pounds	Kilos
Fire Clay and Silica Fire Clay	100	45.4	101	45.8

STANDARD SIZES OF BRICK
WITH DIMENSIONS AND CODE WORDS

In the following tables the code words refer to the names and dimensions of brick sizes but do not indicate the kind of brick nor refer to any particular brand. Therefore, when code words are used in telegrams or in cable messages, it is necessary to state definitely the kind of brick and the brand desired.

Some of the sizes given in the tables are standard for all types of brick; others are not. The letters under the heading "Standard For" indicate the types of brick in which the given sizes are standard.

The standard sizes of Insulating Fire Brick and of Acid-Proof Brick are given on page 48.

Name of Brick	Thickness	*Standard For	Dimensions		Code Word
			Inches	Millimeters	
STANDARD 9″ x 4½″ x 2½″ SIZES					
9″ Straight—2½″ Series	2½″	F-H-S-B	9 x 4½ x 2½	229 x 114 x 63	Babylon
Small 9″ Brick—2½″ Series	2½″	F-H-S-B	9 x 3½ x 2½	229 x 89 x 63	Baccarat
9″ Soap—2½″ Series	2½″	F-H-S-B	9 x 2½ x 2¼	229 x 63 x 57	Backfire
1¼″ Split Brick—2½″ Series	1¼″	F-H-S-B	9 x 4½ x 1¼	229 x 114 x 32	Bachelor
2″ Split Brick—2½″ Series	2″	F-H-S-B	9 x 4½ x 2	229 x 114 x 51	Background
9″ No. 1 Arch—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-2⅛)	229 x 114 x (63-54)	Balsam
9″ No. 2 Arch—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-1¾)	229 x 114 x (63-44)	Bandage
9″ No. 3 Arch—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-1)	229 x 114 x (63-25)	Bandbox
9″ No. 1-X Wedge—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-2¼)	229 x 114 x (63-57)	Bacteria
9″ No. 1 Wedge—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-1⅞)	229 x 114 x (63-48)	Backslide
9″ No. 2 Wedge—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-1½)	229 x 114 x (63-38)	Badger
9″ No. 1 Key—2½″ Series	2½″	F-H-S-B	9 x (4½-4) x 2½	229 x (114-102) x 63	Badinage
9″ No. 2 Key—2½″ Series	2½″	F-H-S-B	9 x (4½-3½) x 2½	229 x (114-89) x 63	Baff
9″ No. 3 Key—2½″ Series	2½″	F-H-S-B	9 x (4½-3) x 2½	229 x (114-76) x 63	Bagasse
9″ No. 4 Key—2½″ Series	2½″	F-H-S-B	9 x (4½-2¼) x 2½	229 x (114-57) x 63	Baggage
9″ Feather Edge—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-⅛)	229 x 114 x (63-3)	Balloon
9″ Neck Brick—2½″ Series	2½″	F-H-S-B	9 x 4½ x (2½-⅝)	229 x 114 x (63-16)	Bagpipe
9″ Jamb Brick—2½″ Series	2½″	F-H-S-B	9 x 4½ x 2½	229 x 114 x 63	Bailiwick
9″ Edge Skew—2½″ Series	2½″	F-H-S-B	9 x (4½-1½) x 2½	229 x (114-38) x 63	Ballad
9″ 48° End Skew—2½″ Series	2½″	F-H-S-B	(9-6¾) x 4½ x 2½	(229-171) x 114 x 63	Baleful
9″ 48° Side Skew—2½″ Series	2½″	F-H-S-B	9 x (4½-2¼) x 2½	229 x (114-57) x 63	Balked
9″ 60° End Skew—2½″ Series	2½″	F-H-S-B	(9-7⅜) x 4½ x 2½	(229-192) x 114 x 63	Balkan
9″ 60° Side Skew—2½″ Series	2½″	F-H-S-B	9 x (4½-3⅛) x 2½	229 x (114-78) x 63	Ballast
STANDARD 9″ x 6¾″ x 2½″ SIZES					
9″ x 6¾″ x 2½″ Straight	2½″	F-H-S-B	9 x 6¾ x 2½	229 x 171 x 63	Bazar
9″ x 6¾″ x 2½″ No. 1-X Wedge	2½″	F-H-S	9 x 6¾ x (2½-2¼)	229 x 171 x (63-57)	Beater
9″ x 6¾″ x 2½″ No. 1 Wedge	2½″	F-H-S-B	9 x 6¾ x (2½-1⅞)	229 x 171 x (63-48)	Beacon
9″ x 6¾″ x 2½″ No. 2 Wedge	2½″	F-H-S-B	9 x 6¾ x (2½-1½)	229 x 171 x (63-38)	Beaming

*F = Fireclay Brick H = High-Alumina Brick S = Silica Brick B = Basic Brick

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STANDARD SIZES

WITH DIMENSIONS AND CODE WORDS (Continued)

Name of Brick	Thick-ness	*Standard For	Dimensions		Code Word
			Inches	Millimeters	
STANDARD 9″ x 4½″ x 3″ SIZES					
9″ Straight—3″ Series	3″	F-H-S-B	9 x 4½ x 3	229 x 114 x 76	Barbed
Small 9″ Brick—3″ Series	3″	F-H-S-B	9 x 3½ x 3	229 x 89 x 76	Bareback
1½″ Split Brick—3″ Series	1½″	F-H-S-B	9 x 4½ x 1½	229 x 114 x 38	Barefaced
9″ Soap—3″ Series	3″	F-H-S-B	9 x 3 x 2¼	229 x 76 x 57	Barefoot
9″ No. 1 Arch—3″ Series	3″	F-H-S-B	9 x 4½ x (3–2¾)	229 x 114 x (76–70)	Baseline
9″ No. 2 Arch—3″ Series	3″	F-H-S-B	9 x 4½ x (3–2½)	229 x 114 x (76–63)	Baseman
9″ No. 3 Arch—3″ Series	3″	F-H-S-B	9 x 4½ x (3–2)	229 x 114 x (76–51)	Basement
9″ No. 4 Arch—3″ Series	3″	F-H-S-B	9 x 4½ x (3–1)	229 x 114 x (76–25)	Baseness
9″ No. 1 Wedge—3″ Series	3″	F-H-S-B	9 x 4½ x (3–2¾)	229 x 114 x (76–70)	Baritone
9″ No. 2 Wedge—3″ Series	3″	F-H-S-B	9 x 4½ x (3–2½)	229 x 114 x (76–63)	Barnacle
9″ No. 3 Wedge—3″ Series	3″	F-H-S-B	9 x 4½ x (3–2)	229 x 114 x (76–51)	Baronet
9″ No. 1 Key—3″ Series	3″	F-H-S-B	9 x (4½–4) x 3	229 x (114–102) x 76	Baroque
9″ No. 2 Key—3″ Series	3″	F-H-S-B	9 x (4½–3½) x 3	229 x (114–89) x 76	Barren
9″ No. 3 Key—3″ Series	3″	F-H-S-B	9 x (4½–3) x 3	229 x (114–76) x 76	Barring
9″ No. 4 Key—3″ Series	3″	F-H-S-B	9 x (4½–2¼) x 3	229 x (114–57) x 76	Basehit
9″ Feather Edge—3″ Series	3″	F-H-S-B	9 x 4½ x (3–⅛)	229 x 114 x (76–3)	Basin
9″ Neck Brick—3″ Series	3″	F-H-S-B	9 x 4½ x (3–⅝)	229 x 114 x (76–16)	Bask
9″ Jamb Brick—3″ Series	3″	F-H-S-B	9 x 4½ x 3	229 x 114 x 76	Battery
9″ Edge Skew—3″ Series	3″	F-H-S-B	9 x (4½–1½) x 3	229 x (114–38) x 76	Basset
9″ 48° End Skew—3″ Series	3″	F-H-S-B	(9–6⅝) x 4½ x 3	(229–160) x 114 x 76	Bassinet
9″ 48° Side Skew—3″ Series	3″	F-H-S-B	9 x (4½–1¹³⁄₁₆) x 3	229 x (114–46) x 76	Bastinado
9″ 60° End Skew—3″ Series	3″	F-H-S-B	(9–7¼) x 4½ x 3	(229–184) x 114 x 76	Batsman
9″ 60° Side Skew—3″ Series	3″	F-H-S-B	9 x (4½–2¾) x 3	229 x (114–70) x 76	Battalia
STANDARD 9″ x 6¾″ x 3″ SIZES					
9″ x 6¾″ x 3″ Straight	3″	F-H-S-B	9 x 6¾ x 3	229 x 171 x 76	Bearable
9″ x 6¾″ x 3″ No. 1 Wedge	3″	F-H-S-B	9 x 6¾ x (3–2¾)	229 x 171 x (76–70)	Beard
9″ x 6¾″ x 3″ No. 2 Wedge	3″	F-H-S-B	9 x 6¾ x (3–2½)	229 x 171 x (76–63)	Bearskin
9″ x 6¾″ x 3″ No. 3 Wedge	3″	F-H-S-B	9 x 6¾ x (3–2)	229 x 171 x (76–51)	Beatitude
STANDARD 9″ x 6″ x 2½″ SIZES					
9″ x 6″ x 2½″ Straight	2½″	F-H	9 x 6 x 2½	229 x 152 x 63	Batavian
9″ x 6″ x 2½″ No. 1 Key	2½″	F-H	9 x (6–5⅜) x 2½	229 x (152–137) x 63	Bathing
9″ x 6″ x 2½″ No. 2 Key	2½″	F-H	9 x (6–4¹³⁄₁₆) x 2½	229 x (152–122) x 63	Battered
9″ x 6″ x 2½″ No. 3 Key	2½″	F-H	9 x (6–3) x 2½	229 x (152–76) x 63	Bayard
STANDARD 9″ x 6″ x 3″ SIZES					
9″ x 6″ x 3″ Straight	3″	F-H	9 x 6 x 3	229 x 152 x 76	Bateau
9″ x 6″ x 3″ No. 1 Key	3″	F-H	9 x (6–5⅜) x 3	229 x (152–137) x 76	Bathtub
9″ x 6″ x 3″ No. 2 Key	3″	F-H	9 x (6–4¹³⁄₁₆) x 3	229 x (152–122) x 76	Battled
9″ x 6″ x 3″ No. 3 Key	3″	F-H	9 x (6–3) x 3	229 x (152–76) x 76	Bauble

*F = Fireclay Brick H = High-Alumina Brick S = Silica Brick B = Basic Brick

STANDARD SIZES

WITH DIMENSIONS AND CODE WORDS (Continued)

Name of Brick	Thick-ness	*Standard For	Dimensions		Code Word
			Inches	Millimeters	
STANDARD 12″ x 4½″ x 3″ SIZES					
12″ x 4½″ x 3″ Straight	3″	S	12 x 4½ x 3	305 x 114 x 76	Cardboard
12″ x 4½″ x 3″ No. 1-X Wedge	3″	S	12 x 4½ x (3–2⅞)	305 x 114 x (76–73)	Carmine
12″ x 4½″ x 3″ No. 1 Wedge	3″	S	12 x 4½ x (3–2¾)	305 x 114 x (76–70)	Carnage
12″ x 4½″ x 3″ No. 2 Wedge	3″	S	12 x 4½ x (3–2½)	305 x 114 x (76–63)	Carnation
12″ x 4½″ x 3″ No. 3 Wedge	3″	S	12 x 4½ x (3–2)	305 x 114 x (76–51)	Carnival
STANDARD 12″ x 6″ x 3″ SIZES					
12″ x 6″ x 3″ Straight	3″	F-H-S-B	12 x 6 x 3	305 x 152 x 76	Becalm
12″ x 6″ x 3″ No. 1 Arch	3″	S	12 x 6 x (3–2¾)	305 x 152 x (76–70)	Cart
12″ x 6″ x 3″ No. 2 Arch	3″	S	12 x 6 x (3–2½)	305 x 152 x (76–63)	Cartman
12″ x 6″ x 3″ No. 3 Arch	3″	S	12 x 6 x (3–2)	305 x 152 x (76–51)	Cartridge
12″ x 6″ x 3″ No. 1-X Wedge	3″	S	12 x 6 x (3–2⅞)	305 x 152 x (76–73)	Carousel
12″ x 6″ x 3″ No. 1 Wedge	3″	F-H-S-B	12 x 6 x (3–2¾)	305 x 152 x (76–70)	Carpet
12″ x 6″ x 3″ No. 2 Wedge	3″	F-H-S-B	12 x 6 x (3–2½)	305 x 152 x (76–63)	Carping
12″ x 6″ x 3″ No. 3 Wedge	3″	F-H-S-B	12 x 6 x (3–2)	305 x 152 x (76–51)	Carriage
12″ x 6″ x 3″ No. 1 Key	3″	S	12 x (6–5½) x 3	305 x (152–140) x 76	Cascade
12″ x 6″ x 3″ No. 2 Key	3″	S	12 x (6–5) x 3	305 x (152–127) x 76	Casserole
STANDARD 12″ x 9″ x 3″ SIZES					
12″ x 9″ x 3″ Straight	3″	S	12 x 9 x 3	305 x 229 x 76	Castaway
12″ x 9″ x 3″ No. 1-X Wedge	3″	S	12 x 9 x (3–2⅞)	305 x 229 x (76–73)	Casting
12″ x 9″ x 3″ No. 1 Wedge	3″	S	12 x 9 x (3–2¾)	305 x 229 x (76–70)	Casual
12″ x 9″ x 3″ No. 2 Wedge	3″	S	12 x 9 x (3–2½)	305 x 229 x (76–63)	Catacomb
12″ x 9″ x 3″ No. 3 Wedge	3″	S	12 x 9 x (3–2)	305 x 229 x (76–51)	Catalog
STANDARD 13½″ x 4½″ x 3″ SIZES					
13½″ x 4½″ x 3″ Straight	3″	F-H-S-B	13½ x 4½ x 3	343 x 114 x 76	Catamaran
13½″ x 4½″ x 3″ No. 1 Arch	3″	S-B	13½ x 4½ x (3–2¾)	343 x 114 x (76–70)	Catamount
13½″ x 4½″ x 3″ No. 2 Arch	3″	S-B	13½ x 4½ x (3–2½)	343 x 114 x (76–63)	Cataract
13½″ x 4½″ x 3″ No. 3 Arch	3″	S-B	13½ x 4½ x (3–2)	343 x 114 x (76–51)	Catawba
13½″ x 4½″ x 3″ No. 4 Arch	3″	S-B	13½ x 4½ x (3–1)	343 x 114 x (76–25)	Catcher
STANDARD 13½″ x 6″ x 2½″ SIZES					
13½″ x 6″ x 2½″ Straight	2½″	F-H-B	13½ x 6 x 2½	343 x 152 x 63	Bedstead
13½″ x 6″ x 2½″ No. 1 Key	2½″	F-H-B	13½ x (6–5) x 2½	343 x (152–127) x 63	Beggardom
13½″ x 6″ x 2½″ No. 2 Key	2½″	F-H-B	13½ x (6–4⅜) x 2½	343 x (152–111) x 63	Behemoth
13½″ x 6″ x 2½″ No. 3 Key	2½″	F-H-B	13½ x (6–3) x 2½	343 x (152–76) x 63	Belfry
STANDARD 13½″ x 6″ x 3″ SIZES					
13½″ x 6″ x 3″ Straight	3″	F-H-S-B	13½ x 6 x 3	343 x 152 x 76	Catboat
13½″ x 6″ x 3″ No. 1 Arch	3″	S	13½ x 6 x (3–2¾)	343 x 152 x (76–70)	Caterer
13½″ x 6″ x 3″ No. 2 Arch	3″	S	13½ x 6 x (3–2½)	343 x 152 x (76–63)	Caterpillar
13½″ x 6″ x 3″ No. 3 Arch	3″	S	13½ x 6 x (3–2)	343 x 152 x (76–51)	Catfish
13½″ x 6″ x 3″ No. 1-X Wedge	3″	S	13½ x 6 x (3–2⅞)	343 x 152 x (76–73)	Catchfly
13½″ x 6″ x 3″ No. 1 Wedge	3″	F-H-S	13½ x 6 x (3–2¾)	343 x 152 x (76–70)	Catchy
13½″ x 6″ x 3″ No. 2 Wedge	3″	F-H-S	13½ x 6 x (3–2½)	343 x 152 x (76–63)	Catechism
13½″ x 6″ x 3″ No. 3 Wedge	3″	F-H-S	13½ x 6 x (3–2)	343 x 152 x (76–51)	Category

*F = Fireclay Brick H = High-Alumina Brick S = Silica Brick B = Basic Brick

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STANDARD SIZES

WITH DIMENSIONS AND CODE WORDS (Continued)

Name of Brick	Thickness	*Standard For	Dimensions		Code Word
			Inches	Millimeters	
STANDARD 13½" x 6" x 3" SIZES (Cont'd)					
13½" x 6" x 3" No. 1 Key	3"	F-H-S-B	13½ x (6–5) x 3	343 x (152–127) x 76	Beggarly
13½" x 6" x 3" No. 2 Key	3"	F-H-S-B	13½ x (6–4⅜) x 3	343 x (152–111) x 76	Beholden
13½" x 6" x 3" No. 3 Key	3"	F-H-S-B	13½ x (6–3) x 3	343 x (152–76) x 76	Catmint
STANDARD 13½" x 9" x 3" SIZES					
13½" x 9" x 3" Straight	3"	S	13½ x 9 x 3	343 x 229 x 76	Catgut
13½" x 9" x 3" No. 1 Arch	3"	S	13½ x 9 x (3–2¾)	343 x 229 x (76–70)	Cattle
13½" x 9" x 3" No. 2 Arch	3"	S	13½ x 9 x (3–2½)	343 x 229 x (76–63)	Caucus
13½" x 9" x 3" No. 3 Arch	3"	S	13½ x 9 x (3–2)	343 x 229 x (76–51)	Cauldron
13½" x 9" x 3" No. 1-X Wedge	3"	S	13½ x 9 x (3–2⅞)	343 x 229 x (76–73)	Cathedral
13½" x 9" x 3" No. 1 Wedge	3"	S	13½ x 9 x (3–2¾)	343 x 229 x (76–70)	Cathode
13½" x 9" x 3" No. 2 Wedge	3"	S	13½ x 9 x (3–2½)	343 x 229 x (76–63)	Catnip
13½" x 9" x 3" No. 3 Wedge	3"	S	13½ x 9 x (3–2)	343 x 229 x (76–51)	Catspaw
STANDARD 15" x 6" x 3" SIZES					
15" x 6" x 3" Straight	3"	S	15 x 6 x 3	381 x 152 x 76	Casualty
15" x 6" x 3" No. 1-X Wedge	3"	S	15 x 6 x (3–2⅞)	381 x 152 x (76–73)	Cautious
15" x 6" x 3" No. 1 Wedge	3"	S	15 x 6 x (3–2¾)	381 x 152 x (76–70)	Cavity
15" x 6" x 3" No. 2 Wedge	3"	S	15 x 6 x (3–2½)	381 x 152 x (76–63)	Cayenne
15" x 6" x 3" No. 3 Wedge	3"	S	15 x 6 x (3–2)	381 x 152 x (76–51)	Cayuga
STANDARD 15" x 9" x 3" SIZES					
15" x 9" x 3" Straight	3"	S	15 x 9 x 3	381 x 229 x 76	Cayuse
15" x 9" x 3" No. 1-X Wedge	3"	S	15 x 9 x (3–2⅞)	381 x 229 x (76–73)	Ceasing
15" x 9" x 3" No. 1 Wedge	3"	S	15 x 9 x (3–2¾)	381 x 229 x (76–70)	Cedar
15" x 9" x 3" No. 2 Wedge	3"	S	15 x 9 x (3–2½)	381 x 229 x (76–63)	Ceiling
15" x 9" x 3" No. 3 Wedge	3"	S	15 x 9 x (3–2)	381 x 229 x (76–51)	Central
STANDARD 18" x 6" x 3" SIZES					
18" x 6" x 3" Straight	3"	S	18 x 6 x 3	457 x 152 x 76	Century
18" x 6" x 3" No. 1-X Wedge	3"	S	18 x 6 x (3–2⅞)	457 x 152 x (76–73)	Cereal
18" x 6" x 3" No. 1 Wedge	3"	S	18 x 6 x (3–2¾)	457 x 152 x (76–70)	Ceremony
18" x 6" x 3" No. 2 Wedge	3"	S	18 x 6 x (3–2½)	457 x 152 x (76–63)	Chase
18" x 6" x 3" No. 3 Wedge	3"	S	18 x 6 x (3–2)	457 x 152 x (76–51)	Chafe
STANDARD 18" x 9" x 3" SIZES					
18" x 9" x 3" Straight	3"	S	18 x 9 x 3	457 x 229 x 76	Chair
18" x 9" x 3" No. 1-X Wedge	3"	S	18 x 9 x (3–2⅞)	457 x 229 x (76–73)	Challenge
18" x 9" x 3" No. 1 Wedge	3"	S	18 x 9 x (3–2¾)	457 x 229 x (76–70)	Champ
18" x 9" x 3" No. 2 Wedge	3"	S	18 x 9 x (3–2½)	457 x 229 x (76–63)	Chance
18" x 9" x 3" No. 3 Wedge	3"	S	18 x 9 x (3–2)	457 x 229 x (76–51)	Chaos

*F = Fireclay Brick H = High-Alumina Brick S = Silica Brick B = Basic Brick

FIRECLAY AND HIGH-ALUMINA REFRACTORIES

STANDARD SIZES WITH DIMENSIONS AND CODE WORDS

CIRCLE BRICK

Outside Chord 9 Inches
229 Millimeters
Radial Dimension 4½ Inches
114 Millimeters
Thickness 2½ Inches
63 Millimeters



6-INCH CUPOLA AND ROTARY KILN BLOCKS

Outside Chord 9 Inches
229 Millimeters
Radial Dimension 6 Inches
152 Millimeters
Thickness 4 Inches
102 Millimeters



9-INCH ROTARY KILN BLOCKS

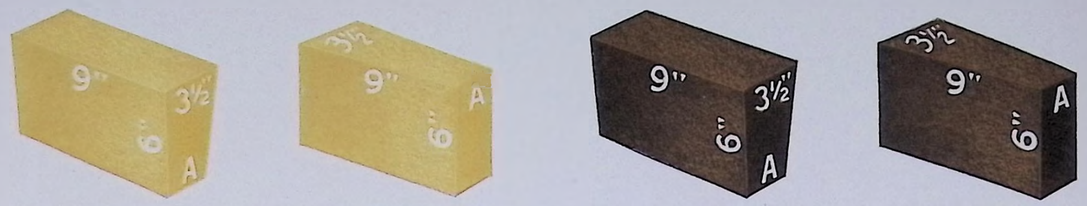
Outside Chord 9 Inches
229 Millimeters
Radial Dimension 9 Inches
229 Millimeters
Thickness 4 Inches
102 Millimeters



Brick or Block Number	Inside Chord of Brick		Inside Diam. of Ring		Outside Diam. of Ring		No. Pieces Per Ring	Code Word
	Inches	MM	Inches	MM	Inches	MM		
24-33 Circle	6 17/32	166	24	610	33	838	12	Bandit
36-45 Circle	7 3/16	183	36	914	45	1143	16	Baneful
48-57 Circle	7 19/32	193	48	1219	57	1448	20	Bangle
60-69 Circle	7 13/16	198	60	1524	69	1753	24	Banjo
72-81 Circle	8	203	72	1829	81	2057	29	Bantam
84-93 Circle	8 1/8	206	84	2134	93	2362	33	Banyan
96-105 Circle	8 7/32	209	96	2438	105	2667	37	Baptism
108-117 Circle	8 5/16	211	108	2743	117	2972	41	Barbarian
120-129 Circle	8 3/8	213	120	3048	129	3277	45	Barbecue
30-42 Cupola or RKB	6 7/16	164	30	762	42	1067	15	Calmed
36-48 Cupola or RKB	6 3/4	171	36	914	48	1219	17	Calomel
42-54 Cupola or RKB	7	178	42	1067	54	1372	19	Calve
48-60 Cupola or RKB	7 3/16	183	48	1219	60	1524	21	Calvanism
54-66 Cupola or RKB	7 3/8	187	54	1372	66	1676	23	Campaign
60-72 Cupola or RKB	7 1/2	190	60	1524	72	1829	26	Camped
66-78 Cupola or RKB	7 5/8	194	66	1676	78	1981	28	Candid
72-84 Cupola or RKB	7 23/32	196	72	1829	84	2134	30	Candidate
78-90 Cupola or RKB	7 13/16	198	78	1981	90	2286	32	Candle
84-96 Cupola or RKB	7 7/8	200	84	2134	96	2438	34	Candytuft
90-102 Cupola or RKB	7 15/16	202	90	2286	102	2591	36	Cannibal
96-108 Cupola or RKB	8	203	96	2438	108	2743	38	Canning
102-114 Cupola or RKB	8 1/16	205	102	2591	114	2896	40	Cannon
108-120 Cupola or RKB	8 3/32	206	108	2743	120	3048	42	Cannonade
114-126 Cupola or RKB	8 5/32	207	114	2896	126	3200	44	Canoeing
120-132 Cupola or RKB	8 3/16	208	120	3048	132	3353	46	Cantaloup
123-135 Cupola or RKB	8 3/16	208	123	3124	135	3429	48	Cantata
126-138 Cupola or RKB	8 7/32	209	126	3200	138	3505	49	Canticle
132-144 Cupola or RKB	8 1/4	210	132	3353	144	3658	51	Cantboard
138-150 Cupola or RKB	8 9/32	210	138	3505	150	3810	53	Cantbook
72-90 RKB	7 3/16	183	72	1829	90	2286	32	Capacious
78-96 RKB	7 3/16	186	78	1981	96	2438	34	Capital
84-102 RKB	7 13/32	188	84	2134	102	2591	36	Capricorn
90-108 RKB	7 1/2	190	90	2286	108	2743	38	Capsized
96-114 RKB	7 19/32	193	96	2438	114	2896	40	Capstan
102-120 RKB	7 21/32	194	102	2591	120	3048	42	Captain
108-126 RKB	7 23/32	196	108	2743	126	3200	44	Captivate
114-132 RKB	7 25/32	198	114	2896	132	3353	46	Captive
117-135 RKB	7 13/16	198	117	2972	135	3429	48	Captivity
120-138 RKB	7 13/16	198	120	3048	138	3505	49	Caramel
123-141 RKB	7 27/32	199	123	3124	141	3581	50	Carbonate
126-144 RKB	7 7/8	200	126	3200	144	3658	51	Carburet
132-150 RKB	7 29/32	201	132	3353	150	3810	53	Carburetor
138-156 RKB	7 31/32	202	138	3505	156	3962	55	Carburize
144-162 RKB	8	203	144	3658	162	4115	57	Carcanet
150-168 RKB	8 1/32	204	150	3810	168	4267	59	Carcel

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ARCH AND WEDGE SHAPES FOR ROTARY KILNS



Arch *Wedge* *Arch* *Wedge*

FIRECLAY AND HIGH-ALUMINA BLOCKS — BASIC BLOCKS

Arch Type Blocks: 9″ x 6″ x (3½″–A), or 229 x 152 x (89–A) millimeters
Wedge Type Blocks: 9″ x 6″ x (3½″–A), or 229 x 152 x (89–A) millimeters

Block Number	Inside Chord "A" of Block		Inside Diameter of Brick Lining		Outside Diameter of Brick Lining		Fireclay and High-Alumina Brick Linings		Basic Linings Laid with No. 16 Gauge Steel Plates		Code Word
							Number Required				
	Inches	MM	Inches	MM	Inches	MM	Per Ring	Per Foot	Per Ring	Per Foot	
ARCH TYPE ROTARY KILN BLOCKS											
60-A-72	2 29/32	74	60	1524	72	1829	64	85	63	84	HABITAT
66-A-78	2 31/32	75	66	1676	78	1981	70	93	68	91	HACHURE
72-A-84	3	76	72	1829	84	2134	75	100	74	98	HACIENDA
78-A-90	3 1/32	77	78	1981	90	2286	80	107	79	105	HACKBUT
84-A-96	3 1/16	78	84	2134	96	2438	86	114	84	112	HADDOCK
90-A-102	3 3/32	79	90	2286	102	2591	91	121	89	119	HAFNIUM
96-A-108	3 1/8	79	96	2438	108	2743	96	128	95	126	HAGBUSH
102-A-114	3 1/8	79	102	2591	114	2896	102	136	100	133	HAIRLINE
108-A-120	3 5/32	80	108	2743	120	3048	107	143	105	140	HALATION
114-A-126	3 5/32	80	114	2896	126	3200	113	150	111	148	HALBERD
120-A-132	3 3/16	81	120	3048	132	3353	118	157	116	155	HALFBACK
123-A-135	3 3/16	81	123	3124	135	3429	121	161	119	158	HALITUS
126-A-138	3 3/16	81	126	3200	138	3505	123	164	122	162	HALLMARK
132-A-144	3 7/32	82	132	3353	144	3658	129	172	127	169	HALOGEN
138-A-150	3 7/32	82	138	3505	150	3810	134	179	132	176	HALYARD
WEDGE TYPE ROTARY KILN BLOCKS											
66-W-84	2 3/4	70	66	1676	84	2134	75	150	74	148	HAMLET
72-W-90	2 13/16	71	72	1829	90	2286	80	160	79	158	HAMSTER
78-W-96	2 27/32	72	78	1981	96	2438	86	172	84	168	HAMULUS
84-W-102	2 7/8	73	84	2134	102	2591	91	182	89	178	HANAPER
90-W-108	2 29/32	74	90	2286	108	2743	96	192	95	190	HANDBAG
96-W-114	2 15/16	75	96	2438	114	2896	102	204	100	200	HANSARD
102-W-120	2 31/32	75	102	2591	120	3048	107	214	105	210	HARBINGER
108-W-126	3	76	108	2743	126	3200	113	226	111	222	HARDHEAD
114-W-132	3 1/32	77	114	2896	132	3353	118	236	116	232	HARICOT
117-W-135	3 1/32	77	117	2972	135	3429	121	242	119	238	HARMONIST
120-W-138	3 1/32	77	120	3048	138	3505	123	246	122	244	HARNESS
126-W-144	3 1/16	78	126	3200	144	3658	129	258	127	254	HARPOON
132-W-150	3 3/32	79	132	3353	150	3810	134	268	132	264	HARVEST

NOTE: To facilitate the keying of Standard Arch Type or Wedge Type Rotary Kiln Blocks, Split Blocks are available of both two-third (⅔) and three-quarter (¾) thickness. Two (2) each of these should be included for each ring of standard full size blocks. They are correctly specified by the Block Number followed by a dash and the fraction which indicates the thickness desired, thus, 60-A-72-⅔ and 60-A-72-¾ or 66-W-84-⅔ and 66-W-84-¾. To order these Split Blocks by code, add "GLAZER" to the code word given in the table, to indicate a block of ⅔ thickness; and add "GLORIED" to indicate a block of ¾ thickness.

APPLICATION OF REFRACTORIES IN FURNACE CONSTRUCTION



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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APPLICATION OF REFRACTORIES IN FURNACE CONSTRUCTION

THE applications of refractory products in a considerable number of representative industrial furnaces are reviewed briefly on the following pages. While it is obviously impracticable to present all types of industrial furnaces and their numerous modifications, the various kinds of furnace practice described have been so chosen as to give a broad survey of the most common industrial applications of the types of refractories which are commercially available, and of the service conditions for which they are advantageously employed.

The designs of the various furnaces shown illustrate good current practice. In general, the drawings do not represent actual furnaces, but are composites, prepared with the cooperation of prominent designers and operators. Harbison-Walker does not design or build furnaces, but gladly cooperates with designers and builders by supplying data regarding the properties of refractory products, by giving information concerning the service conditions under which they are applicable, and by assisting in the design of refractory brick shapes. Harbison-Walker products are used in every type of industrial furnace.

From the discussions which follow, it will be observed that in many cases different kinds of refractories are necessary to meet furnace operating conditions which appear to be almost identical. For a particular application, selection of the most economical and serviceable refractories may require study by an engineer of wide experience in the use of these materials. Such studies are included in the service rendered by the company to users of refractories.

BLAST FURNACE LININGS

IN 1871, Harbison-Walker manufactured its first blast furnace lining. During the years which have followed, the company has made the greater proportion of all the blast furnace refractories used in the United States. The large number of Harbison-Walker linings in service today — more than those of any other manufacture — testify to their high standing in the industry.

Harbison-Walker blast furnace refractories have been used under every possible operating condition, in all sizes and designs of furnaces, and with all classes of ore and fuel. The company has always given special attention to the manufacture of blast furnace refractories, and many world's records on furnace tonnage have been made with Harbison-Walker linings.

The company's brands of blast furnace brick — BENEZET, made in Pennsylvania, and H-W, made in Kentucky — are well known to all operators of blast furnaces. Both of these brands have been supplied in HEARTH and BOSH, INWALL, and TOP quality. However, there is a growing tendency to use brick of only one quality for the entire lining, especially a hard-burned brick of HEARTH and BOSH quality fired at Cone 18. These are marketed under the brand names of H-W 18-PA made in Pennsylvania and H-W 18-KY made in Kentucky. High-fired KENMORE and VARNON super-duty fireclay brick are being used similarly to an increasing extent.

Close laboratory control insures uniformly high quality of the raw materials used, as well as uniformity in every step of the manufacturing process. The sizing to which the clays are ground, the moisture content, the pressure at which the brick are molded, the temperature of firing, and the firing conditions are all kept within predetermined limits. Continuous tunnel kilns are used for firing. The resulting brick meet rigid standards of quality, uniformity in size, and homogeneity of texture.

For all sections of the blast furnace lining, good workmanship of the refractories is important to insure tight and close-fitting construction. Blast furnace refractories should be strong, tough, dense, of uniform texture, and of low permeability. Brick in the top and inwall sections must be highly resistant to the abrasive action of the descending stock; those in the hearth and bosh section must have high refractoriness, stability of volume in service, and high resistance to corrosion.

The vacuum power press process — used for making all Harbison-Walker blast furnace linings — imparts the necessary physical properties to a high degree. In manufacture, the proportions of the different particle sizes in the clay mix are adjusted to give maximum density. A measured quantity of the slightly moist clay mix is charged into each press box. During pressing, a high vacuum is applied over the entire top and bottom surfaces of each brick. Harbison-Walker vacuum pressed blast furnace brick have low porosity, exceptionally low permeability to gases, and high resistance to abrasion and to slag attack.

One of the most important requirements for brick in the top and inwall sections of blast furnace linings is resistance to the disintegrating influences of carbon monoxide gas. Under certain conditions, this gas dissociates with the formation of carbon dioxide gas and solid carbon. The reaction occurs most readily at about 700° to 1000° F., in the presence of a catalyst, such as ferric oxide.

The critical temperature range of 700° to 1000° F. occurs at different distances from the

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working face of the lining in the different zones of the furnace. Its position at any particular elevation in the furnace depends upon the temperature at the working face of the lining, and upon the temperature drop through the lining. In the top section, the critical temperature range may come close to the working face; in the lower part of the stack, it is well back toward the shell.

At the critical temperature, carbon monoxide gas which penetrates the pores of the brick may deposit carbon around any small particles of iron oxide. The deposition of carbon may cause internal stresses great enough to disrupt the bond of the brick, and to cause them to disintegrate.

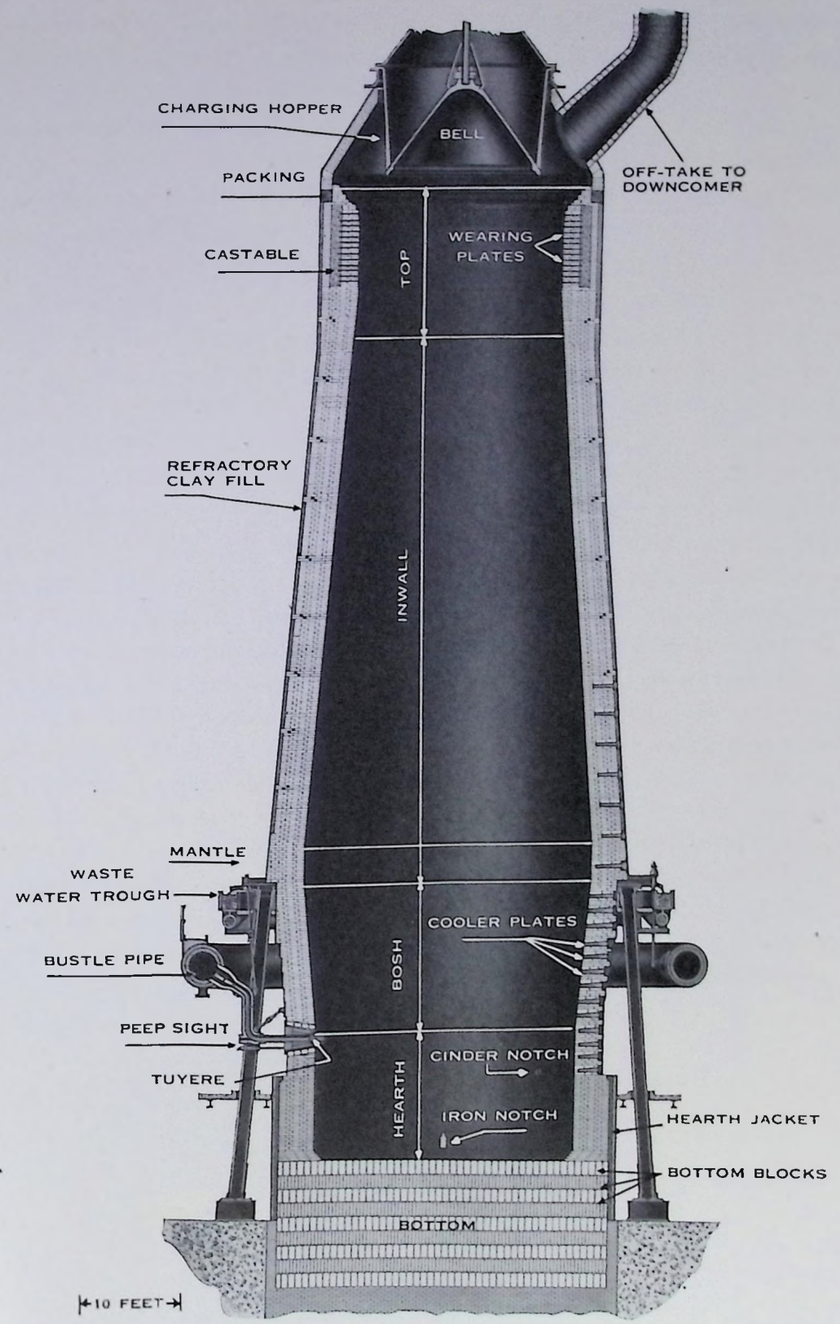
Blast furnace brick of hard burn are more resistant to carbon disintegration than are those of lighter burn, since the higher temperature of firing causes the small amount of iron oxide in the brick to combine chemically with the alumina and silica of the clay. The iron silicate formed does not promote the deposition of carbon from carbon monoxide. Burning the brick in a reducing atmosphere augments the effects of harder burning. Harbison-Walker blast furnace linings are burned under controlled reducing conditions.

For maximum resistance to disintegration by carbon deposition the brands recommended are H-W 18 and high-fired KENMORE or VARNON. In laboratory tests, these brick show no disintegration when exposed to an atmosphere of carbon monoxide within the critical temperature range. The high temperature of firing also has a desirable effect upon other physical properties. The high-fired blast furnace brick of the conventional high duty fireclay type in general are more resistant to penetration by gases and slags than are those of the super-duty type.

Alkalies in small amounts enter the furnace with the burden and are volatilized in the combustion zone. They then ascend with the furnace gases to the upper part of the stack where they condense in large part upon the descending stock, and are again carried down to the combustion zone. The amount of alkalies in the furnace gases thus gradually builds up. Any gas which penetrates the brickwork carries with it volatilized alkalies, which at moderate or high temperatures exert a strong fluxing action, and at lower temperatures condense in the pores of the brick. Under some conditions alkali pick-up can cause the refractories to lose strength because of crystalline changes. While absorption of volatile alkalies cannot be prevented, it can be reduced to a minimum by the use of refractories having low permeability to gases.

The materials of the charge may contain small quantities of zinc compounds. These compounds in the lower part of the furnace are reduced to metallic zinc, which is volatilized. Zinc fumes and vapor in the furnace gases may penetrate the brick, condense and oxidize. Expansion of the particles as a result of oxidation will develop stresses which may weaken the bond of the brick, increase the permeability and thus add to the disintegrating effect of carbon monoxide gas.

Top: Brick for the top section should be tough and strong, to resist abrasion by the descending charge; and they must be resistant to carbon disintegration. The brick are not required to withstand especially high temperatures; however, they must possess properties which are developed only by temperatures of firing so high that only highly refractory brick will withstand them. Low permeability to gases is an important property of brick for the top section. The use of an air-setting high temperature bonding mortar such as HARWACO



Typical Modern Blast Furnace

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BOND or THERMOLITH for laying the brick will further decrease the penetration by gases, increase the resistance to abrasion, and keep the brick in the lining from working loose.

Inwall: Temperatures in the inwall zone are higher than in the top. The refractory lining should have high resistance to abrasion and to carbon disintegration, which, if it occurs, will take place somewhat nearer the shell than in the top section. The brick in the inwall are generally laid with mortar made of refractory plastic fire clay, such as H-W BOND CLAY B.

Bosh: In the bosh section, the lining is exposed to a slag which at high temperatures is one of the most corrosive of all industrial slags. The brick must be highly refractory, and of low permeability and porosity.

Hearth: In building the hearth wall and bottom, bricklaying should be as nearly perfect as possible. The thin tight joints necessary are obtainable only with brick of superior workmanship and uniformity in size. It is important that the wall be of ample thickness and that it be adequately cooled.

Brick in the hearth must be strong and dense, and have stability of volume at high temperatures. Harbison-Walker BOTTOM BLOCKS have given splendid service for many years. Harbison-Walker developments now in progress hold promise of noteworthy improvements in alumina-silica refractories for the construction of blast furnace linings.

General: For lining hot blast mains, bustle-pipes, off-takes and downcomers, the brick and mortar used must be capable of resisting the abrasive action of dust-laden gases moving at high velocity. Harbison-Walker PIPE BRICK are made especially for this service.

The shapes most generally used in blast furnace linings are standard 9″ x 6″ x 3″ straights and keys, 13½″ x 6″ x 3″ straights and keys, and standard bottom blocks, 18″ x 9″ x 4½″. Special shapes are used in the bosh, at tuyere coolers, and at the stock plates.

Harbison-Walker BOND CLAY B is extensively used for laying the brick in the furnace lining. It has excellent workability; upon being heated to moderate temperatures it acquires a dense texture which is retained over a wide range of higher temperatures; and it is more than adequate in refractoriness. The air-setting high temperature cements, HARWACO BOND and THERMOLITH are advantageously employed in many plants for laying brick in the linings of blast furnaces and hot blast mains and in the piping. The high refractoriness of KORUNDAL BONDING MORTAR recommends its use for laying the brick in the hearth walls and bottom.

BLAST FURNACE STOVE LININGS

REFRACTORIES for blast furnace stoves must possess a definite combination of properties. The essential qualities of stove brick are capacity to absorb heat readily from the hot gases, ability to give off this heat rapidly to the air blown through the stove, mechanical strength both cold and at high temperatures, and high resistance to vitrification, to deformation, to the harmful influences of reducing gases, to fumes and dust high in alkalies and to the spalling effects of rapid temperature change.

Stove brick are not subjected to temperatures as high as those which prevail in the melting zone of the blast furnace. However, the weight which they must sustain in service and the long periods of time during which they are subjected to relatively high temperatures result in gradual deterioration due to vitrification; consequently, brick having an adequate margin of refractoriness should be used.

Sections where severe conditions prevail include the combustion chamber and dome, where spalling may occur, and the uppermost section of the checker setting, where volatile alkalies are present at high temperatures. Not only must the refractories have suitable chemical and physical properties to meet these exacting conditions, but they must meet close tolerances as to size. This is especially true of checker brick of the several patented types which are designed for close interfitting to contribute to the stability of the masonry construction.

The evolution of the huge modern blast furnace has necessitated a parallel development in the construction of stoves. A greatly increased volume of blast, properly heated, must be supplied to permit such a furnace to function properly. The heating surfaces of the stoves are often rated on a basis of 500 square feet of surface per ton of iron produced per day. On this basis, a 1000-ton furnace would require 500,000 square feet of heating surface, and a 1500-ton furnace 750,000 square feet. Recently, there has been a trend toward the use of three stoves per furnace. With this arrangement, stoves for a 1000-ton furnace would have 167,000 square feet of heating surface each; those for a 1500-ton furnace would have 250,000 square feet each.

During recent years, the heating surface of individual stoves has in general been greatly increased, although there are still some stoves which have only 40,000 to 60,000 square feet of heating surface. In some cases the greatly increased heating surface has been attained by the adoption of thinner checkers, and in others by the utilization of special shapes, which are often of intricate design. Through many years of experience, Harbison-Walker has perfected methods of processing by which excellent workmanship is obtained in the manufacture of checker shapes of every type.

In blast furnace stoves of modern design and high efficiency, operating temperatures are usually high. In the zone of highest temperature, volatile alkalies and the dusts carried by the gases impose severe fluxing conditions upon the refractories. Moreover, the volatile alkalies tend to be absorbed by the refractories, with formation of the mineral nephelite, and with resultant increase in volume in the portion of the brick affected.

H-W STOVE brick are dense and strong, and possess the proper combination of properties for domes, combustion chambers, and checkers. In many cases it has proved an economy to use power pressed super-duty fireclay brick, especially in flash walls of the combustion chambers, in upper courses of the checkers, and in domes.

The records made by Harbison-Walker stove linings — some of which have been in continuous service for twenty years or more — demonstrate how successfully the company's products meet the requirements.

Harbison-Walker insulating materials are recommended for use in stoves between the refractory ring wall lining and the steel shell, and are of special value in the combustion chamber section.

Paralleling the advances made in the manufacture of brick, there has been a corresponding development in the production of superior high-temperature bonding mortars. H-W FINE-GROUND FIRE CLAY, H-W BOND CLAY B, and the high temperature bonding mortars HARWACO BOND and THERMOLITH are recommended for use in laying brick in domes, ring walls, flash walls, arches and connections.

Modern Refractory Practice: 3rd Edition (1950)
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BOILER SETTINGS

The functions of refractories in boiler furnaces are various. They serve to confine and to radiate heat, to promote combustion, to help maintain combustion gases at proper temperatures, to create turbulence and to direct hot gases into desired paths. Refractories are used for the construction of walls, bottoms, arches, target walls, baffles, burner ports and stacks.

The service conditions to which the refractories are exposed depend upon the size, design and type of setting, the kind of fuel used, the method of firing and the uniformity of operation. Among the factors which affect the life of the refractories are the amount and character of the fuel ash, the rate of heat release, the furnace temperature and atmosphere, and the rapidity of temperature changes. Other factors include the position of the burners with reference to the walls, the length of the flame, the degree of insulation, and the amount of mechanical abuse.

Harbison-Walker refractory materials are used in boiler settings of all types, from those in the largest central power stations to those in manufacturing and commercial plants of every kind and size as well as in the boilers of locomotives, and in marine-type boilers. They are used in the heating plants of many thousands of buildings, ranging in size from large hotels, apartment houses, department stores and hospitals to small dwellings.

High duty fireclay brands which are recognized standards for use in boiler settings are Woodland and Woodland X made in Pennsylvania, Franklin Crown in Ohio, H-W High Grade XX in Kentucky, Walsh XX and Walsh S in Missouri, Coleman XX in Texas and H-W Crown in Alabama.

In ash hoppers and in various ash removal equipment, service conditions may frequently require a very hard, abrasion-resistant brick having also appreciable resistance to spalling. For these applications, good results are secured from the use of H & B Woodland, H-W H & B, Walsh T, and other Harbison-Walker brands of dense high duty fireclay brick. H-W Standard Castable also fulfills the requirements and is advantageously used.

For every type of burner used for firing gaseous, liquid or powdered fuels in boiler furnaces, Harbison-Walker supplies brick shapes in the various classes of alumina-silica refractories, as well as plastic fire brick and castables.

H-W Standard Castable, H-W Super Castable, and H-W Light-Weight Castables are employed for the construction of baffles, burner blocks, insulated sections, and other furnace parts exposed to conditions of only moderate severity. H-W Plastic Fire Brick and H-W Super-Plastic Fire Brick may be used for maintaining boiler side walls and other portions of the settings during operation.

H-W Mortar Mixtures, which contain a substantial proportion of calcined clay, and therefore have a minimum of shrinkage in service, are used for laying boiler brick where thick joints are needed. H-W High Duty Fire Clays are used satisfactorily for laying brick where hot-setting mortars are desired. The advantages attending the use of high quality high temperature cements for boiler brickwork are becoming increasingly evident. Harwaco Bond, Thermolith, and Firebond are used with splendid results in this application.

Harbison-Walker manufactures and stocks special boiler furnace shapes, including many for suspended arches and walls, as well as tube-backing, tube-protecting and baffle tile.

BOILERS WITH WATER-WALLS

In the modern boiler furnace provided with water-walls, refractories are used for backing the water tubes, in baffles and seals, and in walls beyond the furnace proper. In constructions where the tubes are set close together, either burned fireclay tile or monolithic refractory material may be used back of the tubes. The monolithic refractory may consist of Thermolith Batch, of H-W Standard Castable, or of H-W 56 Light-Weight Castable.

Various refractory mixes are recommended for application by means of an air gun.

In the type of construction where there is a space between the tubes, the walls are built of close-fitting refractory tile, with a backing of insulating fire brick. The tile are made of high duty or super-duty fireclay material, or of high-alumina material.

In heavily water-cooled units, a section of brickwork directly exposed to the furnace atmosphere is necessary to promote combustion. While the area of this section is relatively small, both the quality of the brick and their proper installation are of great importance.

The walls beyond the furnace proper are often suspended. They are built of fireclay brick or of insulating fire brick.

For slag-tap bottoms of boilers fired with pulverized coal, good results are obtained from the use of Chromex brick, or of Plastic Thermolith Batch, H-W Special Furnace Chrome, or H-W Magnamix rammed into place.

SETTINGS WITH REFRACTORY WALLS

Combustion chamber walls may rest directly upon the foundations or they may be sectionally supported. The walls are usually built of high duty fireclay brick, 9 inches or 13½ inches thick, with an outside backing of several inches of less refractory clay brick or of insulating fire brick. A boiler setting enclosed in a steel casing is usually built of fireclay brick, with a backing of light-weight castable or of insulating fire brick next to the casing.

In some plants the boiler settings are either partially or entirely of monolithic construction. Plastic fire brick serves for those portions of settings where the prevailing temperatures are high enough to develop a ceramic bond, as in walls of fire boxes and combustion chambers. The utility of castables does not depend upon the development of a ceramic bond and they may be used for service where the temperatures are even lower than 2000° Fahrenheit. Therefore, standard or super-castable may serve for the low-temperature portions of the setting, such as walls of ash pits, furnace walls beyond the combustion chamber, baffles, tube decks and rear arches.

Sectionally supported walls are built of high duty or super-duty fireclay shapes of special design, with a backing of intermediate or low duty fireclay brick, common brick, or insulating fire brick. The special refractory shapes are held in place by steel hangers which are attached to the supporting steelwork. The walls of the hotter portions of the setting are usually air cooled by means of horizontal or vertical ducts between the more refractory brick and the less refractory backing.

For linings which are exposed to the direct action of flame and fuel ash, selection of the most suitable refractory is of especial importance. High duty fireclay brick are used most extensively in this service. For conditions which are more severe than can be met ad-

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vantageously with high duty fireclay brick, super-duty fireclay brick are used. They provide increased resistance to the attack of highly corrosive fuel ash, to high operating temperatures, and to conditions which tend to cause spalling. Harbison-Walker manufactures DEAN super-duty fireclay brick in Pennsylvania, BOONE and KENMORE in Kentucky, and ALAMO and VARNON in Missouri.

In boiler settings with limited combustion space and operated at high ratings, even super-duty fireclay brick may give relatively short life. In some furnaces, ash high in iron oxide or alkalies may be present in large quantities. High-alumina brands provide an additional margin of quality beyond that of super-duty fireclay brick. Harbison-Walker manufactures DIALITE in the 50% alumina class, ANCHOR, ALCOR, and ALCOR XX in the 60% alumina class, and KORUNDAL in the 90% alumina class. These brands in the order named are increasingly resistant to severe operating conditions.

Where common center walls are used, the added severity of conditions caused by heating on both sides should be realized. Ventilation of the center walls will increase the service rendered by any type of refractory. Super-duty fireclay brick or high-alumina brick are recommended for the construction of center walls, especially when they are not ventilated, even though high duty fireclay brick may be adequate for the walls of the setting which are heated on only one side. In some cases it is good practice to ventilate the floors.

In installations where spalling limits the life of the brickwork, the feasibility of reducing the size of large and cumbersome shapes should be considered. This is especially true for super-duty fireclay shapes, which owe some of their most desirable physical properties largely to manufacture by the power press process.

Coal-Fired Furnaces: In hand-fired boiler settings the causes of wear are mainly abrasion from slice bars, especially around the firing doors and in the side walls, and spalling from cold air which enters through the firing doors. Combustion arches are sometimes needed for smokeless firing. High duty fireclay brick are generally used for these arches and either high-duty or intermediate duty brick for the walls. The walls are strengthened by laying the brick with HARWACO BOND.

Many of the settings of stoker-fired boilers are subjected to erosion and corrosion by slag, and to spalling influences. Walls and arches are generally built of high duty or super-duty fireclay brick, or of high-alumina brick of the 60% alumina class, such as ANCHOR. The ignition and combustion arches of chain grate stokers are usually suspended. In some types of stoker-fired boilers, clinker adhesion to side walls and bridge walls has been a problem of major importance, since the brickwork is damaged by removal of the adhering clinker. This difficulty is largely overcome by the use at the clinker line of KORUNDAL high-alumina brick, to which the clinker does not adhere strongly.

With pulverized coal firing, suspended air-cooled walls are common; the walls are generally built of high duty or super-duty fireclay brick. They are often subjected to conditions of severe slag attack, to abrasion and sometimes to spalling. When the temperature is boosted by auxiliary oil firing, the coal ash slag may become very fluid. For this condition, CHROMEX brick are sometimes used to advantage in the combustion chamber lining.

Gas-Fired Boilers: The most common industrial gases are natural gas, blast furnace gas, by-product coke oven gas and producer gas. These vary widely in their calorific values and flame temperatures. Natural gas is practically

free from ash-producing constituents; the others, except when cleaned by thorough washing, contain varying amounts of ash-producing dusts as well as tarry constituents.

Operating temperatures in gas-fired boilers may range from relatively moderate to extremely high. Rapid changes in operating temperatures may cause refractory linings to crack or spall. Rapidly moving gases laden with dust may cause mechanical erosion and in some cases, as with unwashed producer gas, molten ash may penetrate the linings and cause corrosion. Impinging flames may result in localized hot spots and overheating of small areas.

In general, high duty fireclay brick made by the power press method are used in building side walls, front walls and bridge walls, and intermediate duty fireclay brick are used for the cooler portions of the structure. However, for the most severe conditions brick of the super-duty class of fireclay refractories or even those of the high-alumina type may be required for the most vulnerable positions.

Oil-Fired Furnaces: For oil firing, both solid walls and suspended air-cooled walls are employed. The burners should be so arranged that flame does not impinge upon the walls. The refractories are exposed to attack by oil ash. This may be very corrosive, and promote vitrification of the brick surfaces, rendering them susceptible to spalling. The brick selected for the linings will depend upon the severity of service conditions. The company's various brands of high duty and super-duty fireclay brick and ANCHOR brand of high-alumina brick all find application in the linings of oil-fired boiler furnaces.

Wood-Fired Furnaces: For the burning of slabs, sawdust or hogged fuel, an extension type of furnace is generally used, and the fuel is fed through chutes in the furnace arch to stationary grates. The temperatures may be high enough to melt the ash into a corrosive slag, especially when the wood fuel is supplemented by oil. For the furnace linings, Harbison-Walker high duty and super-duty fireclay brick and ANCHOR high-alumina brick meet the service requirements.

Bagasse-Fired Boiler Furnaces: By burning its bagasse in boiler furnaces, the cane sugar mill not only secures practically all of the power needed to operate its machinery, but also disposes of a bulky waste product.

In bagasse-fired furnaces, grates or brick hearths are provided for combustion. However, because of the lightness of bagasse, much of it is carried along by the draft and burned while in suspension. Since the size of the bagasse particles in suspension varies greatly, complete combustion occurs in no definite zone. The largest particles are still burning and giving off CO, after the carbonaceous portions of the smallest particles have become completely gasified and burned to CO_2.

The stalk of sugar cane is rich in potash. Upon the burning of bagasse, part of the potash probably unites with water vapor to form potassium hydroxide and the remainder is concentrated in ash or dust. Carbon monoxide, water vapor, alkali hydrates and alkaline dust, present in practically all parts of the furnace, impose extremely severe conditions upon the refractory linings. In the average bagasse-fired furnace, rapid temperature changes add thermal shock to the other damaging influences which the brick must withstand.

Harbison-Walker products include fireclay brick which meet the exacting requirements for these conditions. Among those from Pennsylvania are WOODLAND or WOODLAND X; from Missouri, WALSH XX or WALSH S; from Alabama, H-W CROWN; and from Texas, COLEMAN XX.

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With the present increased firing efficiencies, all the power required by the mill during the "crop" can be produced by the burning of bagasse. However, during interruption of flow of bagasse to the furnace, and during periods when steam production is needed after cane grinding has been completed, the substitution of another fuel, such as oil or natural gas, becomes necessary. These fuels impose radically different service conditions upon the refractories, especially in the hottest areas of the setting. The super-duty fireclay brick VARNON or ALAMO from Missouri or DEAN from Pennsylvania are recommended for the linings of those portions of the furnace. Their high density, strong resistance to the effects of alkaline slags, high softening points and low spalling tendencies provide the additional margin of quality required.

HARWACO BOND and THERMOLITH, when used for laying the brick, assist materially in excluding reducing gases and sublimed basic fluxes from the joints, and in preventing erosion by ash-laden gases.

Locomotive Boilers: The refractory linings of locomotive fire boxes are subjected to operating conditions of great variability. Linings are heated quickly from cold condition to high temperatures, are subjected to fluctuating temperatures in operation, and are cooled rapidly. During peak operation, heat release per cubic foot of furnace volume is great, and temperatures are extreme. Vibration in service is continuous. The linings must be resistant to violent spalling influences, to fusion, and to the fluxing action of fuel ash. The tile must be of good workmanship to permit close fitting into place; and strong, to permit rough handling.

The millions of Harbison-Walker tile used annually in both coal and oil-burning locomotives of the various types are proof of their high reputation. For advantageous delivery to all parts of the United States, Harbison-Walker makes locomotive tile in Alabama, Kentucky, Missouri, Ohio, Pennsylvania and Texas.

Marine Boilers: The steam power plants for marine service have been developed to a high state of efficiency to meet a definite combination of requirements. The power must be developed in units which are light in weight, and which require the minimum of space. The refractory linings of the boiler settings must be capable of withstanding not only the operating conditions normal to boiler furnaces having high heat release per cubic foot of furnace volume, but also vibration and the heavy stresses and shifting of stresses caused by the rolling and pitching of the vessels. The cold face temperatures of the refractory walls must be lower than is usual in stationary boiler settings, both to conserve heat and to avoid overheating the air in the boiler rooms.

Most marine boilers are fired with oil; however, a considerable number are still fired with coal, either by hand or by means of stokers. The furnaces may have either refractory walls or water-walls. The former are more general.

For the high-temperature portions of settings with refractory walls, common practice favors the use of walls 9″ thick built with super-duty fireclay brick such as ALAMO or VARNON. The refractory brick are anchored to the steel casing, and adequately insulated by means of insulating fire brick and other insulating materials.

For the walls of the furnaces beyond the combustion chambers, it is customary to use high duty fireclay brick, backed by several inches of insulation, or insulating fire brick with a backing of block insulation. The high duty fire brick portions of the walls are generally 4½″ thick. Baffles also may be constructed of high duty fireclay brick.

Some Harbison-Walker brands widely used in marine service are ALAMO, VARNON, WALSH XX, WOODLAND, H-W CROWN and ANCHOR.

For the portions of the settings where monolithic refractories are applicable, the following materials may be used, depending upon the location in the setting and the specific service requirements:

H-W PLASTIC THERMOLITH BATCH
H-W PLASTIC FIRE BRICK
H-W SUPER-PLASTIC FIRE BRICK
H-W STANDARD CASTABLE
H-W SUPER-CASTABLE
H-W 56 LIGHT-WEIGHT CASTABLE

Heating Plants—Commercial and Small Industrial: Stokers in small commercial heating plants frequently have hearths of plastic fire brick or refractory concrete made of castable material. In larger commercial units the stokers generally are provided with fire boxes lined with high duty or super-duty fireclay brick, or with plastic fire brick. Along the clinker line of boiler settings in small industrial plants, the lining material may be high duty fireclay brick, super-duty fireclay brick, or high-alumina brick of the 50% or 60% alumina classes, depending upon the severity of the slagging action.

Insulating fire brick find considerable application as back-up material. The firebrick linings are ordinarily as thin as practicable, consequently the temperatures at the interface between refractory and insulation are relatively high. H-W 20 insulating fire brick are recommended for service as the back-up material.

In gas-fired installations, the combustion chambers are usually built of standard sizes of fireclay brick or of insulating fire brick. The brand to be selected is governed by service conditions. Insulating fire brick are easily cut, and consequently can be fitted readily into the restricted spaces of a small furnace.

Oil-fired industrial and commercial heating furnaces require refractory combustion chambers. H-W 26 and H-W 28 insulating fire brick are well adapted to this service. They have marked sound-absorbing qualities, and diminish the roar frequently caused by oil burners. Their heat capacity is low, hence a furnace built of insulating fire brick can be heated rapidly. Other lining materials used in heating plants of this type are fireclay brick, usually backed up with insulating fire brick; high-alumina brick of the 50% or 60% alumina classes for severe conditions; plastic fire brick; and precast shapes, which may be made advantageously of Harbison-Walker castables.

Heating Plants—Domestic: Domestic stokers fired with bituminous coal generally have a refractory hearth built around the stoker retort. The hearth usually consists of refractory concrete or plastic fire brick over a bed of sand. Among the advantages of these hearth materials are the convenience with which they may be installed in places of irregular shape, and the fact that they can be used to form hearths free from joints. Proper care in selection and installation is necessary to avoid cracking and to assure good workmanship.

Gas-fired conversion burners for combustion chambers in domestic heating plants are usually provided with refractory shapes of special design. These are normally fired products in either fireclay or insulating material.

Most oil burners in domestic heating plants are of the gun type. The combustion chambers are built of fireclay shapes or of insulating firebrick shapes, or of precast shapes made from refractory or insulating castable material.

H-W UNIVERSAL CIRCLE BRICK or BOOK TILE are ideally suited for construction of combustion chambers of either gas-fired or oil-fired domestic heating plants.

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CARBON PRODUCT FURNACES

The construction of multiple-pit carbon electrode baking furnaces, with their great size and intricate system of flues, demands the highest standards of workmanship and quality in the refractories used. The walls are relatively thin, yet they must resist soaking heats and heavy loads. The refractories must be mechanically strong, stable in volume, and uniform in size. High resistance to reducing gases and to volatile alkalies is essential. Reducing gases tend to cause deterioration of the brick, and volatile alkalies in the furnace gases promote vitrification and shrinkage. In brick which separate the pits from the flues, permeability to gases may be an advantage to facilitate escape of gases given off by the carbons being baked.

Through the years, H-W High Grade XX, Woodland and Walsh XX have proved most excellent refractories for the walls of the pits. The super-duty brands Alamo and Varnon are employed also for this specialized service. The high-alumina brick Alcor, Anchor and Coralite are used in limited zones where very high refractoriness is required.

In some carbon electrode baking furnaces, where the units to be processed are unusually large, Star silica brick are used in the walls, and provide greater thermal conductivity and superior load bearing properties. Their utility for such service is limited by their tendency to spall below a dull red heat.

Battery electrodes, motor brushes, and a variety of small carbon products are baked in refractory saggers. H-W calcined flint clay and kaolin, H-W Weathered Bond Clay B, and H-W D clay are processed into saggers of maximum strength. The saggers may be handled repeatedly, and survive a maximum number of burns. Harbison-Walker high duty and super-duty fireclay brick, insulating fire brick, and bulk insulation are used with excellent results in baking furnaces.

Small rectangular carbon baking furnaces used for baking special carbon products are built with an inner lining of super-duty fireclay brick, such as Alamo, with a backing of high duty fireclay brick such as Woodland.

In the linings of retort furnaces and of rotary kilns used for activating carbon, Harbison-Walker brands of high duty and super-duty fireclay brick are giving excellent service. While operating conditions are not extremely severe, high standards of workmanship are required.

Within recent years the production of carbon black by the channel method has been supplemented by manufacture of soft carbon black in furnaces of special design in which the cracking of natural gas is accomplished with a high degree of efficiency. The operating conditions, which include localized high temperatures, high pressures, and strongly reducing atmospheres, have been met by Harbison-Walker brands of high duty and super-duty fireclay brick, silica brick, high-alumina brick and insulating fire brick. The frequent necessity for brick shapes of relatively intricate design places a high premium upon excellent workmanship and uniformity in size.

Harbison-Walker high temperature bonding mortars, such as Harwaco Bond and Korundal Bonding Mortar are recommended for laying the brick in carbon recovery units.

CASTING FERROUS METALS

The service requirements of the various refractories used in the casting of metals in the steel plant and in the foundry are so specialized that every step in their manufacture must be carefully controlled. Brick for this service must be mechanically strong, and resistant to spalling and to corrosion and erosion by slags.

Ladle Linings: In the steel plant, the materials used for lining the ladles are standard sizes of brick, modified shapes, and ramming mixtures. The large ladles employed in open-hearth and electric steel plants are generally lined with a special kind of fireclay brick which has the property of expanding considerably when heated to operating temperatures. The expansion helps to make tight linings. However, a more refractory ladle brick which does not expand finds application also.

In foundry practice, mixing ladles may have either brick or monolithic linings, depending upon the size and shape of the ladles and the service conditions. The lining material employed is usually high-fired super-duty fireclay brick, high duty fireclay brick, or plastic fire brick. In most mixing ladles the refractory linings have a backing of insulating fire brick or bulk insulation. Receiving and holding ladles are generally lined with either super-duty or high duty fireclay brick, usually with a backing of insulating fire brick.

Pouring ladles and transfer ladles are of three general types: (1) lip-pour, (2) teapot, and (3) bottom-tap. The larger ladles are usually lined with refractory brick and the smaller ones with a monolithic refractory. Large lip-pour ladles are often provided with fireclay skimmer brick to hold back the slag when the metal is poured. Fireclay brick are generally used in the bottoms, even when the rest of the lining consists of monolithic material. Teapot ladles of medium size may be lined with H-W Super-Plastic Fire Brick or with a mixture of 85% to 95% H-W Silica Ganister and 5% to 15% H-W Bond Clay B by weight. The pouring spouts are built of special shapes, of either fire clay or silica material. Large bottom-tap ladles are usually lined with fireclay brick. They are equipped with stopper-rod assemblies in fireclay material, consisting of sleeves, stoppers and nozzles.

The sides of shank and hand-pour ladles may be lined with H-W Super-Plastic or H-W Standard Plastic Fire Brick or with ramming mixtures of silica ganister and fire clay. The bottoms are usually lined with special brick shapes.

For use in contact with basic slags, a mixture of 80% to 90% of H-W Grain Magnesite with 10% to 20% of H-W Bond Clay B is common practice.

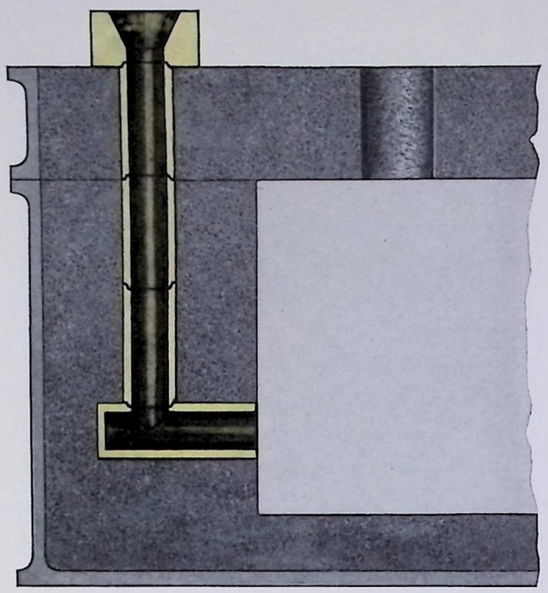
Firebond, Thermolith and Harwaco Bond high temperature bonding mortars are used advantageously for laying ladle linings.

Sleeves and Nozzles: Fireclay brick shapes having high resistance to thermal spalling and to metal erosion are used for sleeves and nozzles. They must have adequate refractoriness and the nozzles must be somewhat pyroplastic to insure tight seating of the stopper. Good workmanship is an essential requisite to insure proper fit on the stopper rod and correct size of nozzle opening.

Gate and Runner Brick: For use in steel plants where bottom-pour ingot practice is employed, Harbison-Walker supplies runner brick shapes of the various sizes and designs required. These shapes are made of high duty fireclay material, processed to meet the particular requirements.

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In foundry practice, sand inclusions are a common cause of defective castings. The use of Harbison-Walker gate and runner brick



Foundry Mold Assembly
Showing Use of Gate and Runner Shapes

greatly reduces difficulty from this cause. They are supplied in a variety of sizes for proper gating of castings of any weight. Harbison-Walker runner brick are made with plain ends or with interlocking ends, with projections at both ends or with recesses at both ends. Crosses, tees and ells are also available, together with suitable cups or funnels.

Fireclay Binders for Molding Mixes: Among the factors which directly affect foundry operating costs is the durability of the bond of the molding mixes. For economy, the amount of binder which must be added to maintain the strength of molding mixtures must be low. H-W MOLDSAND BOND and H-W WEATHERED BOND CLAY B are unexcelled in durability. This is an important advantage in the production of heavy iron and steel castings, for which the bonding strength of the mold must be maintained for relatively long periods of time at high temperatures.

Among the advantages of H-W MOLDSAND BOND and H-W WEATHERED BOND CLAY B are these: (1) high refractoriness, (2) adequate "developed hot strength", (3) low hot contraction above 1500° F., which minimizes cracking of molds and casting surface defects, (4) excellent flowability and resilience, and (5) maintenance of workability of molding mixes during storage periods.

Highly Refractory Molding Materials: The production of steel castings and of heavy castings in general taxes the refractoriness and strength of silica sand molds to their utmost. To meet these severe conditions, Harbison-Walker offers two highly refractory molding materials, CALAMO and MAGNAMOLD.

CALAMO is an alumina-silica refractory, calcined at a high temperature to provide hard and strong grains, and ground to definite sizings suitable for foundry use. The rate of thermal expansion of CALAMO is low — no higher than that of fireclay brick and much lower than that of silica sand. The thermal expansion of CALAMO, unlike that of silica, increases at a uniform rate with rise in temperature. This characteristic favors its use not only in molds and cores but also in investment molds for precision castings.

MAGNAMOLD consists largely of crystalline magnesia (periclase), ground to definite sizings. The temperature of complete melting of MAGNAMOLD is well above 3500° F. It is able to absorb large amounts of ferrous and ferric oxides with relatively little effect upon its melting temperature. When used with appropriate binders, it is an ideal molding medium for service in which the high temperatures required are beyond the working limit for silica or alumina-silica materials.

CERAMIC KILNS

CERAMIC ware is fired in kilns under widely varying conditions, involving differences in kiln design, type of fuel, kiln atmosphere, and temperature of firing. Downdraft periodic kilns and continuous tunnel kilns constitute an overwhelming majority of present-day units, with a strong trend in favor of tunnel kilns.

Periodic Kilns: For kilns used in firing sewer pipe, hollow tile, face brick, other building brick and some types of refractory brick, Harbison-Walker brands of high duty and intermediate duty fireclay brick are widely used with excellent results. Harbison-Walker super-duty fireclay brands fit into more severe applications with economy.

In the construction of kilns operated at high temperatures, ALCOR XX, ALCOR and ANCHOR high-alumina brick are used. For very high operating temperatures, H-W CORUNDUM, KORUNDAL and FORSTERITE are recommended. KORUNDAL burner blocks are standard with many companies, especially those using residual oils having a highly alkaline ash. KORUNDAL RAMMING MIXTURE is used for burner block bushings and inserts and for complete burner blocks. KORUNDAL brick have become well established for the construction of piers and muffles. For many years, the company has specialized in the manufacture of floor and riddle tile.

Tunnel Kilns: Continuous tunnel kilns are widely used for firing nearly all types of ceramic ware. Obviously, these kilns should be so constructed that even minor repairs are reduced to a minimum.

Harbison-Walker products comprise all commercial refractories for the entire construction of all designs of tunnel kilns. Included among the various high-alumina brick, super-duty, high duty and intermediate duty fireclay brick are those which are particularly adapted for use under conditions of soaking heats, as in heavily insulated crowns. COLEMAN XX, VARNON, ANCHOR and ALCOR XX are examples.

In the parts of kilns subjected to temperatures of 2100° to 3000° F., such as fire boxes and side walls and crown of the firing zone, the use of STAR and VEGA silica brick is very advantageous. These brick are of especial value in kiln sections where arches built of other refractories would tend to sag, and where walls would tend to shrink and lean. Factors which are especially important with silica brick construction are proper design, sufficient allowance for thermal expansion, and correct technique in laying.

For extremely high temperature service, the use of KORUNDAL in walls and crown of the burning zone and for burner blocks is best practice. Important savings in fuel will result from the judicious use of H-W insulating fire brick and H-W diatomaceous earth as insulation for the kiln walls and crowns.

Car tops for tunnel kiln cars are subjected to heavy loads, and to the spalling influence of rapid heating to kiln operating temperature, and cooling to atmospheric temperature. In many cases, they are exposed at times to reducing gases. Based upon experience in its tunnel kiln plants, Harbison-Walker has developed car top refractories of superior quality.

Bonding Mortars: For laying brick of the various classes, Harbison-Walker furnishes bonding mortars of corresponding quality. FIREBOND is recommended for laying fireclay brick or silica brick, HARWACO BOND for fireclay brick and high-alumina brick of the 50% and 60% alumina classes and KORUNDAL BONDING MORTAR for KORUNDAL and H-W CORUNDUM brick.

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COKE OVENS

THE manufacture of coke in the United States was begun on a small scale about 1850. The rate of production increased slowly for a few years, then more and more rapidly to meet increasing demands for coke to be used in the production of pig iron. Prior to 1893, coke was made only in beehive ovens. Since then, by-product ovens have come into general use. In 1948, almost sixty-eight million tons of coke, out of a total of approximately seventy-four million tons, were made in by-product ovens.

By-Product Ovens: The development of refractories of the character and quality best adapted for service in the various parts of the oven structure has been no small factor in the growth of the by-product coke industry. The earliest by-product ovens were constructed with fireclay brick linings; later, clay-bonded silica brick were found to give better service. Today, the oven walls and regenerator walls are built entirely of lime-bonded silica brick, while the checkers, and refractories for the charging holes, off-takes, waste heat flues and door linings consist largely of high duty fireclay brick. Intermediate duty and low duty fireclay brick are used on the pad and in the top. About 65 per cent of the brick used in the construction of a modern battery of by-product coke ovens are silica refractories.

Harbison-Walker has played a most important role in the development of coke oven refractories. The company has furnished by far the largest proportion of the entire requirements of high grade refractories used in the construction of by-product coke ovens on this continent. There are now in service in the United States and Canada approximately 16,000 by-product coke ovens. In the construction of the greater percentage of these, the refractories were of Harbison-Walker manufacture.

The company's development of power pressed silica liner brick for coke oven walls has proved of great value to the coke oven industry. The accuracy of dimensions and the high mechanical strength of these brick make possible the construction of smooth oven walls which are highly resistant to abrasive action. Their thermal conductivity is somewhat higher than that of hand-made liners of the same material.

All fireclay brick made by Harbison-Walker for service in by-product coke ovens — including those for checkers, doors, and quenching wharfs — are of the specific quality and workmanship required.

The use of H-W COKE OVEN SILICA FIRE CLAY or of FIREBOND for laying the silica brick in the ovens is strongly recommended. The latter is preferable for those parts of the construction where gas-tight joints are essential.

The economy of Harbison-Walker patching mortars for coke ovens has been established for use in hot patching and for sealing any gas leaks which may occur about the ovens.

Comfortable working conditions for the operators of coke ovens can be obtained by proper insulation. For this purpose Harbison-Walker insulating fire brick and bulk insulation are employed advantageously.

Bee-Hive Ovens: WOODLAND and HIGH GRADE XX high duty fireclay brick are recommended for construction of bottoms and side walls of bee-hive coke ovens. STAR and XX SILICA brands of silica brick are regarded as standard materials for construction of the crowns.

COPPER

THE rapid progress of metallurgical science has brought about many changes in the design and operation of furnaces used in the production of copper. Increased rates of production have been accompanied by higher operating temperatures, increased activity of chemical reactions and larger volumes of metal, slag and gases. All of these have imposed increasingly severe conditions upon the refractories of which the furnaces are built. Continuous research has enabled Harbison-Walker to supply refractories best suited for service in the various types of furnaces employed.

Reverberatory Smelting Furnaces: Reverberatory furnaces used for smelting copper ores are about 115 feet, more or less, in length and about 25 to 30 feet in width. In some cases, they may be as much as 35 feet wide in a section at the firing end. In general, the charge consists of flotation concentrates or a mixture of raw ore and concentrates, roasted or unroasted. The fuel may be natural gas, oil or powdered coal. Temperatures in the smelting zone will range from 2700° to 3000° F.; at the skimming end, about 2000° to 2300° F.

At one time, silica brick were used practically to the exclusion of all other refractories for the complete construction of copper reverberatory furnaces. Today, silica brick have been largely supplanted by basic refractories for the more vulnerable positions in the furnaces. Higher temperatures, with greater gas velocities and consequent greater dusting from the charge, are responsible for this transition from silica to basic refractories.

Sprung arch roofs are most commonly built entirely of silica brick. A roof construction which is sometimes used to great advantage consists of silica brick in the major portion of the roof with shoulders of MAGNEX, laid with steel plates, in the charge hole area. The MAGNEX brick shoulders extend inward from the skewbacks for a distance of about 54 inches on both sides of the furnace; the length of the shoulders coincides with the length of the smelting zone of the furnace.

For roofs built entirely of basic brick, suspended arch construction is used. METALKASE brick (with steel casings as an integral part of the brick) or MAGNEX brick (with the steel applied as the brick are laid) are employed for this construction. Under furnace operating conditions, the ends of the steel casings or plates near the hot face of the brick oxidize and fuse, bonding the brick firmly together. The steel casings reduce the tendency of the brick to spall, and greatly increase the life of the roofs.

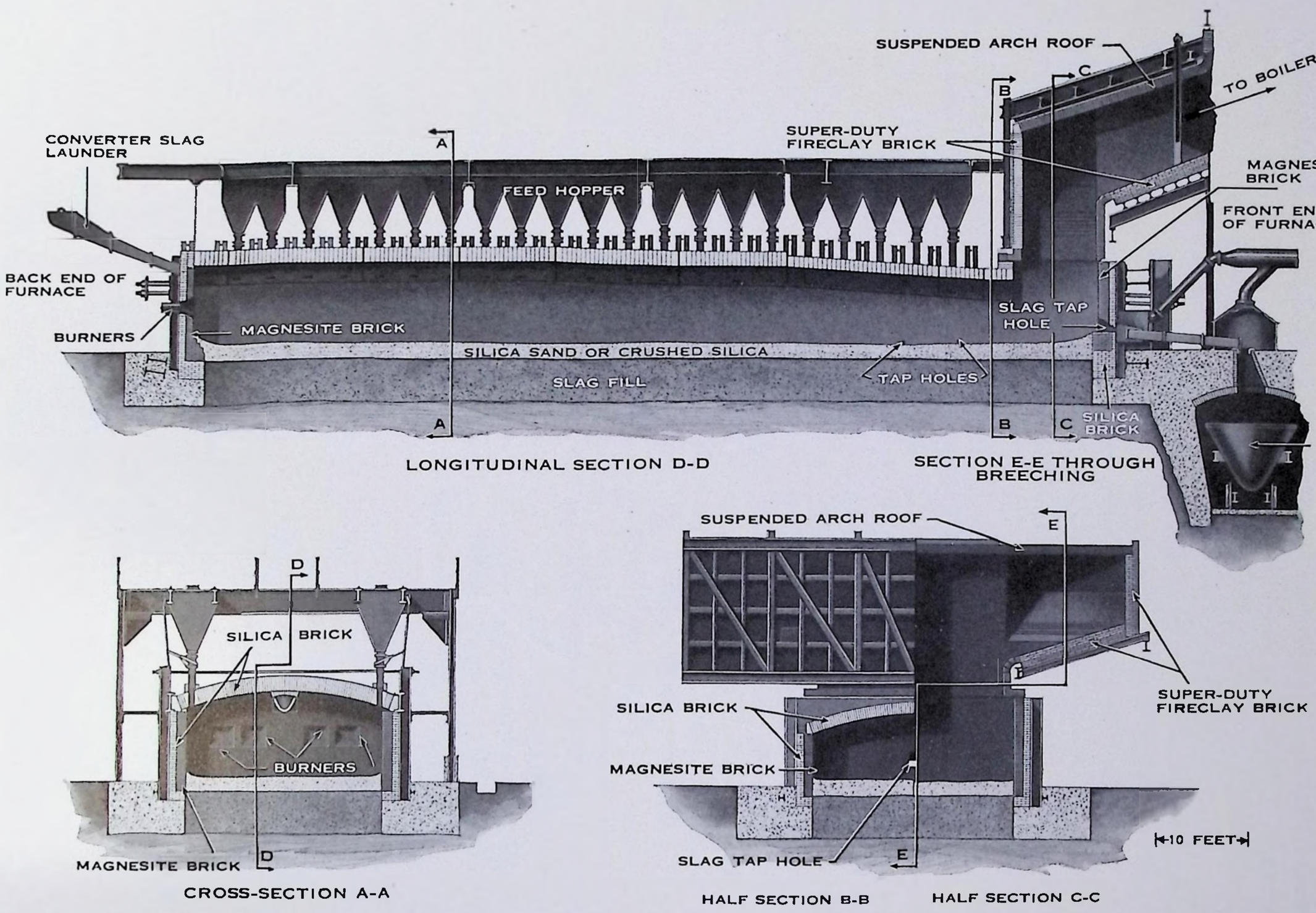
At the firing end, the upper side walls are advantageously built entirely of MAGNEX or METALKASE brick. The lower side walls are built of MAGNEX backed with silica or high duty fireclay brick, or they may be built entirely of silica brick.

Beyond the firing zone the side walls above the slag line may be advantageously built of MAGNEX, backed with silica brick. When service conditions are moderate, silica brick may be used for the entire thickness of the wall. At and below the slag line, H-W MAGNESITE or MAGNEX give best service.

As shown by the drawing on page 186, the bottom generally consists of several feet of crushed silica rock sintered into place over a slag fill. However, basic refractory bottoms of grain magnesite or of crushed chrome ore are used also.

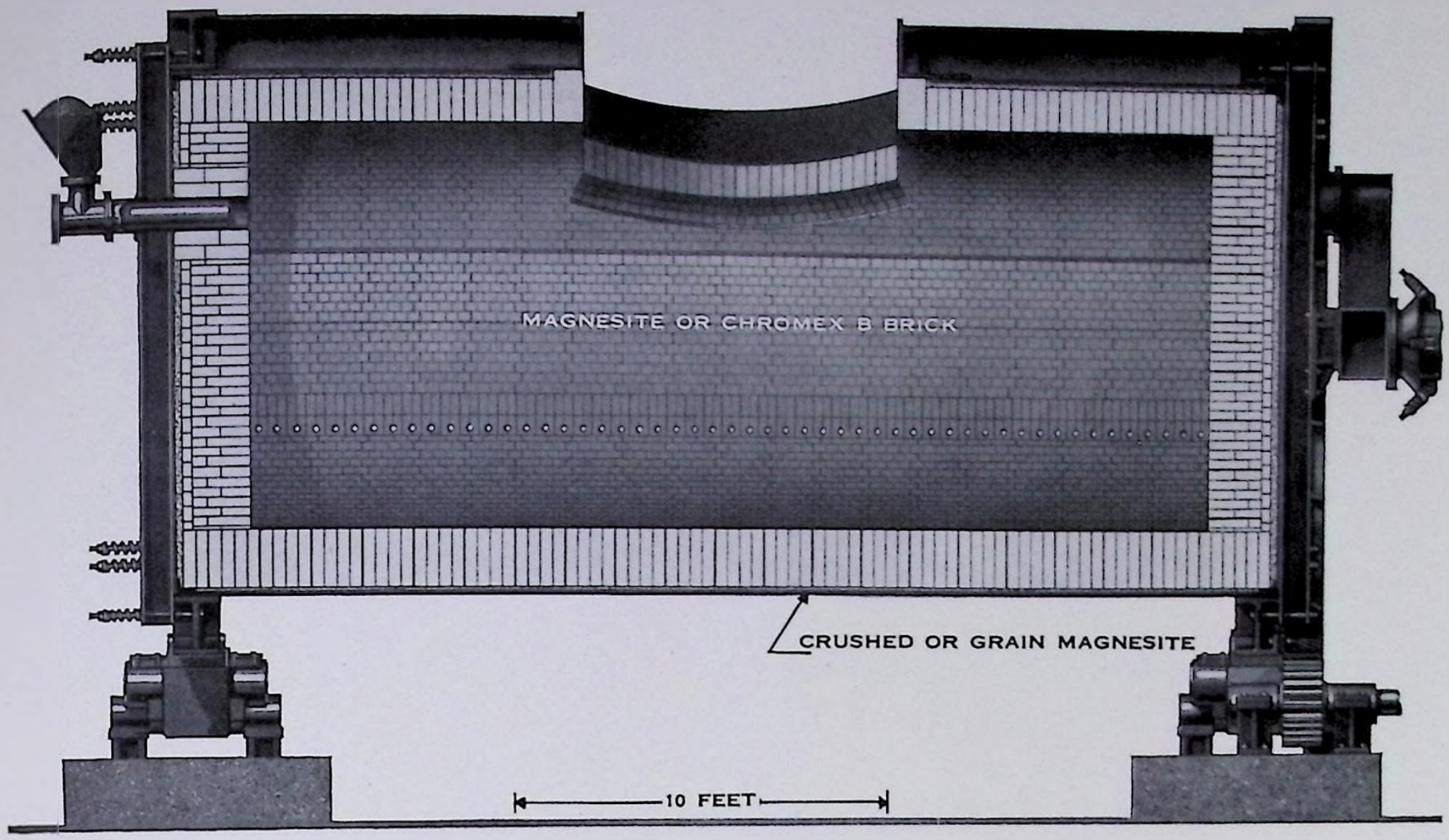
STAR or VEGA silica brick are recommended for positions in the furnace where the use of silica refractories is practicable or economical.

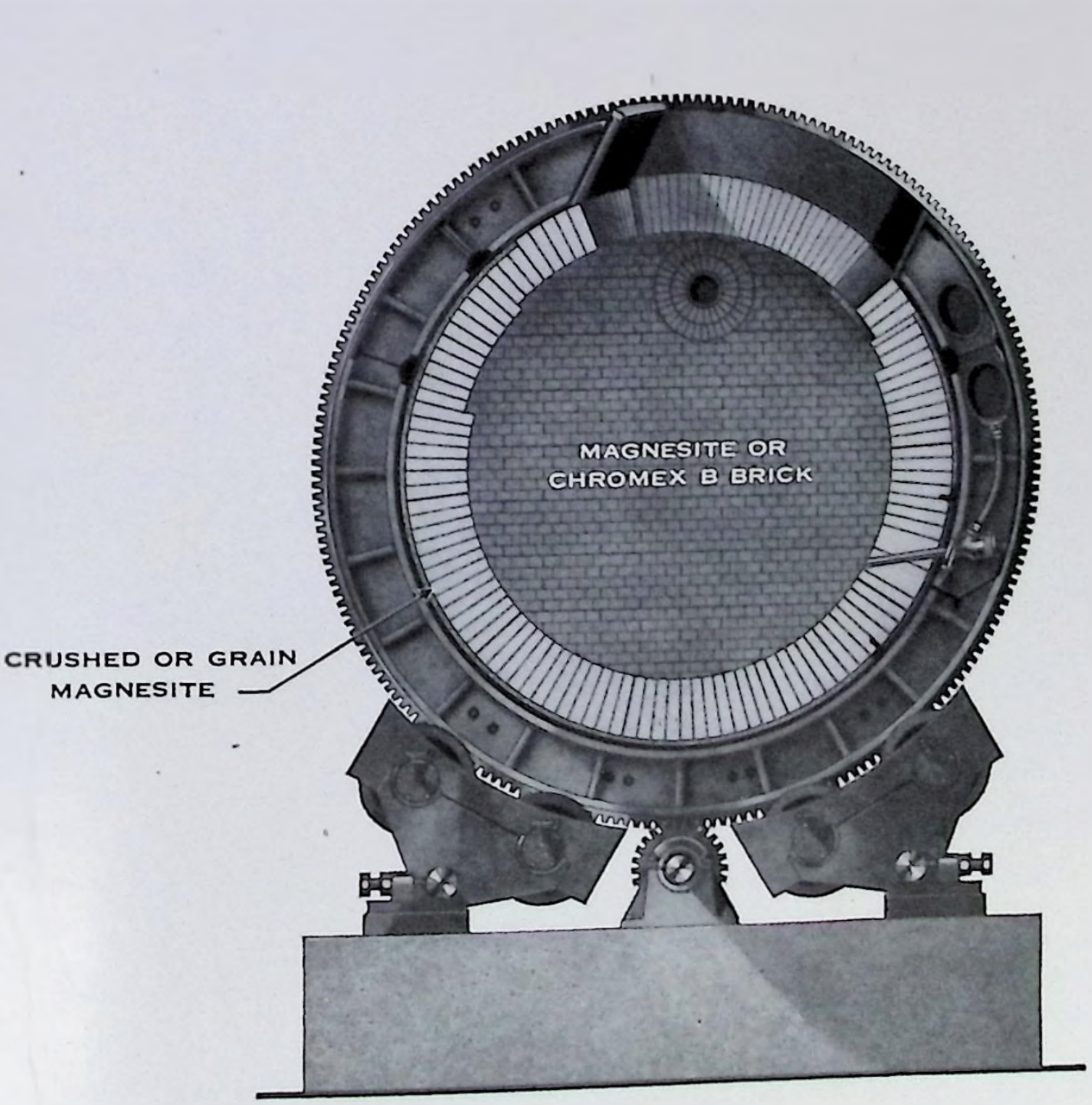
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Typical Reverberatory Copper Smelting Furnace

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Typical Copper Converter

The choice between the two will depend upon the severity of operating conditions.

Converters: Copper converters are lined with basic brick. The tuyere section is exposed to the most severe wear, and the lining in this section and in the bottom is usually 18 inches thick. A lesser thickness is adequate for the remainder of the lining. Frequently grain magnesite to a thickness of 1 to 2 inches is used between the shell and the lining to level up over the rivets and to form a cushion to supplement expansion joints provided at intervals between the brick. Some operators now advocate laying the brick directly against a welded shell; when this is done, expansion allowance is provided at intervals between the brick, and by mechanical adjustments at the ends.

With the development of the basic converter, H-W MAGNESITE brick very promptly established their place as the standard of high quality and economy for the lining. These brick continue as the product of preference at many copper smelters. At some smelters CHROMEX B, a hard-burned chrome-magnesite brick, is used to very good advantage.

Holding and Anode Furnaces in the Smelter: For holding furnaces in which the molten blister copper from the converters is kept hot for casting into slabs or cakes, H-W MAGNESITE or MAGNEX brick are used for the lining. The roof may be of H-W MAGNESITE, MAGNEX, high duty fireclay brick, super-duty fireclay brick, or silica brick, depending upon service conditions and upon the design of the furnaces.

If blister copper is to be cast into anodes, it is refined further in tilting or stationary furnaces, which are advantageously lined with H-W MAGNESITE, MAGNEX or CHROMEX brick. VEGA or STAR silica brick are used in the roofs of the stationary furnaces.

Furnaces in the Copper Refinery: After smelting, copper is refined further by electrolytic or by fire processes; the electrolytic process is most widely employed.

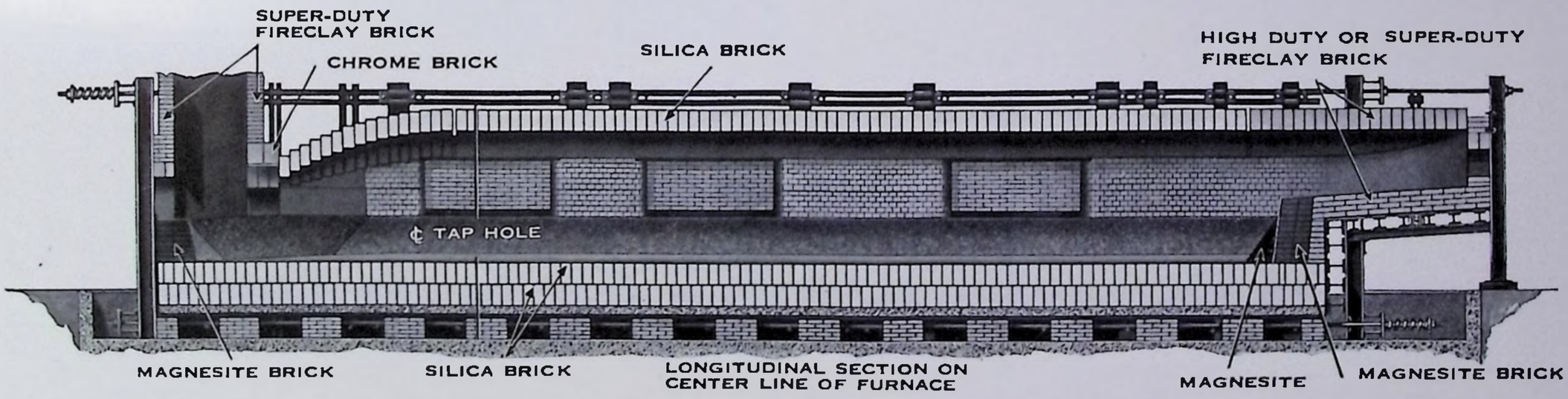
Copper anode remelting and wirebar furnaces are reverberatories usually 25 to 40 feet in length, and 16 to 18 feet wide. The details of the linings vary somewhat from plant to plant, depending upon the practice, the location of the plant, and the relative costs of the various refractories. The invert arch bottoms generally are built of two courses of silica brick; in some cases the working bottom is constructed of H-W MAGNESITE brick. The latter are recommended for use in the lower side walls, up to and slightly above the slag line. The upper walls, at the poling end, may be built of H-W MAGNESITE, MAGNEX or CHROMEX basic brick. In the firing or melting end, these walls may be built of MAGNEX or CHROMEX basic brick, VEGA or STAR silica brick, or super-duty fireclay brick, depending upon the particular operating conditions.

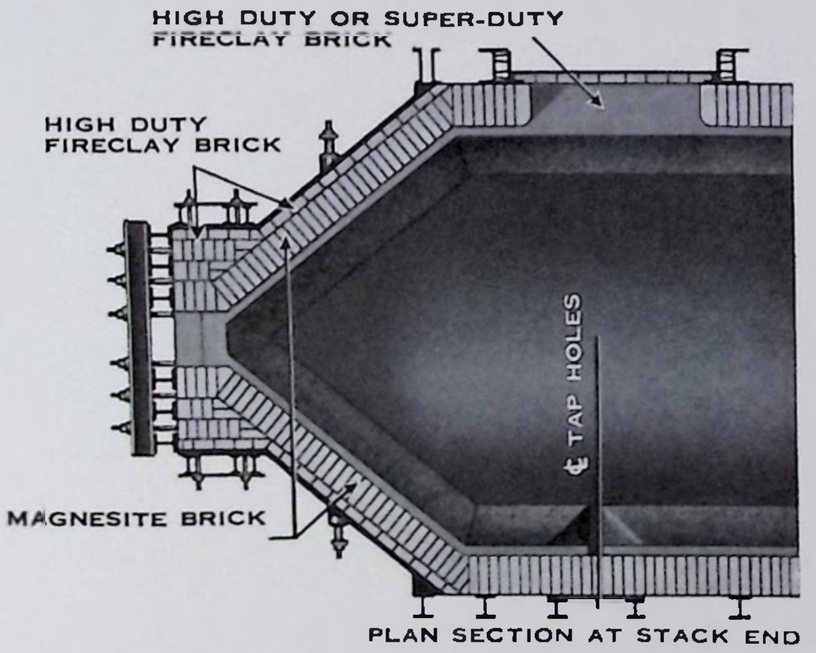
VEGA or STAR silica brick are used for the roofs of refinery furnaces operating on primary metal. VEGA super-duty silica brick may be employed for the construction of the entire roof or confined to the positions of greatest wear, such as domes or hoods. Verb arches may be constructed of VARNON super-duty fireclay brick, of silica brick, and in some practices, of CHROMEX basic brick.

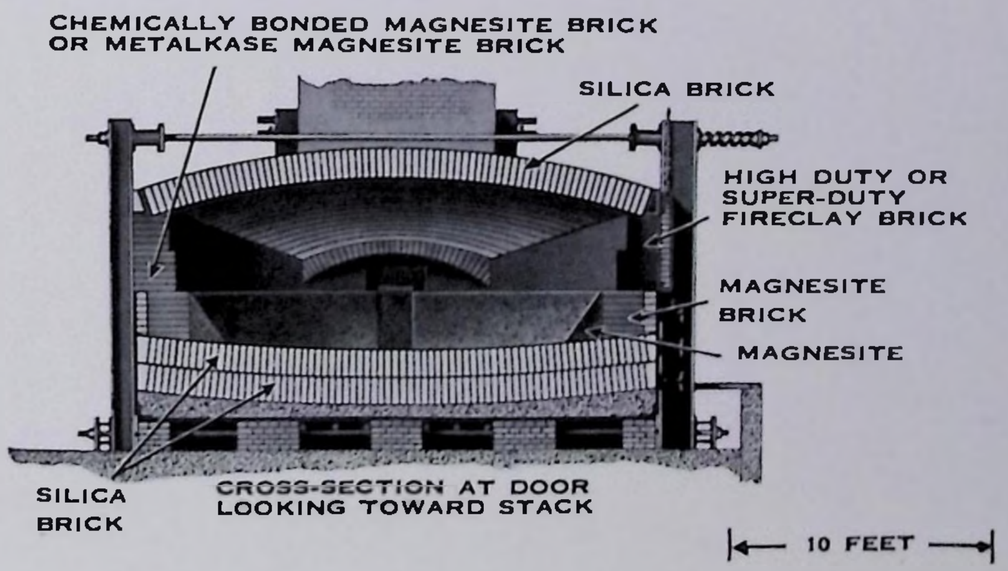
For secondary metal melting furnaces, the refractories used in general are the same as those employed for the construction of anode remelting and wirebar furnaces.

Electric arc furnaces are being adopted to an increasing extent for the production of copper of an unusually high degree of purity. Basic refractories are used for construction of the entire lining, including the roof. Hard burned magnesite brick comprise the bottom, upon

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Typical Copper Anode Furnace

which may be superimposed a monolithic working hearth of grain magnesite. MAGNEX for the side walls and roofs fulfills the requirements very satisfactorily.

Auxiliary Furnace Parts: For off-takes and connecting flues of copper smelting and refining furnaces, the type of refractory having the most economical balance between first cost and service will depend upon the conditions that prevail. For example, if the refractories are exposed to high temperature, and to gases moving at high velocity with entrained basic dust, the brick which should be considered are MAGNEX, CHROMEX, CHROMEX B, FORSTERITE, and METALKASE. For service of less severity, the refractories which will give most economical service may be brick of the 60% alumina class, super-duty fireclay brick, high duty fireclay brick or silica brick, depending upon the particular furnace conditions.

Roasters: Copper sulphide ore concentrates are roasted prior to being charged into the reverberatory matte furnace. Details concerning refractories for multiple hearth furnaces used as roasters will be found on pages 232 to 234.

Waste Heat Boilers: The increasing output of reverberatory matte smelting furnaces, together with the modern practice of locating waste heat boilers close to the furnaces, results in higher boiler furnace temperatures, and greatly increased rates of evaporation. To meet these conditions, there has been a trend toward wider use of super-duty fireclay brick for the settings. Harbison-Walker brands of high duty and super-duty fireclay brick meet the requirements satisfactorily. Boiler furnace refractories are discussed further on pages 174 to 179.

Acid Resisting Structures: For flues and stacks exposed to acid vapors, acid-proof brick should be used. These brick fill the need also for lining acid tanks and for copper electrolytic tank insulators. DURO or W-ACID brands of acid-proof brick are recommended.

Insulation: The economies resulting from insulation have been demonstrated in many non-ferrous metallurgical furnaces, especially in plants where the cost of fuel is high. The practicability of insulation in any particular case, will depend upon the combination of conditions that prevail. Harbison-Walker insulating fire brick and bulk insulation meet a wide range of service requirements. They are described on pages 131 to 136.

Mortar Materials: For each type of refractory brick there is a corresponding Harbison-Walker refractory mortar material. The possible economies resulting from the use of high temperature cements and special mortar materials merit careful consideration.

HARWACO BOND is used for laying fireclay and high-alumina brick. THERMOLITH has a wide range of application. It may be advantageously employed for laying all types of basic brick as well as fireclay, super-duty fireclay, high-alumina and silica brick. It is used also as a filler or tamping material around converter tuyere pipes. In cases where the design of the brick conforms to the contour of the tuyere, THERMOLITH is recommended as a seal or grout between the brick and the tuyere. FIREBOND is employed for laying silica brick and high heat duty fireclay brick.

STARBOND and VEGA BOND hot-setting silica bonding mortars are recommended for laying and grouting silica brick subjected to especially severe service conditions.

Additional data on refractory mortar materials, plastic fire brick, ramming mixtures, and castables are given on pages 111 to 124.

CUPOLAS

IN foundry practice, the cupola furnace is used mainly for melting gray iron. It is also employed in duplex processes for the initial melting of steel and malleable iron. Factors influencing the life of the refractory linings of cupolas are the nature of the charge, the method of charging, the character of the flux, the ash content of the fuel, the velocity of the blast, the duration of the heat, the temperature of tapping, and the continuity of operation.

Fireclay brick are so generally used for cupola practice that they may be regarded as standard for this service. Their adoption has come about as a result of their combination of desirable physical and chemical properties, and their relatively low cost.

The thickness of cupola linings is rarely less than 6 inches, and ranges from this up to 12 inches or more. The inner or working lining is generally built of standard 9″ x 6″ x 4″ cupola blocks. The backing between the working lining and the shell may consist of 9″ splits, 2-inch brick, or straights, set on end; or more frequently of a combination of 9″ arch brick and straights, laid to form a back-up lining 4½ inches thick. Standard 9″ circle brick also are frequently used to form a 4½-inch lining. Under some conditions of service, especially with continuous melting practice, the backing is advantageously built with 9″ x 6″ x 4″ cupola blocks.

Some of the smaller cupolas are lined with standard 9″ circle brick, or with standard 9″ arch brick in combination with 9″ straights. However, a lining composed of cupola blocks has fewer joints and is therefore preferable, since joints offer points of ready attack by slag.

H-W UNIVERSAL cupola blocks, which were developed and introduced by Harbison-Walker, have two important advantages over the standard radial cupola blocks. First, the curvature of the ends insures the maintenance of tight joints, and thus retards penetration by metal and slag. Second, only one shape (No. 602-4) is needed for lining any cupola in which the diameter inside the brickwork is 2′ 6″ or larger; consequently, use of this block eliminates the necessity for carrying a stock of many different sizes in plants having cupolas of different diameters. In the table on page 54 will be found the number of pieces required for cupolas of various diameters.

It is good practice to provide a ½-inch space filled with calcined clay of good quality between the brick lining and the metal shell. Harbison-Walker ground calcined clay is recommended for this service.

Above the charging-door level, the operating temperatures are low. For this service, Harbison-Walker power pressed fireclay brick are used to good advantage because of their excellent resistance to spalling. It is good practice to lay the fire brick in this zone with HARWACO BOND or FIREBOND to seal joints effectively and to give the masonry a strong durable bond.

Below the charging doors and above the melting zone, the lining must resist the abrasive action of the descending charge. The requirements of the usual practice will be met by strong, dense, and tough cupola blocks made by the de-aired extrusion process. However, if service conditions tend to cause spalling, power pressed or hand-made brick may be preferable. Under severe conditions, such as those prevailing in the continuous melting of charges having a high content of steel, the backing should be built of cupola blocks of the same refractoriness and high quality as that of the blocks used for the working lining.

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In the melting zone, some operators provide a boshed lining by placing an additional 9-inch split or straight brick against the shell back of the first few courses of cupola blocks above the lower tuyeres; above these courses, the lining is sloped back to the normal diameter. The purpose of this practice is to provide a slight overhang, which will keep molten metal, slag and coke away from the tuyeres.

Service conditions in the section immediately above the tuyeres, at the slag line, and in the well are severe. The brick are required to resist high temperatures, corrosion, erosion, and penetration by slag and metal. Brick made by the extrusion process are frequently preferred. The hard burned super-duty fireclay brick VARNON and KENMORE are being used to an increasing extent for the melting zone and well.

H-W MAGNESITE and PERIKLASE brick are used successfully in the linings of wells and melting zones of cupolas in which the slag is kept continuously basic by accurate control, as in the production of iron low in sulphur.

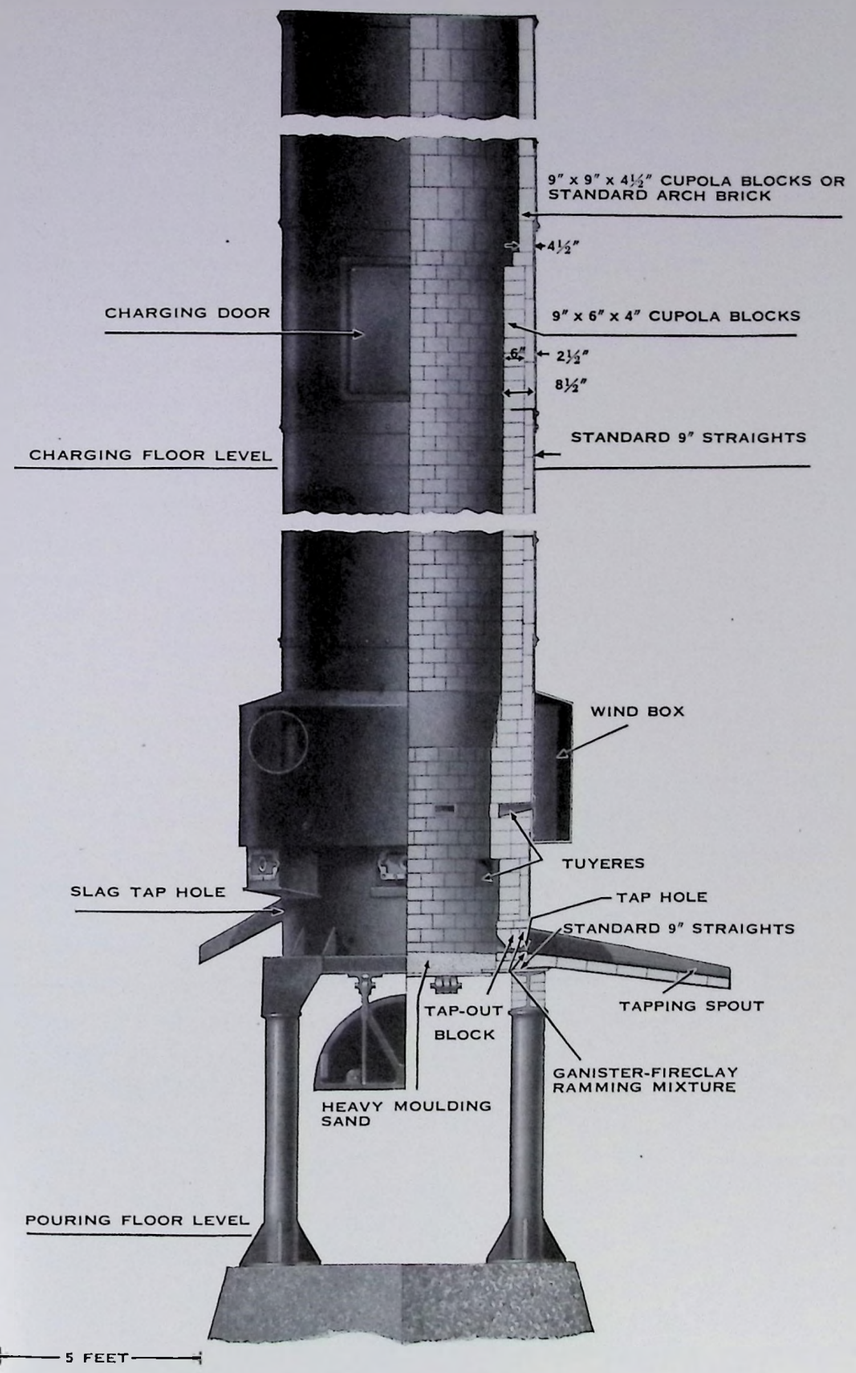
STAR silica brick are used in the linings of a relatively small number of cupolas in which continuous melting practice is followed, and in which the service conditions are especially severe. Provision for thermal expansion must be made for silica brick linings; this is all the more important because they do not soften sufficiently at the usual furnace operating temperatures to compress and thus compensate for the thermal expansion. They have low resistance to spalling below 1200° F., but are practically immune to thermal spalling above 1200° F.

Tap-out and slag-hole blocks are either of the same quality as the brick of the melting zone, or of higher quality. Wherever possible, they should be so designed that they can be manufactured by machine methods. Tap-out and slag-hole blocks are illustrated on page 54.

The air-setting bonding mortars HARWACO BOND and FIREBOND are recommended for use in laying up cupola linings. These mortars become hard and strong merely upon drying. They are not blown out of the joints by gases moving at high velocity, or scoured away by the abrasion of the descending charge. They are highly resistant to penetration by slag.

The importance of proper maintenance of refractory linings in cupolas cannot be too strongly emphasized. Care in chipping away slag and slagged areas and in the installation of patches will be amply rewarded by longer life of the linings. Slag should be chipped out of scars before patching; otherwise, softening of the remaining slag will cause the patches to loosen and be carried away, exposing the lining to further attack. Patches may be made with fireclay brick of whatever size is necessary, with a bedding of high quality plastic fire clay such as H-W FOUNDRY CLAY or H-W WEATHERED BOND CLAY B. Another method consists in ramming into the eroded depression a mixture of H-W GROUND SILICA GANISTER and H-W WEATHERED BOND CLAY B.

Metal from the cupola is tapped into a ladle or fore-hearth. The erosive action of hot metal while being poured can quickly damage the refractory linings. Alkaline fluxes added for desulphurizing have a strongly corrosive action upon the refractories. Hard burned and dense high duty fireclay brick made by the extrusion or power press processes, or super-duty fireclay brick made by the power press process, are best adapted to this service. The super-duty brands VARNON and KENMORE of an especially hard burn are used with excellent results. In some cases, H-W PLASTIC FIRE BRICK is used advantageously. For patching, H-W GROUND SILICA GANISTER bonded with H-W WEATHERED BOND CLAY B may be employed.



Section of Typical Cupola

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ELECTRIC FURNACES

MANY metals and minerals are melted, refined or otherwise processed in electric furnaces. Steel and iron are the principal products but the amounts of nickel, copper, copper alloys and other non-ferrous metals add up to significant tonnages. The production of calcium carbide, ferro-alloys, abrasives, phosphoric acid and the graphitizing of carbon have also attained important proportions.

Commercial production of electric steel in the United States began on a small scale in 1906 and since then largely supplanted the crucible process for the manufacture of tool steel and related products. The demand for accurately controlled steels of various analyses to meet modern metallurgical requirements has brought about a steady growth in the development of the electric furnace, and today there is a wide range of individual units varying in holding capacity from ¼ ton to 100 tons.

Five types of electric furnaces are now in general use. These are: (1) the three-phase direct arc furnace generally used in the melting and refining of steels, iron, copper and nickel; (2) the single-phase indirect arc furnace most frequently used in the melting of iron, copper and copper alloys; (3) the single or three-phase submerged arc furnace used in the production of ferro-alloys, abrasives, calcium carbide and phosphoric acid; (4) the resistance furnace used for graphitizing, melting of copper alloys and heat treating; (5) the induction furnace used for melting steels and non-ferrous metals and alloys.

IN THE STEEL PLANT AND IRON FOUNDRY

Three-Phase Direct Arc Furnaces: In general, electric steel for ingots is produced in basic furnaces, while steel for castings is produced in both basic and acid furnaces. The capacities of these furnaces range up to 15 tons for foundry use, and up to 90 tons for use in ingot shops. The bottoms of the basic units are made of magnesia materials, while in acid units the bottom consists of silica material.

The furnaces may be either door-charged or top-charged. The life of the refractories, especially those in the roof, door jambs, and arches, is influenced by the method of charging. This follows from the fact that the method of charging largely determines both the amount of mechanical abuse to which the lining is subjected by the charging equipment, and the extent to which the brick are subjected to thermal shock through chilling by cold air.

For both basic and acid practice, silica brick are most widely used in roof construction. The life of such roofs may vary from 30 to 750 heats, depending upon furnace operating conditions. The strength of silica brick at high temperatures is sufficient to keep the roof rigid. STAR silica brick meet the exacting conditions to which most electric furnace roofs are subjected. For operating temperatures which exceed the safe range for STAR, VEGA super-duty silica brick are recommended. The refractoriness of VEGA is the ultimate which can be secured commercially in silica brick. The roofs may be built either of special shapes or of standard sizes. The latter must be cut to fit, particularly around the electrode openings. In general, division of the roof brick into the smallest practicable sizes is desirable to enhance resistance to spalling.

In the production of alloy steels at especially high temperatures, the use of high-alumina brick such as ANCHOR, ALCOR, ALCOR XX and KORUNDAL in the roofs is frequently an economy. They may be employed for the entire roof, or merely for rib sections or the central electrode section. For construction of the roofs of furnaces operated intermittently, and in which spalling conditions are unusually severe, high duty fireclay brick or the super-duty fireclay brick ALAMO or BOONE may be preferable to silica brick.

In small furnaces not over five feet in diameter, and having a rated capacity not exceeding a ton, rammed roofs of high-alumina batches, such as KORUNDAL RAMMING MIXTURE, are being used successfully.

In the side walls of both basic and acid steel furnaces excellent results are secured from STAR silica and from VEGA super-duty silica brick. In basic furnaces the use of METALKASE brick in the upper side walls from a level just above the slag line to the roof skewbacks has become standard practice in many plants. In some furnaces, CHROMEX B and occasionally H-W MAGNESITE brick are used.

Harbison-Walker high duty fireclay brick, super-duty fireclay brick or high-alumina brick often are employed advantageously in door arches and jambs, where the temperature changes are most rapid and spalling influences severe. In basic steel furnaces, hard burned H-W MAGNESITE, H-W CHROME, or CHROMEX B brick are used in the sub-bottom and lower side walls, extending one or two courses above the door level. These refractories possess ample refractoriness and are resistant to attack by strongly basic slags.

In basic furnaces, the working bottom immediately above the hearth brick is commonly built by ramming H-W MAGNAMIX into place. This cold-setting material is made of Washington magnesite, and has a high magnesia content. Some operators prefer to form the working bottom by burning-in H-W DEAD-BURNED MAGNESITE GRAINS. H-W MAGNAMIX is employed advantageously for building and repiping tap holes and for the maintenance of banks and furnace bottoms.

Generally a few courses of high duty fireclay brick are placed beneath the sub-bottom in both basic and acid furnaces.

In acid electric steel furnaces, silica brick are used in the lower side walls and sub-bottom. The latter is covered with a rammed or sintered bottom, which may consist of a mixture of H-W GROUND SILICA GANISTER and H-W BOND CLAY B.

The service conditions in electric furnaces used for the melting of gray iron, or of iron for malleable castings, are similar to those in electric steel melting furnaces, except that the temperatures of operation are lower, and the furnaces are usually kept in more constant operation. The refractory linings generally are of the same materials as those used in acid electric steel melting furnaces.

Either FIREBOND or THERMOLITH high temperature cement may be used to advantage in electric furnaces for laying electrode rings, for coating the inner face of the roof, for grouting the roof, and for laying brick in door jambs, arches, and side walls.

Indirect Arc and Induction Furnaces: The indirect arc electric furnace has some important applications for melting high grade cast iron, and to some extent for melting alloy steel. Harbison-Walker basic and alumina-silica refractories are being successfully used for the construction of linings in furnaces of this type. For the linings of induction furnaces, Harbison-Walker furnishes brick shapes of special design as well as ramming mixtures.

Modern Refractory Practice: 3rd Edition (1950)
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IN NON-FERROUS METALLURGY

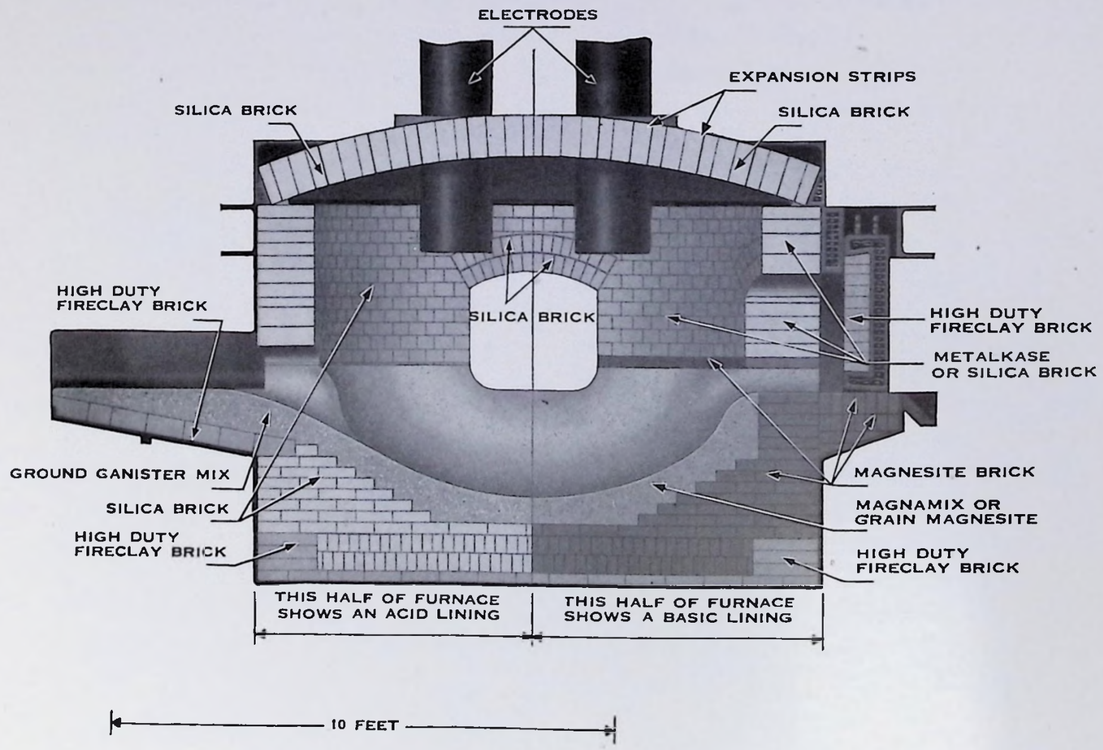
In the non-ferrous field, electric furnaces of several types are employed. They are used for a wide variety of purposes, each of which involves a relatively small production.

The refractories used in the linings differ widely. In general, the most successful refractory materials for the linings of direct arc furnaces for melting nickel and copper are hard-burned magnesite brick for the bottoms, MAGNEX or hard-burned magnesite brick for the side walls, and burned or chemically-bonded magnesite-chrome, silica, or alumina-silica brick for the roofs. The latter include high duty fireclay brick, super-duty fireclay brick, and high-alumina brick.

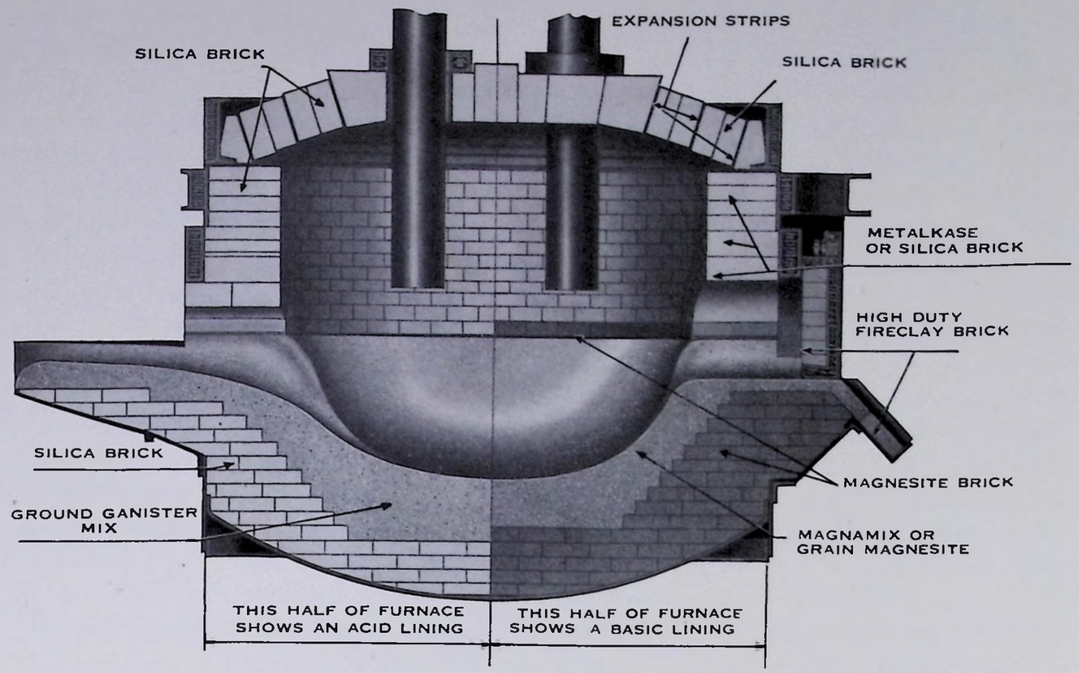
Indirect arc brass melting furnaces may be advantageously lined with Harbison-Walker high-alumina brick. ALUSITE brand is recommended for this service.

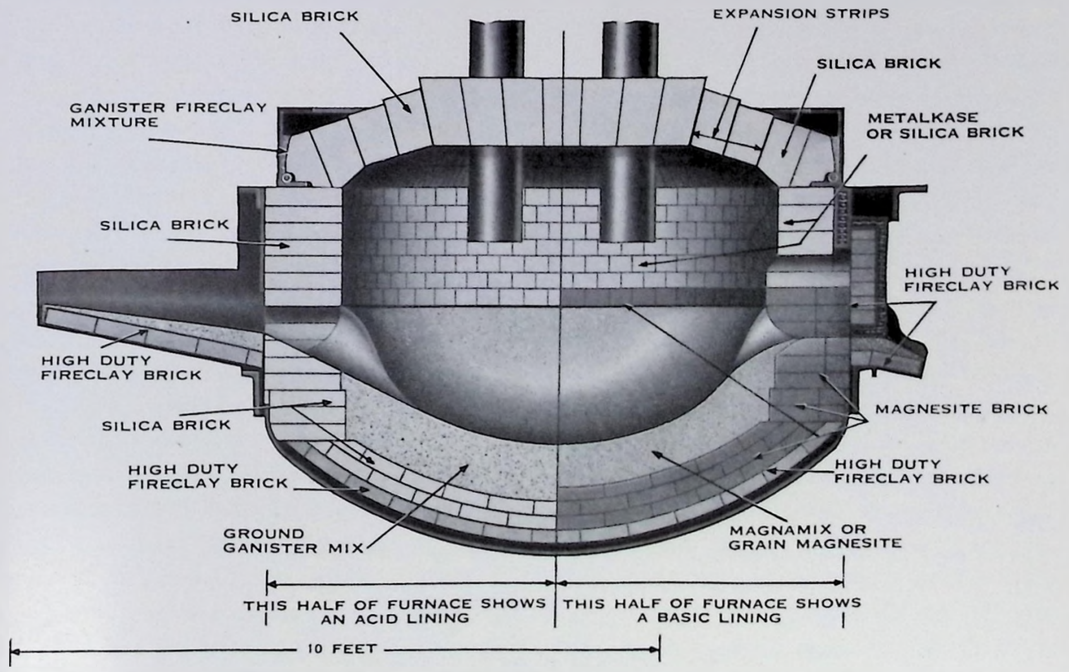
For induction furnaces used in the manufacture of many non-ferrous alloys, Harbison-Walker supplies standard monolithic lining materials such as KORUNDAL RAMMING MIXTURE and THERMOLITH BATCH, and also special refractories made of high-alumina or basic materials to fit particular needs.

Electric resistance furnaces are used for many purposes. The refractories which should be used in any specific case will depend upon the service conditions.



Typical Electric Steel Melting Furnace





Typical Electric Steel Melting Furnaces

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THE GAS PLANT

To the operators of gas plants, the proper selection of refractories is highly important, since loss of production resulting from shutdowns for relining or for repairs may be a matter of vital importance, particularly during the winter months.

Water Gas: In water gas generators, the refractory linings are subjected to the corrosive and abrasive action of ash and slag and also to mechanical damage resulting from the removal of clinker. In the carburetors and superheaters the refractories used in checkers and arches may be required to withstand the action of strongly reducing gases and water vapor, the spalling influence of rapid changes in temperature, attack by corrosive fluxes, the harmful influence of carbon deposited within the pores of the brick, mechanical stresses, and other destructive influences.

Harbison-Walker brands of fireclay brick are widely used for the linings of generators, carburetors, and superheaters; also in the domes, gas connections and mains. Under severe operating conditions the use of super-duty fireclay brick and high-alumina brick in generator linings is economical.

In the generators of water gas sets, standard practice calls for the installation of double linings of fireclay brick, usually with insulating material next to the shell. The inner portion of the double lining usually consists of standard 6-inch radial blocks; the outer portion is usually built of circle brick, with a backing of 2½ inches of insulating fire brick. The carburetors and superheaters normally have a single fireclay brick lining, with a backing preferably of insulating fire brick.

In the clinker zone of gas generators, it is general practice to use highly refractory lining materials, especially when part of the oil for enrichment is introduced into the generator. For severe conditions DIALITE, a brick of the 50% alumina class, and ALAMO and VARNON super-duty fireclay brick are used with marked success. For more moderate service conditions, WOODLAND X, TYRONE, HIGH GRADE XX, WALSH T and H-W CROWN brands of high duty fireclay brick may be employed.

Water-jacketed mechanical generators require no refractories in the clinker zone. However, refractories are required in the section directly above the jacketed area. ALAMO super-duty fireclay brick are recommended for this service.

In carburetors and superheaters, the checker brick are called upon to meet very exacting conditions. This is especially true when oils of low specific gravity used for enrichment are introduced into the carburetors. The brick must withstand both high temperatures and thermal shock. For such service, the economy of using ALAMO brand of super-duty fireclay brick has been amply demonstrated. For less severe conditions, GAS WIDEMIRE, WOODLAND and WALSH XX checkers, as well as other Harbison-Walker high duty brands of fireclay brick, give satisfactory service. In the superheaters of water gas sets in which the carburetors are not provided with checkers, ALAMO checkers are used advantageously.

Refractories in the cross-over connections must be highly resistant to abrasion. The requirements are met by Harbison-Walker brands of high duty fireclay brick developed especially for such service. For the most severe conditions which may prevail in the piping, VARNON, a super-duty fireclay brick of a special hard burn, is recommended.

Coal Gas: In coal gas benches, the gas retorts must be built of strongly bonded material, capable of withstanding the abrasive action of the moving charge. They must be sufficiently tough and dense to resist shelling off during scurfing. Retort shapes must be of exceptionally good workmanship to insure tight-fitting joints. STAR silica retort shapes represent a high standard for retort construction.

Producer Gas: A relatively clean producer gas, practically free from tarry condensates, is made from anthracite coal or coke in water jacketed producers which require no refractory lining in the generator or in the gas mains. Producer gas made from bituminous coal must leave the producer at a temperature of 1300° to 1400° F. in order to maintain the volatile portion of the coal in a gaseous state, and to prevent condensation of tar in the mains.

Gas producers for bituminous coal must be lined with refractory brick to protect the upper part of the shell from the hot gases, to resist abrasion of the fuel bed, and to facilitate the removal of clinkers from the lining in the hot zone. The gas outlet or "gooseneck" also must be lined with a refractory of adequate strength, because a hard coke builds up in this section and must be removed daily with steam lances or other means.

In gas producer linings, TYRONE, WALSH T, FRANKLIN CROWN or H-W CROWN brands of high duty fireclay brick serve well for normal operating conditions, while ALAMO has advantages where the service is severe. In the gas outlet connection, high duty brick such as WOODLAND or WALSH XX are used.

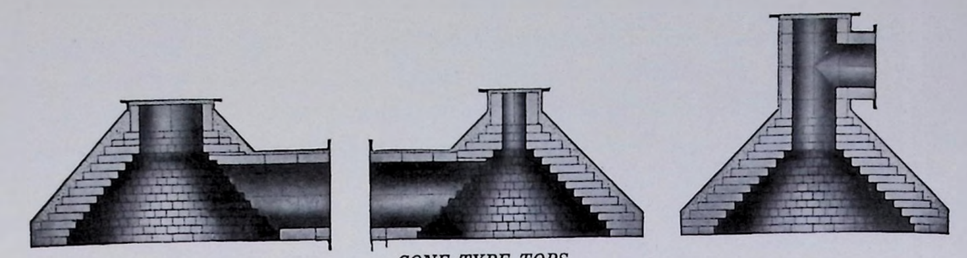
Since the gas leaving the producer contains dust and the volatile portion of the coal, the dust catcher and gas mains are advantageously constructed with sloping bottoms, to permit daily removal of the accumulated dust. They are lined with insulating fire brick to keep the temperature of the gas sufficiently high to prevent much of the condensation of the tar in the mains and burners. A 4½" lining of H-W 26 insulating fire brick, with a backing of 4½" of H-W 16 brick, provides an efficient lining with excellent insulating properties. Such a lining is resistant to the spalling action of steam lancing, and withstands the high temperatures which prevail periodically when the mains must be "burned out" to remove tar deposits.

Reforming of Natural Gas: The refractory linings of furnaces employed for the cracking of natural gas are subjected to mechanical stresses and rapid temperature changes, and are exposed to reducing gases and steam. High duty fireclay brick give excellent service in the linings, domes and flues. Super-duty fireclay brick are used to better advantage where the conditions are severe, and also for service in arches which must support heavy loads at operating temperatures.

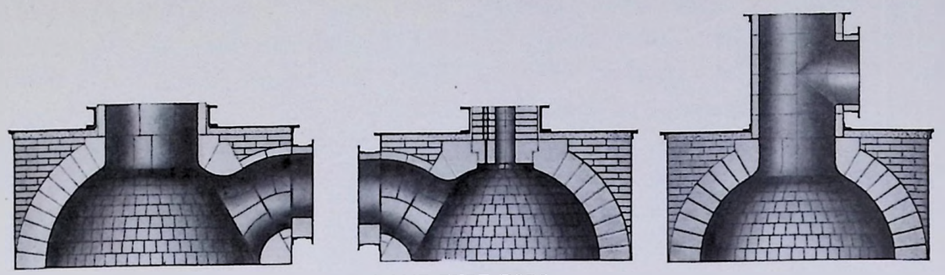
Oil Gas: High duty fireclay brick serve well for the linings of generators and checker chambers of oil gas sets, as well as for the lower courses of checkers. Super-duty fireclay brick are used for the top courses of the checkers because of their excellent resistance to thermal spalling, and their higher capacity for the storage of heat.

Bonding Mortars: The bonding mortars THERMOLITH, FIREBOND and HARWACO BOND all have applications in the gas plant. THERMOLITH is recommended for laying brick in the linings of water gas generators, especially in the domes and cross-over connections. FIREBOND is used successfully both for laying brick in gas producer linings, and for patching retorts in coal gas benches. HARWACO BOND is employed for laying high duty and super-duty fireclay brick in the linings of water gas sets and gas producers, and H-W 26 insulating fire brick in the hot blast mains.

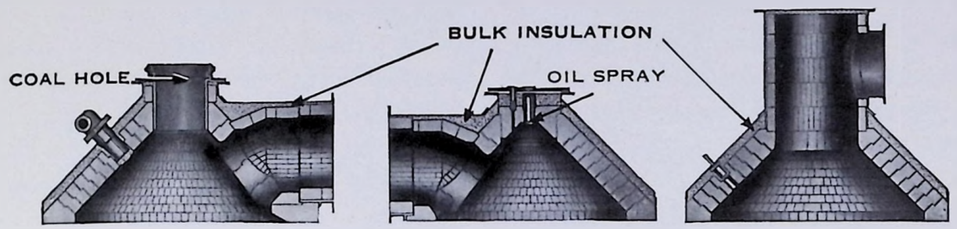
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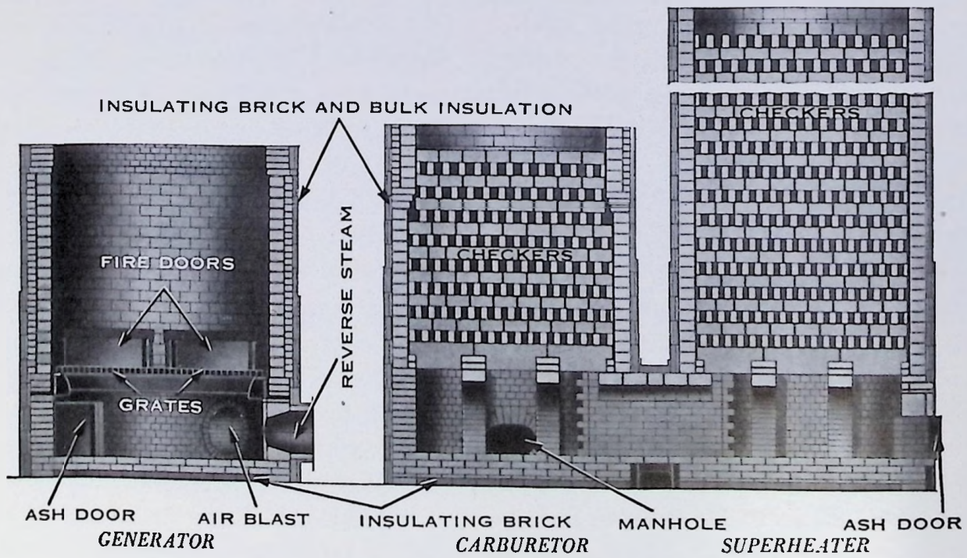
CONE TYPE TOPS



DOME TYPE TOPS



PATENTED CONE TYPE TOPS



Typical Water Gas Generator Set Showing Various Types of Tops

GLASS

CONTINUOUS glass tanks are today being operated regularly at greatly increased rates of production, and at temperatures which were considered inadvisable, or even entirely impracticable, just a few years ago. Furnaces originally designed to produce glass at the rate of one ton per day for each ten or twelve square feet of melting area have been stepped up to one ton for each six or seven square feet, or to even higher rates of production. In recently built tanks, a ton of glass per day for each five square feet of melting area is not exceptional for peak production.

Marked improvements in the quality of glass have been made, and new types of glass having more desirable properties for specific uses are being produced commercially. Developments in the design of glass melting furnaces and radical changes in construction have played their parts in these accomplishments.

The best selection of refractories for a glass tank is one which gives a completely balanced life for all parts of the furnace. This requires special attention to vital spots, where failure might necessitate a shut-down for repairs long before a general rebuild of the entire tank becomes necessary.

Not many years ago, silica and high duty fireclay brick were the standard refractories for the superstructure and regenerators of glass tanks. Under the more severe operating conditions which now prevail, the chemical activity of the alkaline dusts and fumes is frequently so intensified in certain parts of the furnace that silica brick or high duty fireclay brick would be corroded rapidly. Consequently, adoption of the more resistant super-duty fire clay, high-alumina, and forsterite refractories for the construction of ports, downtakes, and checkerwork, has come about step by step with the trend toward higher operating temperatures.

The severity of the conditions which the refractories must resist in different parts of the furnace depends largely upon the temperatures, and upon the amount and kind of alkaline dusts and fumes in the furnace gases. Lime, soda, and other materials used in the manufacture of glass react chemically at high temperatures with various refractory materials. Volatile alkalies are especially corrosive, since they penetrate readily into the pores of the brick. Borax, used in the manufacture of certain glasses, reacts vigorously with fireclay refractories, and sodium sulphate is extremely active as a flux in reducing atmospheres.

Furnace design, composition of the glass batch, and operating conditions vary so widely from plant to plant that no entirely definite rules can be laid down for the selection of refractories. In each case, selection from the wide range of types now available must be based upon the specific conditions which prevail in the different parts of the furnaces.

Cap Construction: For the construction of the caps, silica brick continue to be almost universally the standard. Improvements in the manufacture of STAR silica brick, and the development of VEGA super-duty silica brick, have increased the practical possibilities of high-temperature, high-output production. In general, the power pressed silica brick now widely used for furnace caps have a lower porosity than the brick available in the past. Even a small decrease in porosity is sufficient to effect an appreciable decrease in the amount of alkalies absorbed by the brick. The smoothness of the brick surfaces, their freedom from warpage, and the accuracy of brick dimensions con-

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tribute to a uniformly tight fit. It has been proved desirable to lay the cap brick with full but thin buttered joints and to grout them with a special high-silica bonding mortar such as STARBOND or VEGA BOND. Tight impermeable joints contribute greatly to best service.

The usual thickness for silica brick caps is 12 inches. However, caps 13½ inches, 15 inches, or even 18 inches thick are now in service. The thickness of the brick is generally 3 inches; a width of 6 inches is preferable to 9 inches. For some of the smaller tanks making special glasses, high-alumina brick caps are sometimes used.

Insulation of the refining end of the caps of glass tanks is becoming common practice; insulation of the melting end is less common. At the high temperatures prevailing, the insulating material which serves best is a lightweight silica brick, H-W 444, which has an insulating value at least three times that of silica brick of the usual density. It can be used safely at temperatures up to 2900° F. Since its chemical composition is similar to that of silica brick, there is no fluxing between silica brick and insulation at the interface. In the operation of glass tanks, especially those having insulated caps, the flame should not be permitted to impinge upon the roof.

Walls and Ports: At moderate operating temperatures, fireclay brick or silica brick give entirely satisfactory service in walls and ports. However, at the high temperatures now prevailing in many furnaces of both side and end port designs, materials of higher refractoriness are required. The most severe conditions occur in floors, walls, jambs, and necks of the ports, and in breast walls, burner blocks, tongue arches, and division walls.

The first step beyond the conventional refractories of a few years ago is fireclay brick of the super-duty class. Two types are available: one of standard burn, and one of a special high-temperature burn. In some cases these brick have replaced silica brick in port side walls and necks, and also in port arches.

Above super-duty fireclay brick in refractoriness are high-alumina brick of the 50% and 60% alumina classes (DIALITE and ANCHOR), manufactured from diaspore clay. The 60% alumina brick (ALCOR and ALCOR XX) containing fused alumina (artificial corundum) have proved even more serviceable.

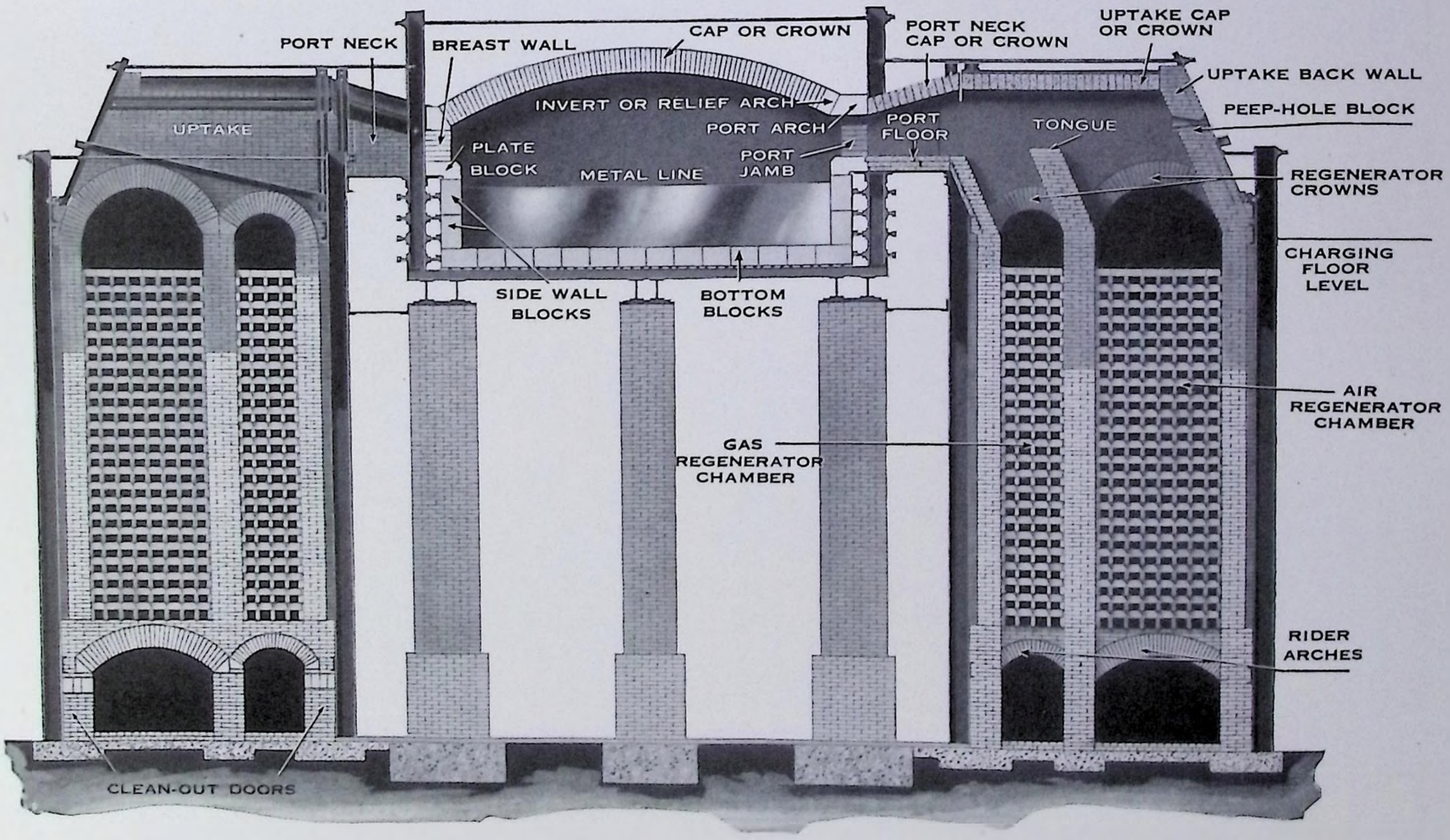
KORUNDAL brick, containing approximately 90 per cent alumina, are used in jambs and other parts of ports, as in burner blocks, and in other vulnerable parts of the superstructure.

The hard-burned magnesium-silicate refractory FORSTERITE, when used in the ports, has made possible longer and more efficient campaigns. This is attributable to the excellent resistance of FORSTERITE to the fluxing action of volatile alkalies and alkaline dusts and to its resistance to wetting by molten fluxes.

Regenerator Walls and Arches: Under the usual conditions of operation, high duty fireclay brick have been adequate for construction of the regenerator walls and arches. In tanks operated at high rates of output, super-duty fireclay brick are being used to an increasing extent. Many tanks in which various glasses are made operate under conditions too severe for even super-duty fireclay brick, or high-alumina brick. In such cases, FORSTERITE fulfills the requirements satisfactorily.

Regenerator Checkers: The regenerator checkers are exposed to the action of alkaline dust at temperatures considerably below that of the melting zone of the tank. At the top of the checkerwork the temperature may be as high as 2500° F., and in some instances appreciably higher. At the bottom of the check-

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Cross Section of Typical Producer Gas Fired Glass Tank

ers the temperature is considerably lower and condensation of volatilized alkalies may occur. During clean-out periods the brick are subjected to influences which tend to cause spalling.

The behavior of the checkers depends upon the temperature, the extent and rapidity of the temperature fluctuations, the amount and composition of alkaline dust and fumes in the furnace gases, the amount and composition of slag drip from the arch, the kind of checker brick used, the type of construction, the kind of fuel, and the manner of cleaning the checkers. For a given kind of checker brick, the service will vary with the temperatures and operating conditions.

Brick for checker service should stay clean and should not become appreciably encrusted; the openings should remain clear, and the rate of wear should be slow. These requirements can be met or closely approached by selection of the brick best suited to the service conditions.

The same kind of brick is needed in the top checker courses as in the port side walls and arches. For conditions not excessively severe, high duty fireclay brick are adequate. Various Harbison-Walker brands of power pressed and extruded brick are used advantageously as checkers. These brick have high resistance to penetration by slags and to spalling.

Super-duty fireclay brick are tending to replace high duty fireclay brick for use in checkers. The regenerators of a large proportion of the glass tanks now in service are checkered either partially or entirely with fireclay brick of the super-duty class.

In many regenerators, super-duty fireclay brick are not adequate for the top checker courses. In such cases, the choice for either gas or air chambers may be DIALITE (50% alumina class), ANCHOR or ALCOR (60% alumina class), ALUSITE (70% alumina class), or KORUNDAL (90% alumina class), depending upon furnace conditions. Of these, KORUNDAL is most resistant to fluxing by alkaline dusts. FORSTERITE brick are strongly recommended for use as checkers in air chambers but not in gas chambers. They are not attacked by alkaline dusts, and are highly resistant to wetting, glazing and clogging.

In some cases — as in the regenerators of tanks melting boro-silicate glass — STAR silica brick or VEGA super-duty silica brick are used for the checkers.

Mortar Materials: In glass tank construction, THERMOLITH, an air-setting mortar material with a chrome ore base, is widely used for laying the brick in regenerator walls and uptakes. However, it may not be employed in furnace ports where the chrome ore might affect the color of the glass. HARWACO BOND, an air-setting mortar with a high-alumina base, is used advantageously for laying fireclay or high-alumina brick in the ports and regenerators. FORSTERITE BONDING MORTAR is preferred for laying FORSTERITE brick. THERMOLITH, HARWACO BOND, or FIREBOND are employed for laying the brick in the lehrs.

STAR silica clay, STARBOND, and VEGA BOND comprise a series of silica mortars especially suited for laying silica brick in the various parts of the glass tanks. STAR silica clay is the usual cement for laying brick not subjected to the most severe treatment. STARBOND is measurably more refractory, and VEGA BOND represents the ultimate among all silica mortars for the most severe conditions to which silica brick are subjected in service.

HEATING FURNACES

THE group of furnaces known as "heating" or "reheating" furnaces covers a wide field in the processing of both ferrous and non-ferrous metals. In this general classification are the following types of furnaces:

Angle heating	Ingot heating
Annealing	Normalizing
Bar mill	Plate heating
Billet heating	Rivet heating
Blooming mill	Rod mill
Bolt heading	Seamless tube
Brazing	Skelp
Butt- and lap-weld pipe	Slab heating
Carburizing	Stress relieving
Controlled atmosphere	Strip mill
Forge	Welding
Galvanizing	Wire mill
Heat treating	Upsetting

In no other group of furnaces are there such great differences in size, design and operating conditions. Every gradation in size is found, from small rivet heating furnaces to large continuous normalizing furnaces two hundred or more feet in length, and stress-relieving furnaces thirty feet high. Any fuel may be used as a source of heat — coal, gas, oil, tar, powdered coal or combination fuels — or the heating may be done electrically. Regenerators or recuperators may or may not be provided. The furnace may be any one of several types: hearth, pit, muffle, or tunnel. It may be stationary, rotating, stationary except for a rotating hearth — and in some cases even portable. The material under treatment may be heated in batches in an "in-and-out" type of furnace; or it may pass intermittently or in a continuous stream through a furnace having either a stationary or a moving hearth. The operating temperatures cover a wide range extending from moderately low to very high.

The wide differences in furnace design and operation are naturally accompanied by great variations in the severity of the service to which the refractories are exposed. Among the factors which have a bearing upon the life of the linings are the continuity of operation, the kind of fuel, the temperature, the furnace atmosphere, the character of the flame, the rapidity of temperature fluctuations, the degree of abrasive action, the corrosive effect of any iron scale or ash which may be present, and mechanical abuse. Through wise selection of refractories for the linings, the item of furnace repair costs may be rendered almost negligible for mild service conditions, and kept within economical limits for severe conditions.

Hearths: Among the factors which determine the type of refractory material best adapted for service in heating furnace hearths are the temperature, the amount of scale, and the degree of mechanical abrasion.

Depending upon the service requirements, the hearth may be built of dense, tough, high duty or super-duty fireclay brick, high-alumina brick of the 70% alumina class such as ALUSITE, or hard-burned H-W CHROME or H-W MAGNESITE brick. H-W CHROME brick have high mechanical strength and resistance to penetration and attack by molten scale. H-W MAGNESITE brick are strong and highly refractory; they have the unique property of ability to absorb large amounts of iron oxide with little change in strength and rigidity.

The use of either PLASTIC THERMOLITH BATCH or MAGNAMIX provides a convenient method of forming the hearth contours with a ramming material which is mechanically strong and highly resistant to abrasion and to penetration by slags.

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Side Walls: In the side walls, the classes of refractories most generally used are high duty and super-duty fireclay brick. For extremely severe conditions, the use of the high-alumina brick ALCOR (60% alumina class) or even KORUNDAL (90% alumina class) is often an economy. In many cases it is advisable to use several courses of H-W CHROME brick along the walls where molten scale comes in contact with the refractories. PLASTIC THERMOLITH BATCH may also be employed to protect the side walls against slag attack.

Roofs: In general, the roofs are subjected to service conditions similar to those which the side walls must withstand. In sprung arch roofs an additional factor of importance is the stress from the thrust of the arch.

In the roofs as in the side walls, the type of fuel employed may influence the choice of refractories. The alkalies in the ash of oil fuel have a strongly corrosive effect. The resistance of alumina-silica brick to this effect increases with increasing alumina content.

Sprung arch roofs of heating furnaces which are seldom shut down may be built with STAR silica brick, XX SILICA brick, or one of the company's brands of high duty or super-duty fireclay brick. For most severe conditions, ALCOR or KORUNDAL may be employed. ALCOR XX and KORUNDAL are used in bungs of furnaces heated to extremely high temperatures.

Many heating furnaces now have suspended roofs, built with such brands as WOODLAND X, WALSH XX, ALAMO, VARNON or ANCHOR.

Annealing Furnaces: In choosing refractories for annealing furnaces, it must first be known whether it is necessary to provide for storage of heat within the furnace structure, or to provide for low heat capacity, with sharp response to desired changes in temperature. In the first case, a dense refractory would be chosen; in the second, consideration would be given to the use of insulating fire brick.

The relatively low temperatures prevailing in annealing furnaces are within the range for which brick of the intermediate duty class are suited. However, high duty and super-duty fireclay brick, which have far higher resistance to temperature change, are extensively used also. Their resistance to thermal shock may be an important factor in obtaining the life of many years which these furnaces are frequently expected to give.

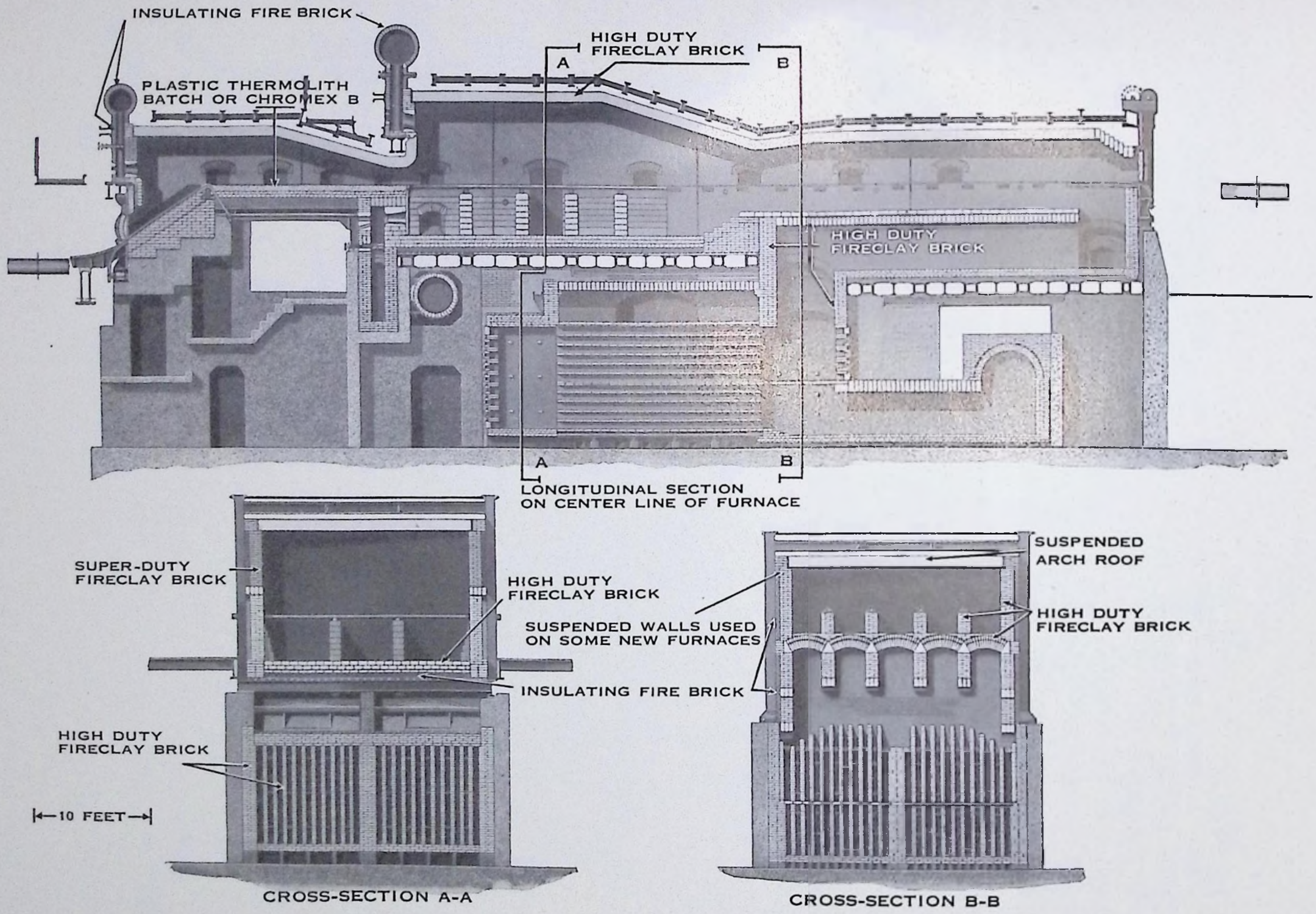
If the furnace atmospheres contain significant amounts of carbon monoxide or hydrogen, it is advisable to use a refractory which is highly resistant to the harmful effects of these gases. For these conditions, a hard-burned super-duty fireclay brick such as VARNON or KENMORE brand is recommended. The insulating fire brick H-W 26 and H-W 28 are also highly resistant to disintegration by carbon monoxide.

In the types of annealing furnaces which must be heated and cooled quickly, insulating fire brick, generally of the 2300° or 2600° classes, are used to advantage. CALAG bulk insulation is used to insulate furnace roofs, and H-W LIGHT-WEIGHT CASTABLE or CALAG concrete to insulate the foundations.

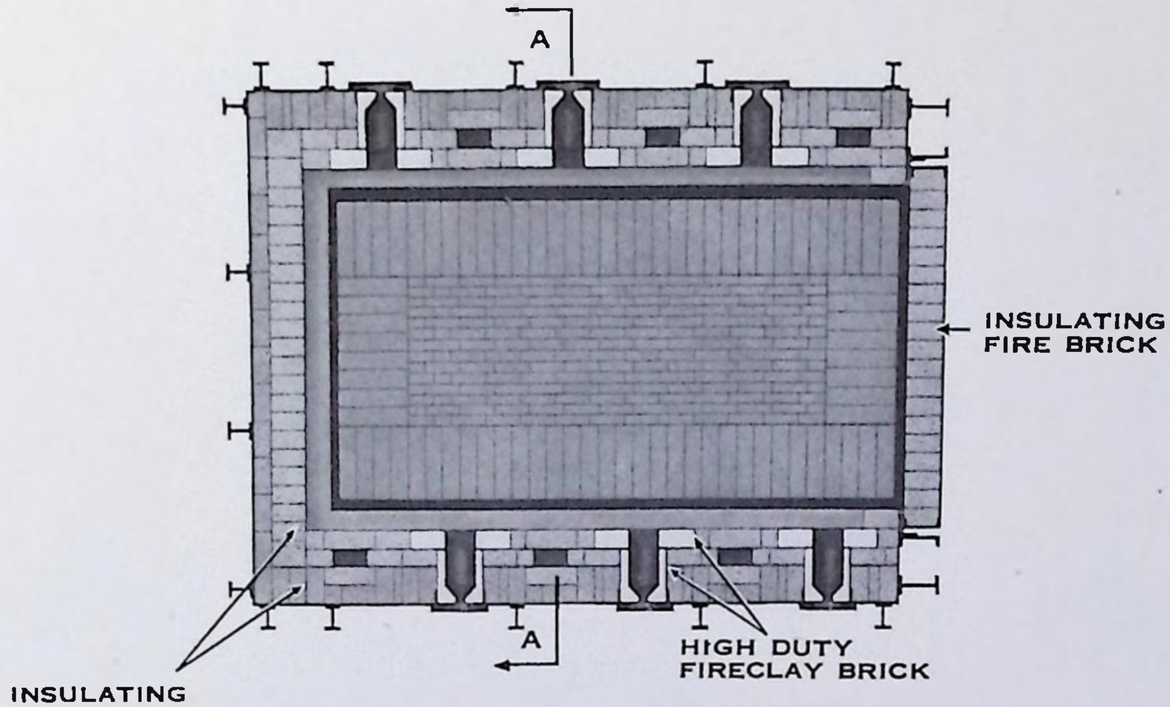
Castables are often used in annealing furnaces to form monolithic linings of refractory concrete. Where the temperatures permit, they may be employed to form the side walls, and in some cases they may be used for the hearths or for the pedestal blocks.

Many annealing furnaces are operated within a temperature range at which hot-setting bonding mortars will not develop a strong ceramic bond. Under these conditions it is best practice to lay the brick with an air-setting mortar, such as THERMOLITH, FIREBOND or HARWACO BOND.

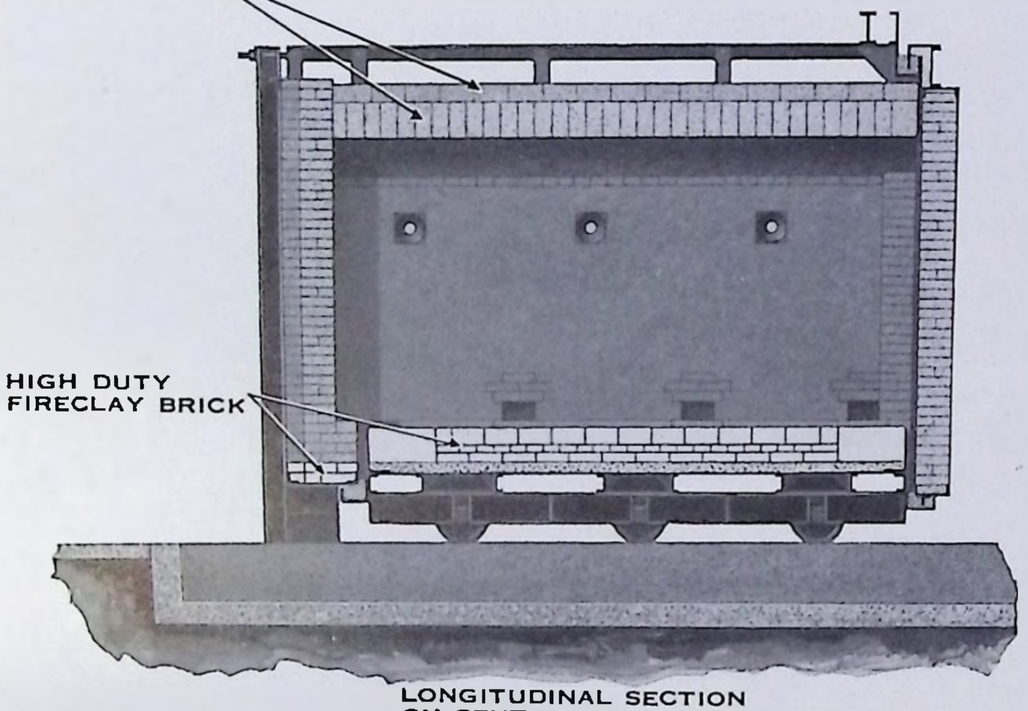
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Triple Fired Billet Heating Furnace

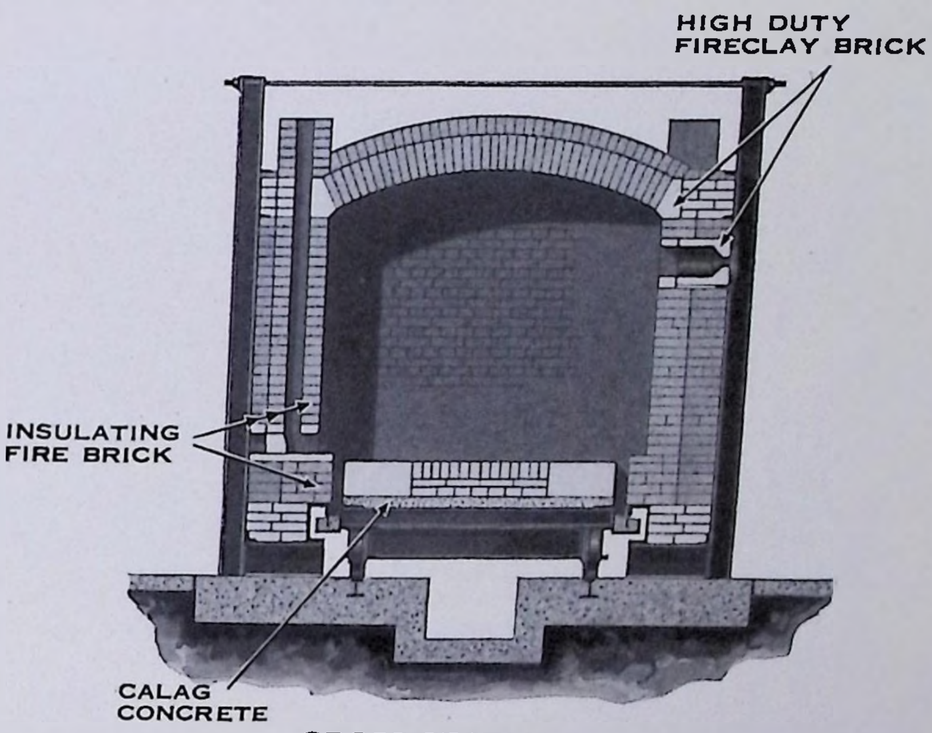


PLAN SECTION ON CENTER LINE OF BURNER PORTS



LONGITUDINAL SECTION ON CENTER LINE OF FURNACE





CROSS-SECTION A-A

Car Type Annealing Furnace

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INCINERATORS

While the great majority of incinerators are used by municipalities for burning garbage and other waste material, a considerable number are employed for disposing of industrial waste products. In each class of incinerators, there are a number of well-established designs built by engineering companies which specialize in such construction. The wide range of Harbison-Walker products permits selection of those best suited for each type of incinerator.

While the temperatures prevailing in most incinerators are only moderately high except locally, the destructive influences to which the brick linings are exposed are severe. Corrosive ash, high in potash, results from the burning of organic materials such as animal and vegetable matter, wood and paper. Frequently tin, lead or other metals and broken glass are present. At the combustion temperatures maintained, the metals may oxidize and have a destructive effect upon refractories. Usually ash or clinker in a more or less viscous state will penetrate the brick to a slight depth, and fly ash will adhere to the walls and roof. In the removal of this clinker and fly ash the brick are generally subjected to considerable mechanical abuse.

The linings are subjected alternately to flame impingement and to sudden cooling caused by the introduction of damp or wet charges.

Frequently, the brick in the door jambs and charging holes are subjected to scuffing by the tools used to distribute the bed.

Harbison-Walker refractories recommended for use in incinerator linings have the combination of properties required for greatest resistance to the various destructive influences. The brick supplied for walls and sprung-arch roofs are of the proper texture for resistance both to slag penetration and to conditions which tend to cause spalling. The brands most in demand for this service are Walsh XX, Woodland X Dash, H-W Crown, and High Grade XX high duty fireclay brick, and Alamo, Boone, and Dean super-duty fireclay brick.

Flat suspended roofs have become widely used in incinerator construction. Harbison-Walker maintains stocks of the brick shapes required in the construction of the various types of suspended roofs. Satisfactory service is obtained from brick of the same brands as those used in the walls or in sprung-arch roofs.

Harwaco Bond, used for laying the brick in the entire construction, contributes much to good service. This mortar material has proved especially advantageous for laying both sprung and suspended roofs.

For smaller incinerators of some designs, the construction of upper portions of the walls with H-W Plastic Fire Brick, and of arches and charging holes with either H-W Standard Castable or H-W Super-Castable, is frequent practice.

With the increasing application of insulation in incinerator construction, the choice of the insulating material has become more exacting. Full information regarding the best type of insulation for specific service conditions will be furnished upon request.

Since the majority of incinerators are installed and operated under the jurisdiction of municipalities, the refractories used are generally purchased on definite specifications. Harbison-Walker products satisfactorily fulfill the requirements of these specifications for all the widely accepted types of incinerators.

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LADLES—HOT METAL TRANSFER

Molten iron from the blast furnace is commonly tapped into transfer ladles mounted on railroad trucks. The iron in the ladles is then moved by rail to any point desired. Generally, it is taken to an open-hearth plant, where it is used for direct charging to the open-hearth furnaces, or to metal mixers of 600 to 1200-ton capacity. Less frequently, the molten metal is transferred to a continuous casting machine and cast into pigs. The transfer ladles consist of cylindrical steel shells lined with fireclay brick. Their capacity ranges from 75 to 150 tons or even more of hot metal.

The lining of a hot metal transfer ladle is usually 9 inches to 13½ inches thick. High duty fireclay brick of maximum density have been considered standard for this service. Brands widely used for ladle linings are Walsh T, Benezet H & B, H-W H & B, and H & B Woodland. To secure the required density, the brick are preferably made by the vacuum power press process, or by the extrusion process and repressed. For severe conditions, such as those which prevail when the metal is desulphurized in the transfer ladle or held in the ladle for long periods of time, best results are secured from high-fired super-duty fireclay brick such as Varnon or Kenmore. Even for the usual operating conditions, these brands are preferred by some operators.

In lining hot metal transfer ladles, it is usual practice to tamp a mixture of ground quartzite and fire clay, 1 to 1½ inches thick, directly against the shell. Sometimes a backing of 9-inch splits or 2-inch brick is used instead. The brick should be laid with the thinnest possible joints and keyed as tightly as possible.

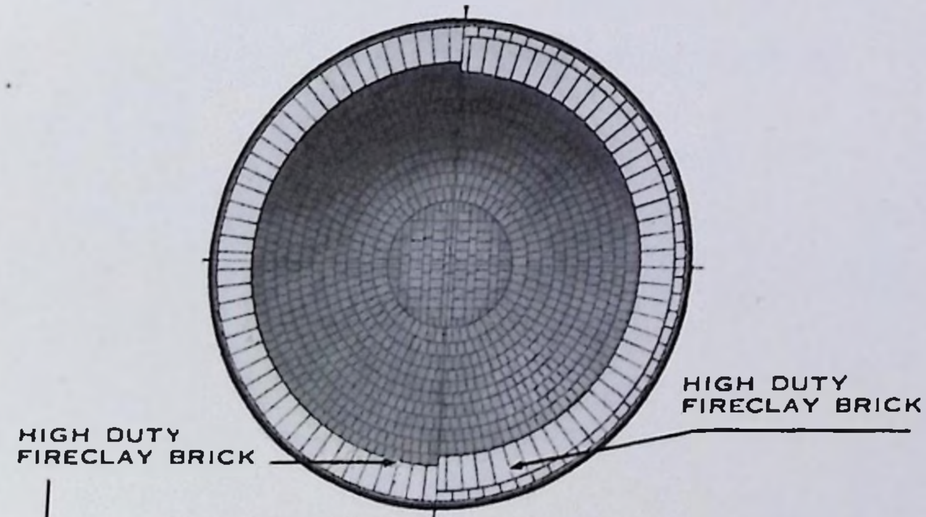
Of equal importance to choice of the brick is selection of the bonding mortar. Thermolith, a high temperature bonding mortar with a chrome base, will serve excellently when deoxidizing agents such as aluminum are not employed in large amounts. Mortars which are unaffected by deoxidizers are Korundal Bonding Mortar, Harwaco Bond, and fine ground fire clay; and also a mixture of 75% H-W Calcined Flint Clay with 25% of H-W Weathered Bond Clay B.

Among the factors which influence the life of the ladle linings are the length of travel, the number of pours after filling, the length of time the metal is stored in the ladle, and the time between pouring and refilling.

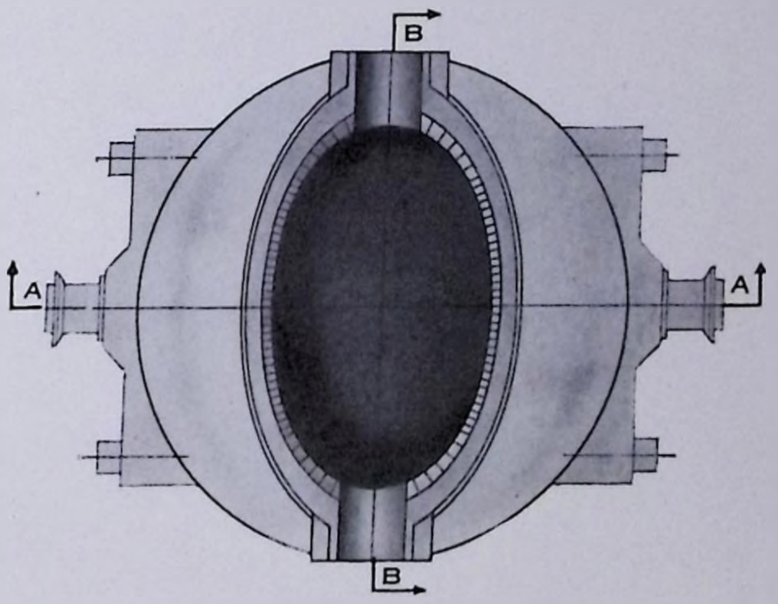
Wear on the linings is much less severe when the metal from the transfer ladles goes into large open-hearth ladles in perhaps two pours, than when it goes into relatively small ladles, requiring a large number of pours, with considerable shifting of the transfer ladle. The life of the lining is generally longest when the transfer ladle is used in conjunction with a continuous pig casting machine, and when the position of the ladle may be reversed for both filling and pouring.

At some plants, transfer ladles kept in continuous operation are cooled somewhat by blowing air into them between trips. This practice lowers the mean temperature of the linings, and has a favorable effect upon the life of the refractories.

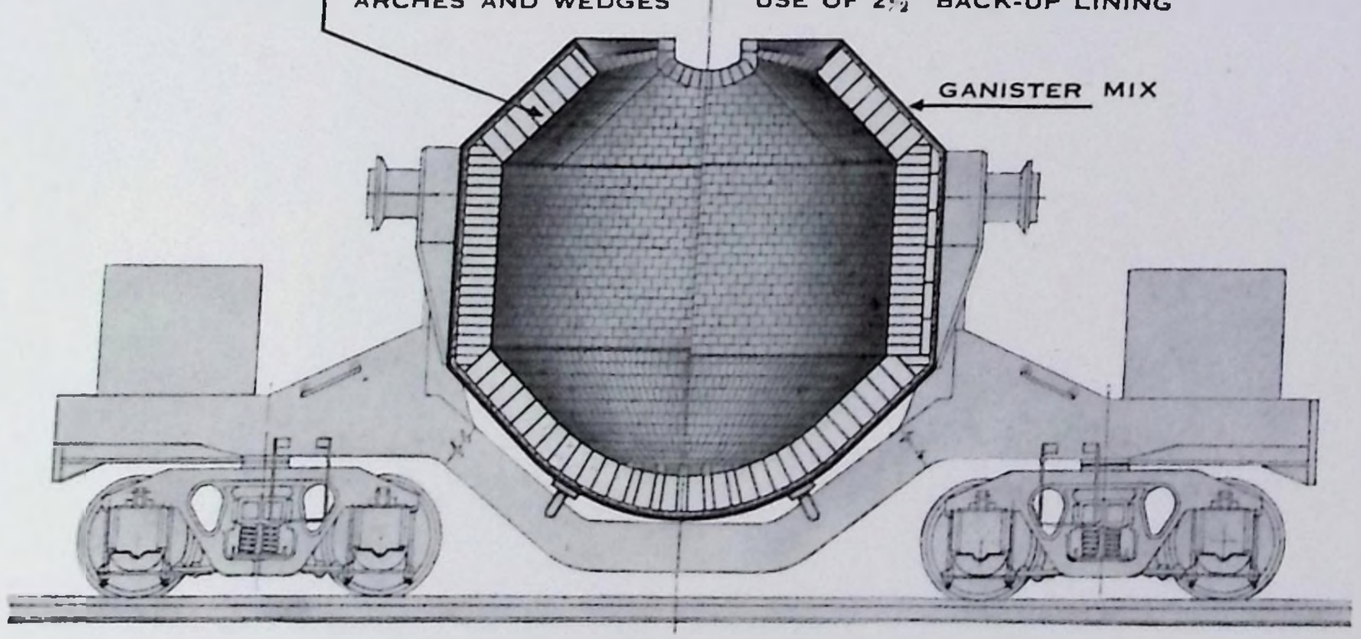
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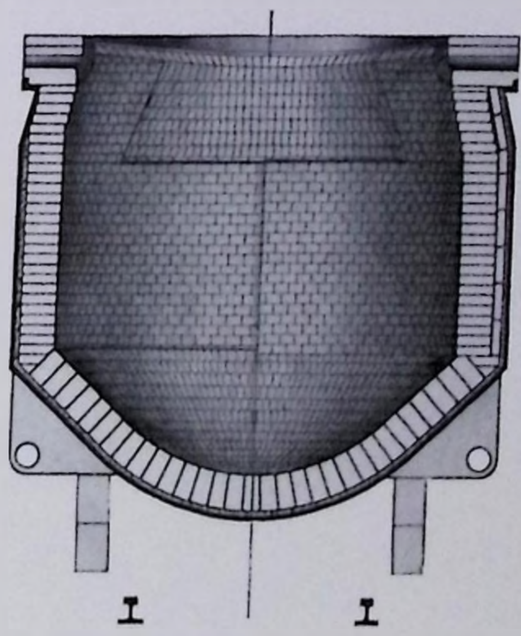
PLAN SECTION



PLAN VIEW



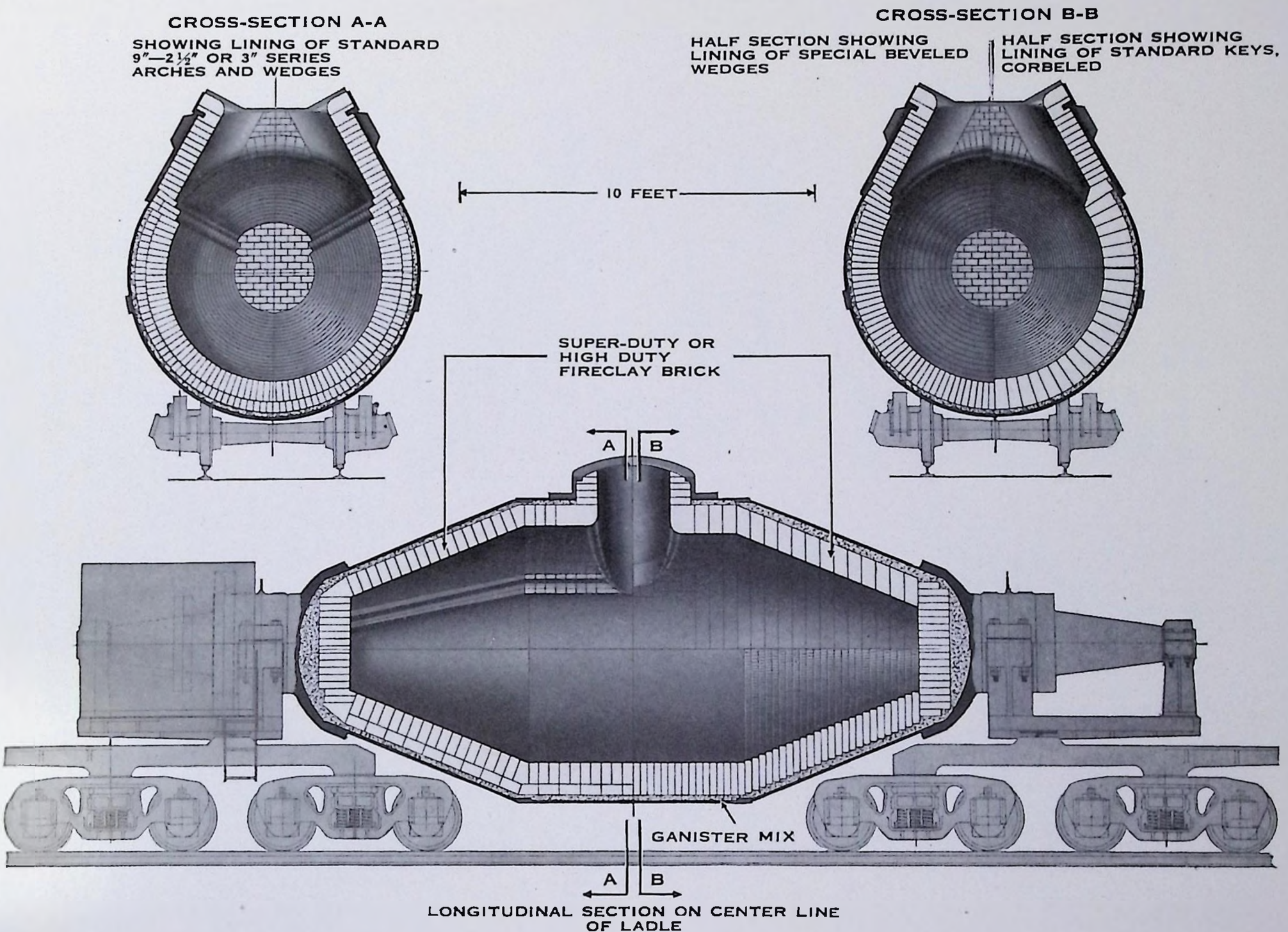
CROSS-SECTION A-A



CROSS-SECTION B-B

Hot Metal Transfer Ladle

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Hot Metal Transfer Ladle

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LEAD

MAN has used lead in some of its forms since earliest recorded history. In addition to being a soft malleable metal of low fusion point, having the remarkable power to coat itself with its own durable oxides or salts, lead is foremost among the media in which the precious metals may be gathered, and from which they are readily separated.

Selected high grade ores gave up metallic lead by reduction in the most primitive pot furnaces. The hand bellows made possible the use of the ancient rock furnace and later, the adobe furnace, which time has matured into the modern blast furnace. For the primitive lead furnace the refractories were limited to the available rocks and clays.

The metallurgist of today may select from a wide range of suitable refractories of reliable composition and quality. However, many of the recent advances in the metallurgy of lead have resulted in higher furnace temperatures with a consequent increase in the corrosive properties of the compounds of lead. Under present conditions, lowest furnace maintenance costs are obtained only by careful selection of the best available refractories.

Sintering Machines: Super-duty fireclay or high duty fireclay brick, laid with HARWACO BOND, are recommended for the linings of sintering machine ignition stoves.

Lead Blast Furnaces: In the crucible of the modern lead blast furnace, dense and tough fireclay brick of high duty quality give satisfactory service. The brick may be produced by either the extrusion or the power press method of manufacture. WALSH T brick are outstanding for this service. The mortar material for laying these brick should be of proper composition and refractoriness. For several courses at the top of the crucible wall, where corrosion is usually most active, H-W MAGNESITE brick, laid with THERMOLITH, are used with satisfactory and economical results.

Above the water jacket, the lining is exposed to reducing atmospheres and to the channeling action of the blast, with resulting localized high temperatures. It is standard practice to use high duty fireclay brick in this position. In furnaces operated on high production schedules it has proved economical to use H-W MAGNESITE brick, laid with THERMOLITH, for several courses between the water jackets and the fireclay brick above.

Lead Kettles: High duty and intermediate duty fireclay brick laid with HARWACO BOND are standard materials for lining the combustion chambers. With proper provision in the furnace design to relieve the brick from the load of the kettle, the use of H-W INSULATING FIRE BRICK exposed to direct contact of the hot furnace gases afford economies.

Softening Furnaces: High duty fireclay brick of dense and tough physical properties are recommended for the bottom invert arch, which may be 9, 12 or 13½ inches thick. It is desirable that all or most of the brick be tapered. The excellent experience with WALSH T in this application commends it for this purpose.

For the lower side walls, from the invert to a level slightly above the slag line, H-W MAGNESITE or CHROMEX B brick, laid with THERMOLITH or with H-W PERIKLASE Bonding Mortar, are used with excellent results. When spalling conditions are severe, ALUSITE high-alumina brick are used in preference to basic brick.

For the upper or exposed side-wall areas and for the roof, ALUSITE high-alumina brick are recommended for very severe service condi-

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tions and super-duty fireclay brick for service conditions that are less severe. For mortar material, HARWACO BOND or THERMOLITH is recommended. The same refractories as those used in the upper walls and roof should be employed for lining the off-take which connects the furnace with the flue system.

Dross Furnaces: The work of these furnaces varies widely with the character of the dross to be treated and the products produced. In their simplest role, they may be used merely for sweating lead from an irony dross. The residue is returned to the blast furnace. If much copper and arsenic are present, it may be desirable to tap lead, matte and speiss.

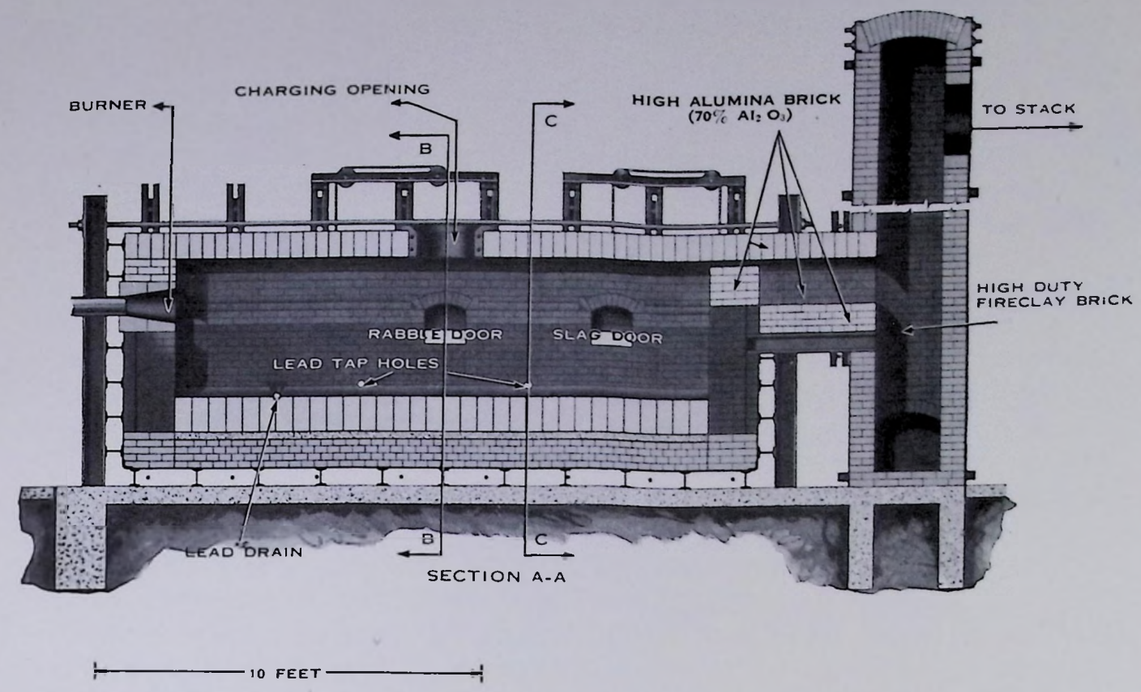
The refractories used for the bottom invert and lower side walls of the dross furnace are similar to those used in the softening furnace. However, for the upper side walls, roof and off-take, best results are secured from ALUSITE 70% alumina brick. They are laid with HARWACO BOND or THERMOLITH.

Cupels: Where maximum life of the lining is of prime importance, H-W MAGNESITE or H-W PERIKLASE brick laid with PERIKLASE Bonding Mortar are preferred. However, the brick tend to absorb precious metals, and in the cupellation of bullion high in gold and silver, the locking up of inventory may become an important consideration. Magnesite brick, if finely ground and mixed with siliceous ores, may be smelted readily in the blast furnace. But any magnesite brick, when thoroughly impregnated by bullion, is difficult to crush or grind and most difficult to smelt if not properly prepared. For this reason some plants use magnesite brick for the cupel walls only. The bottom is made of a mixture of crushed limestone and cement or of crushed fireclay brick and Portland cement, rammed into place. High duty or super-duty fireclay brick are recommended for the arches or tops.

Lead Oxide Furnaces: Dense high duty fireclay brick satisfactorily serve as lining materials in furnaces used for the production of the lead oxides red lead and litharge. WALSH XX, WALSH T, and other Harbison-Walker brands of high duty fireclay brick perform very satisfactorily in this application. The temperatures involved are relatively low, so that resistance to penetration and spalling are the most important requirements for the brick used in the various types of lead oxide furnaces.

Lead oxides for some applications are manufactured in furnaces operating at temperatures above the melting points of the oxides. H-W PERIKLASE and H-W MAGNESITE brick in the hearths, side walls and arches of such furnaces have proved the most satisfactory of all refractories for this service, not only because of their greater resistance to attack by molten lead oxide, but also because the use of these brick prevents contamination by impurities from the refractory materials.

Lead Recovery Furnaces: In general, the refractories which have proved best for the construction of lead softening furnaces serve well for the corresponding parts of lead recovery furnaces. In some cases, the secondary or scrap metal to be recovered by remelting and refining contains foreign materials which make the use of dense high duty fireclay brick the most economical for construction of the lower side walls. WALSH T brick are outstanding for this service. When these are used in the lower side walls, the upper side walls and roof frequently are built of Harbison-Walker high duty or super-duty fireclay brick.



Typical Lead Drossing Furnace

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LIME KILNS—VERTICAL

THERE are great variations in the size and design of vertical shaft kilns employed so extensively for the production of agricultural, building, and chemical lime. The raw limestone or dolomite is charged at the top of the kilns in the form of lumps several inches in diameter. In descending, it passes successively through preheating, burning, and cooling zones. Combustion of coal or oil fuel usually takes place in an external fire box or Dutch oven. Coke when used is usually charged with the stone; natural and producer gas are usually center fired. The life of the lining is affected by such variables as the size of the rock, its cleanness and hardness, the evenness of distribution of the charge, the quality of the fuel, the draft, and the burning temperature.

Abrasive action of the descending charge is greatest in the top section. In the intermediate zone, the abrasive effect of the charge is less, while the spalling influences may be somewhat greater. In the burning zone, high temperatures and chemical reactions between charge and lining are conditions which the refractories must resist. These conditions are frequently intensified when the kiln is operated under forced or induced draft.

In oil-fired kilns, the alkalies of the oil ash exert a strongly fluxing action upon the refractories. In coal-fired kilns with Dutch oven fire boxes, slagging by coal ash may be severe. Linings are frequently damaged during removal of adhering coal-ash clinker.

For lining the top section, fireclay brick which are dense, strong and highly resistant to abrasion, are used. The intermediate zone is lined with high duty fireclay brick of adequate resistance to spalling. For the burning zone, the choice of refractories will depend upon the severity of the treatment imposed upon the lining. High duty fireclay brick are most widely used. For severe conditions, super-duty fireclay brick such as VARNON or KENMORE or high-alumina brick such as ANCHOR or ALUSITE may be employed. In some shaft kilns, STAR silica brick are used in the burning zones, because of their high resistance to abrasion and their rigidity at high temperatures. The use of silica brick in lime kilns is limited by their tendency to spall when subjected to rapid changes in temperature below 1200° F.

In relieving arches and arches over the eyes of the kilns, longer life and greater productive capacity result from the use of Harbison-Walker super-duty fireclay brick, or CORALITE, a high-alumina brick containing approximately 80 per cent alumina. STAR silica brick are frequently employed in relieving arches, and STAR or XX SILICA in arches over the eyes. CORALITE and KORUNDAL brick serve well in the burner arches of center gas-fired kilns.

For lining the cooling zones of shaft lime kilns, DURO or WYLAM A abrasion-resistant brick render unusually good service.

The use of Harbison-Walker insulating fire brick as a backing for the refractory lining, especially in the hot zones of kilns, reduces the temperature fluctuations which occur when lime is drawn.

The air-setting high temperature bonding mortar HARWACO BOND is employed very advantageously for laying fireclay and high-alumina brick in the kilns; FIREBOND is recommended for laying silica brick.

Rotary Kilns: The various kinds and classes of refractories employed for construction of rotary lime and lime recovery kilns are discussed on page 237.

MALLEABLE IRON FURNACES

THE melting and refining of malleable iron are accomplished in furnaces of the reverberatory type, usually having removable roof sections called "bungs". The furnace is commonly referred to as a "malleable" or "air" furnace. The fuel is generally pulverized coal, although oil is used also. In the direct melting process, the charge consists of cold metal; in the duplex process it consists of molten iron from a cupola.

Brick used in the bungs must be adequately refractory to withstand the high temperatures of melting. They must have sufficient mechanical strength to sustain the pressure to which they are subjected in the bung frames, and to withstand occasional rough handling without injury. In addition, they must not shrink at high temperatures and they must be of suitable texture and composition to resist the spalling effects of severe thermal shock caused by rapid melting schedules, or by the removal of the bungs for charging the furnace. WALSH XX, H-W HIGH GRADE XX and WOODLAND bung brick meet these requirements.

For service in the side walls above the slag line, the brick must be highly refractory, resistant to spalling, and resistant to corrosion by fuel ash and molten slag. For this service, the brands recommended are the high duty brick WALSH S, H-W HIGH GRADE S and H & B WOODLAND. These brick are manufactured by the power press or extrusion processes, with special attention to uniformity of burn. Where spalling conditions are especially severe, super-duty fireclay brick may be employed advantageously. ALAMO and BOONE super-duty fireclay brick serve excellently for this purpose.

At and below the slag line, the side wall brick must resist the erosive effect of molten metal, and the corrosive action of slag high in iron oxide. In general, the same brands of brick are used as those employed above the slag line. In some cases, the use of ALCOR XX high-alumina brick of the 60% alumina class is economical for this vulnerable location.

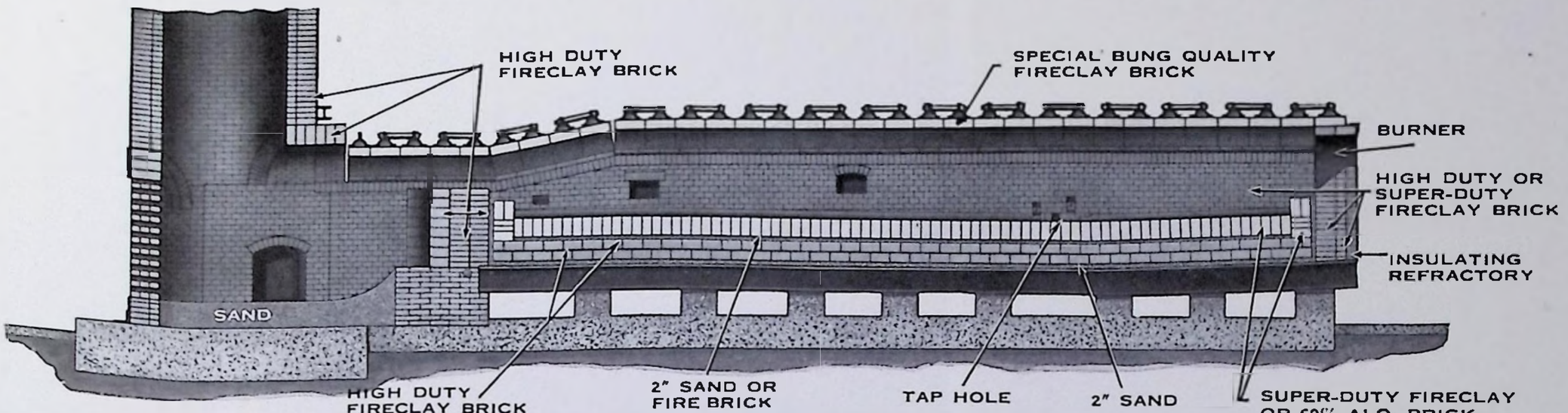
Side walls generally consist of a permanent wall 4½ inches thick, built of high duty fireclay brick, with a replaceable inner wall 9 inches thick, of header construction, built of either high duty or super-duty fireclay brick. The burner end wall is frequently insulated with such brick as H-W 20 or H-W 16 insulating fire brick. For best results, side wall brick are laid with dipped joints, using a thin slurry of HARWACO BOND.

Tap-hole blocks should be set in such manner that they are easily replaced. This may be accomplished by setting them in a replaceable false wall 9 inches thick outside the side wall, with a suitable opening through the side wall. High duty fireclay brick, such as WALSH, H-W HIGH GRADE XX, and WOODLAND are generally used for tap-hole blocks. For severe conditions it frequently is economical to select VARNON or KENMORE super-duty fireclay brick, or ALCOR high-alumina brick.

In the air furnace, sand bottoms are giving way to ventilated brick bottoms. With this construction, the entire furnace rests upon a steel pan, beneath which air can circulate. The working bottom may be built of ALAMO, BOONE, VARNON or KENMORE super-duty brick or of ANCHOR high-alumina brick, depending upon service conditions.

In the installation of the working bottom, the brick are laid as tightly as possible, usually in the form of an inverted arch skewed against the side walls. In some cases the bottom is

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Typical Malleable Furnace Fired with Pulverized Coal

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crowned, and occasionally it is skewed beneath the walls. Brick for this service are carefully selected for uniformity of width and freedom from warpage, to attain the thinnest possible joints between rings. The brick may be laid with very thin dipped joints of high temperature bonding mortar, such as HARWACO BOND, KORUNDAL BONDING MORTAR or ANKORITE; or they may be laid dry and later grouted thoroughly with a thin slurry of the bonding mortar.

The stack arch and stack are generally built of high duty fireclay brick laid in a high temperature bonding mortar such as HARWACO BOND.

Some malleable iron is produced by melting the metal in cupolas, and refining it in electric furnaces. For this service, the cupola is lined with dense high duty or super-duty fireclay brick of hard burn. The roof and side walls of the electric furnaces are built of silica brick. The bottoms are of monolithic construction, for which a mixture of H-W GROUND SILICA GANISTER and H-W BOND CLAY B is recommended.

Rotary furnaces also are used for the production of malleable iron. These furnaces consist of horizontal steel cylinders with conical ends, and are generally fired with powdered coal. A back-up lining of high duty fireclay brick is placed next to the steel shell, with an inner or working lining of STAR silica brick. In the installation of these linings, the proper technique must be followed, in order to secure the maximum life in service.

Harbison-Walker products have successfully served the malleable iron industry for many years. The wide distribution of the company's manufacturing units permits Harbison-Walker to serve malleable plants economically, regardless of their location.

Adequate stocks are maintained of the standard sizes required for the various sections of the malleable furnace, as well as of the commonly used shapes such as door tile and tap-hole blocks. The company also supplies high duty and super-duty fireclay brick, as well as insulating fire brick of various classes, for use in annealing ovens and in core ovens.

METAL MIXERS

IN many steel plants, hot metal from the blast furnaces is stored in metal mixers. These are holding furnaces of various shapes and sizes ranging up to 1200 tons capacity. They are mounted on trunnions to permit periodic pouring of the hot metal into transfer ladles for transportation to the open-hearth furnaces or to Bessemer converters.

Metal mixers are generally lined with a double ring of dense, hard-burned fireclay brick of the high duty class. Among the brands used for this service are WALSH T and H & B WOODLAND. For more severe service, VARNON superduty fireclay brick or ALCOR XX high-alumina brick are recommended. Under some conditions, basic brick are used around the pouring spouts, in the jambs, and for several courses at the metal line.

Lining replacements for metal mixers are infrequent, and usually only the inner course is renewed. Occasionally, patching and repairs to the lining around the spout are necessary.

High duty fireclay brick linings are generally laid with fine ground high duty fireclay. If service conditions are especially severe they may be laid with the high temperature cement HARWACO BOND or with one of the company's high-alumina mortar materials. In service where deoxidizers such as aluminum are not used, THERMOLITH bonding mortar serves admirably.

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METALS—NON-FERROUS

The service conditions in furnaces employed in non-ferrous metallurgy vary widely, and the refractories must meet highly specialized requirements. Selection of the proper refractories is often vital to the success of the processes employed in the reduction, refining and melting of these metals. Over the years, Harbison-Walker has supplied refractories especially adapted to meet the various needs.

Aluminum: Beginning with the first step in the treatment of the bauxite from which aluminum metal is recovered, Harbison-Walker refractories are used for lining the rotary kilns in which the ore is dried and calcined.

The alumina of the calcined bauxite is recovered by chemical solution, followed by precipitation as aluminum hydroxide. The hydroxide is calcined in large rotary kilns in which the combined water is driven off and aluminum oxide is formed. From the time the aluminum industry began, Harbison-Walker has supplied refractories especially adapted to withstand the severe conditions of abrasion and fluxing to which the kiln linings are subjected. The super-duty fireclay brick VARNON serves for lining the high-temperature zone; high duty fireclay brick of high strength and density serve for the remainder of the lining.

Aluminum metal is obtained by reduction of the refined oxide. The major tonnage of the metal is produced in high-temperature electrolytic cells provided with carbon electrodes which have been prefired in carbon baking furnaces. Harbison-Walker high duty and super-duty fireclay brick and mortars are used advantageously for the construction of carbon baking furnaces of various types.

The carbon employed for making the electrodes is generally petroleum coke, which is calcined to remove volatile constituents. This is done economically in rotary kilns. ALAMO super-duty fireclay brick are standard for lining the high-temperature zones, and WALSH XX and H-W SPECIAL for lining the remainder of the furnace. The use of VARNON prolongs the life of the nose rings.

Synthetic fluorides which augment the cryolite used in the electrolytic cells are prepared in furnaces lined with special fireclay refractories manufactured by Harbison-Walker.

Aluminum melting and holding furnaces and ladles as well as the secondary melting furnaces must be lined with the proper refractories to secure the most economical operation and best metallurgical results. The conditions to which the refractory linings are exposed differ, depending upon the position in the furnaces. To meet the various requirements, Harbison-Walker supplies dense high duty fireclay brick with special characteristics, high-alumina brick of several classes, chrome brick and the necessary mortar materials.

Bismuth and Cadmium: The furnaces employed for the recovery of bismuth and cadmium and the refractories used for the linings are similar to those used in the metallurgy of lead. These refractories are discussed on page 213.

Copper: For refractories employed in the copper industry, the reader is referred to page 185.

Lead: Information concerning the refractories used in the lead industry is given on page 213.

Magnesium: The requirements for the linings of the chlorinators, electrolytic cells and melting furnaces employed in the production of magnesium are very exacting. DURO acid-proof brick, VARNON super-duty fireclay brick, and KORUNDAL and other brands of H-W high-alumina brick are used advantageously.

Nickel: The furnaces and refractories employed in the metallurgy of nickel correspond closely to those used in the metallurgy of copper. The reader is therefore referred to pages 232 to 234 for data on refractories used in roasters, and to pages 185 to 190 for a description of the refractories required for the various copper smelting and refining furnaces.

Multiple-hearth roasters built of high duty fireclay brick and insulating fire brick serve for roasting the ore concentrates, which are charged into reverberatory furnaces for smelting. The walls and suspended roofs of the reverberatories are usually built of basic refractories. The matte produced is blown in Peirce-Smith converters lined with hard-burned magnesite or chrome-magnesite brick. To some extent, raw concentrates are smelted in blast furnaces. The matte flows into settlers lined with chrome brick, from which it is tapped for charging to the converters. The anode furnaces generally have super-duty fireclay brick bottoms, high-alumina brick side walls, and silica brick roofs.

Tin: For the usual operating conditions, bottoms and side walls of tin smelting furnaces are advantageously constructed of Harbison-Walker high duty fireclay brick. For most severe operating conditions, KORUNDAL brick are recommended for the construction of bottoms as well as those portions of the side walls which come into contact with the molten tin. In the roofs ALAMO and VARNON give outstanding service. In general, these same refractories serve for the construction of tin dross reverberatory furnaces, although under certain conditions basic refractories such as H-W MAGNESITE, H-W CHROME and CHROMEX are used at the slag and metal line.

Zinc: For refractories employed in the zinc industry, the reader is referred to page 241.

MISCELLANEOUS USES OF REFRACTORIES

MODERN REFRACTORY PRACTICE is so broad in scope and its pages are so limited in number that some important industrial applications of refractories can be reviewed but briefly. The refractory materials required for the construction of the furnaces employed are of many types and classes and have widely differing chemical and physical properties.

Artificial Abrasives such as fused alumina and the carbides of silicon and boron are produced in various types of electric furnaces at extremely high temperatures. Grains of these materials are mixed with suitable bonding agents and molded under heavy pressure into various shapes which are used for cutting and grinding. Shapes of such character that they must depend for their strength upon a ceramic bond are fired in kilns suited to the requirements. Harbison-Walker is prepared to supply refractory lining materials of highest quality with properties entirely adequate for service in electric furnaces and kilns of all types.

Brasses and Bronzes comprise a large variety of copper alloys, and widely diversified types of furnaces are employed in their production.

Large reverberatory furnaces are used for melting brasses of every composition. The invert arch bottoms may be built of STAR silica brick, H-W MAGNESITE brick, or any of the various classes of alumina-silica refractories. H-W MAGNESITE or CHROMEX B brick are frequently used in the lower side walls. VARNON super-duty fireclay brick give excellent service in upper side walls and roofs, although STAR silica brick and VEGA super-duty silica brick also are common in roof construction.

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Harbison-Walker supplies many kinds of refractories for the linings of furnaces required for melting brasses and bronzes, including rotary furnaces, and the various designs of arc, induction and resistance electric furnaces.

Calcium Carbide is produced at high temperature in electric furnaces lined with high duty fireclay brick. As the charge consisting of coke and lime becomes fused, a monolithic protective coating forms on the surface of the lining. H-W MAGNESITE and KORUNDAL brick and shapes, and MAGNAMIX, a basic ramming mixture, serve most advantageously for the construction of the walls at the tap holes.

Chemical Processes of many types, both organic and inorganic, including those used in the manufacture of acids, alkaline bases, explosives, synthetic fibers, plastics and numerous other products, require furnaces built of refractories. A great variety of Harbison-Walker products, including refractory brick, bonding mortars, insulating fire brick, plastic fire brick, castables and ramming mixtures are used in the construction of the various furnace linings. Resistance to chemical attack is the essential property for materials required for lining acid equipment. DURO and W-ACID brands of acid-proof brick are the standards of quality for this requirement.

Frit Furnaces used for the production of glazes and enamels are lined with high duty or super-duty fireclay refractories having the required combinations of properties. The chemical composition of the refractories is of major importance. Low porosity, low permeability and good workmanship also are essential.

Nitrogen is produced by a process which requires the application of extremely high furnace temperatures. High duty and super-duty fireclay brick and high-alumina brick of various classes are adequate for most of the service requirements. Periclase refractories and corundum refractories are used for lining parts of the furnaces where highest temperatures prevail.

The Phosphorus Industry, during the past several decades, has expanded from the drying and calcining of phosphate rock and the manufacture of phosphoric acid by the sulphuric acid method, to the large scale production of elemental phosphorus in electric furnaces and blast furnaces, and also to the production of super-phosphates. Refractories which meet the requirements of this service are Harbison-Walker super-duty fireclay brick, high-alumina brick and acid-proof brick, and brick of other types for special needs. Chrome refractories are finding application for the linings of defluorinating kilns in which phosphate rock is heated to very high temperatures.

Sulphur Burners are of various types and designs, and service conditions range from relatively moderate to extremely severe. The burners are constructed of high duty or super-duty fireclay brick or of high-alumina brick. KORUNDAL, a refractory of 90% alumina content, is used most advantageously for vulnerable parts of baffles in burners in which unusually high temperatures are generated.

Titanium Oxide, in recent years, has come into prominence commercially as a white pigment. In the furnaces employed for the recovery of titania from the mineral ilmenite, and for calcining titania, Harbison-Walker refractories of various types and classes are used.

OPEN-HEARTH STEEL FURNACES

BASIC OPEN HEARTH

In few types of industrial furnaces are the refractories requirements so varied and so specialized as in the different portions of the basic open hearth. The roof brick must withstand the corrosive action of basic dust and fume at exceedingly high furnace temperatures, and must have sufficient strength and rigidity to sustain the arch stresses. Refractories in the front and back walls are exposed to high temperatures, the cutting action of flame, and the splashing of slag and metal. The hearth material should be highly refractory, and resistant to the scouring action of the bath, and to corrosion by slag. End walls and bulkheads are subjected to the erosive action of dust particles in rapidly moving gases. The checkers are required to absorb and give off heat quickly, to serve for extended campaigns without fluxing, and to resist spalling. The various refractories supplied by Harbison-Walker for service in basic open-hearth furnaces meet these exacting requirements.

Roofs: Open-hearth roofs of the design most commonly used consist of silica brick sprung arches of the ribbed ring type, similar to the ribbed ring arch illustrated on page 280. Bonded roofs also are fairly common. STAR silica brick have long been recognized as the standard of quality for this application. The properties which make them so valuable for open-hearth roofs are their high refractoriness and resistance to the fluxing action of the basic dust and fume, their high mechanical strength and rigidity at temperatures almost up to their melting point, their constancy of volume above a red heat, their freedom from thermal spalling within the high temperature range, their lightness of weight, which contributes to low arch stresses, and their uniform excellence of workmanship. These properties are developed to the maximum commercial degree with the aid of skilled inspection and laboratory control at every stage of manufacture.

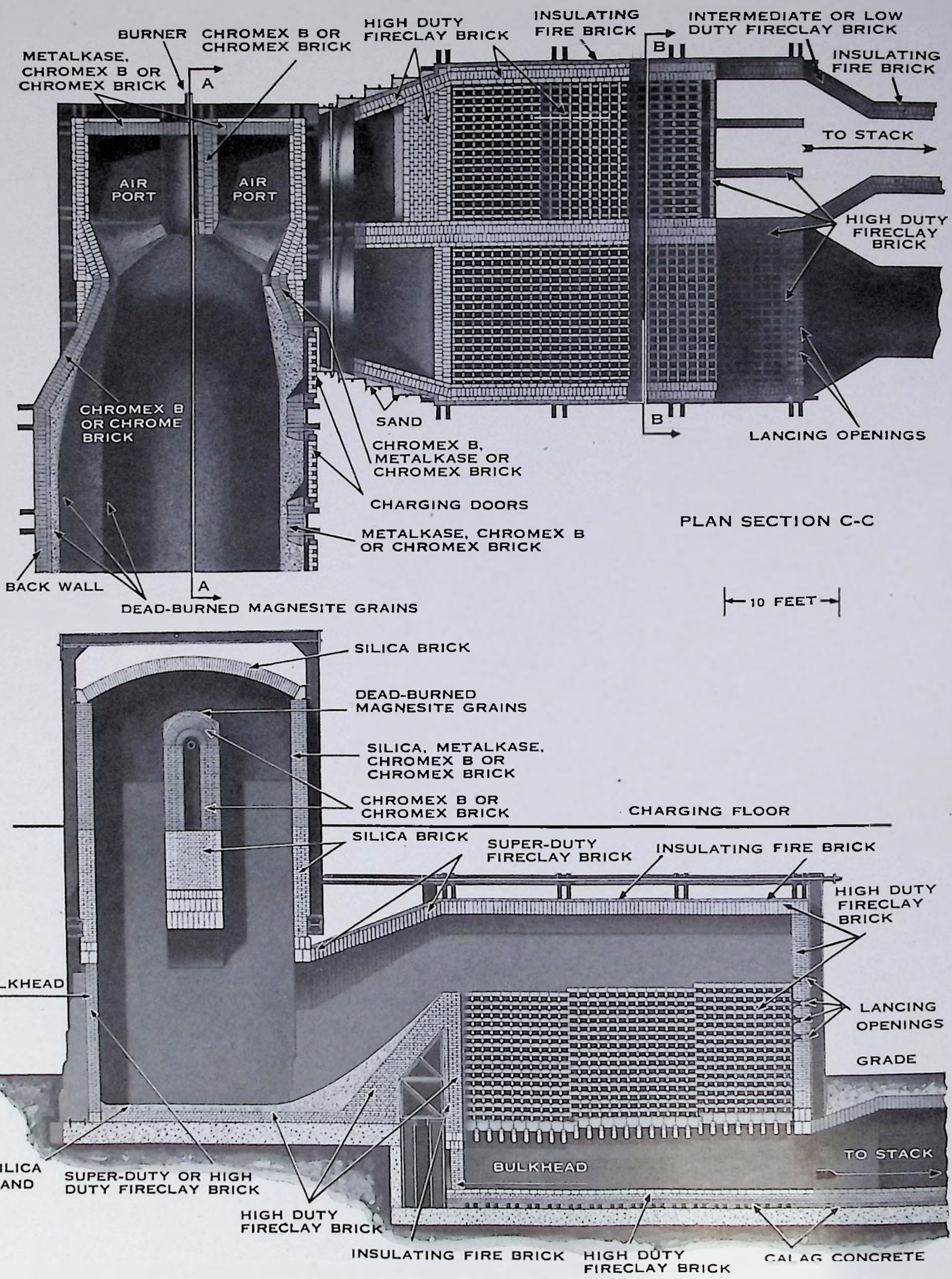
Open-hearth roofs are not subjected to conditions of equal severity across their entire widths. Conditions which tend to cause erosion of the roof brick are generally much more severe near the back and front walls than in the central portion. It is therefore logical to make roofs thicker near the skewbacks than at the center by the provision of thickened roof sections or shoulders, which have the additional thickness on the under side only.

As a further step toward the attainment of balanced roof life, VEGA super-duty silica brick are often used in sections of the main roof where maximum corrosion occurs, and in the sections at the base of the sloping portion of the roof at each end. The remarkable refractoriness of VEGA is strikingly illustrated, as a roof campaign progresses, by their superior resistance to corrosion.

METALKASE magnesite-chrome brick are frequently used to advantage for the back wall skewbacks and for several adjoining courses of roof brick. This practice is especially advantageous in tilting furnaces, in which these sections of the roof may come in contact with the slag above the bath when the furnace is tilted for pouring.

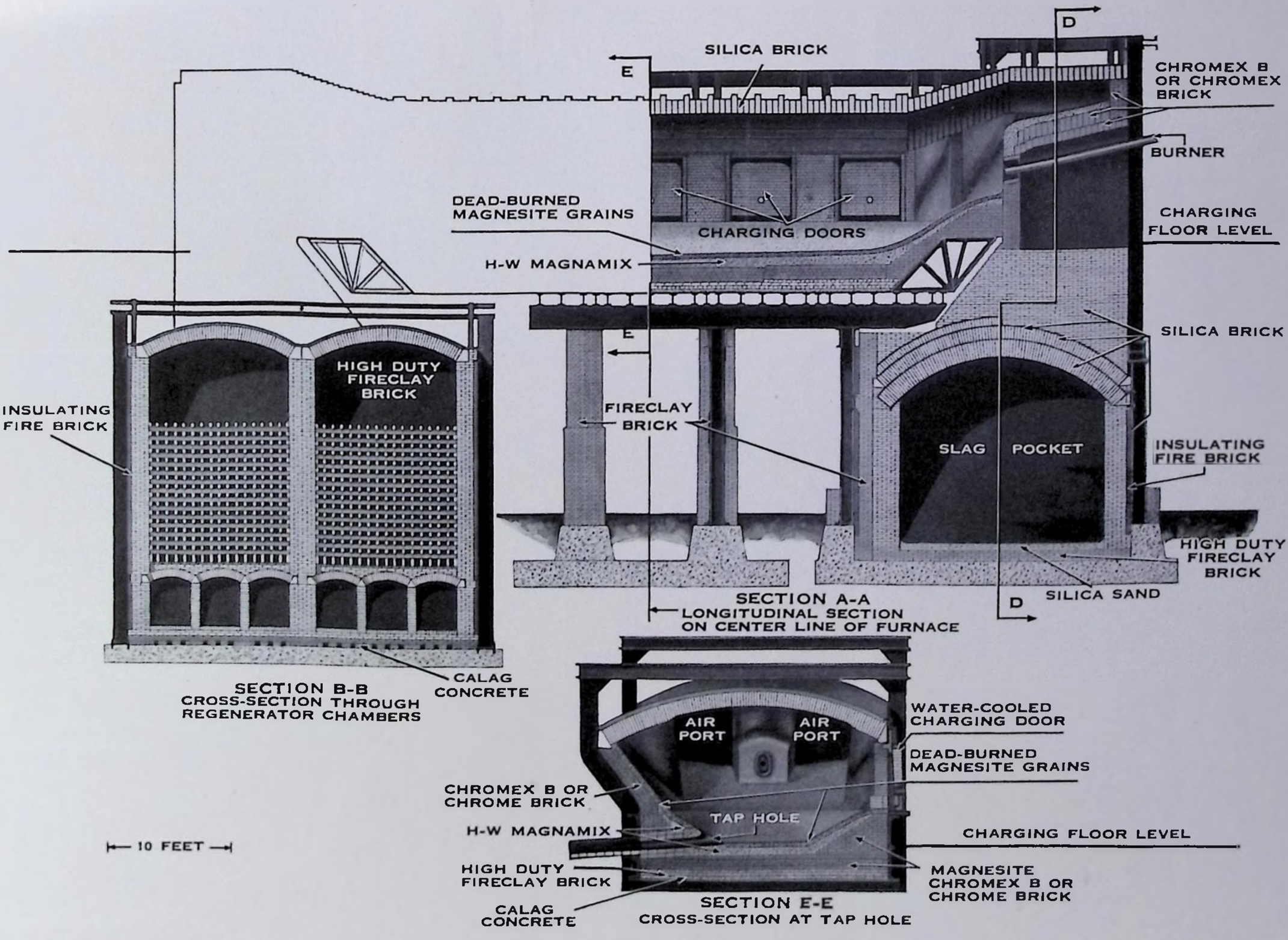
The introduction of oxygen with the fuel may give a more intense flame, and tend to shorten the life of the refractories in the roof. For such conditions VEGA is particularly recommended. When oxygen is introduced through a lance to accelerate the lowering of

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Typical Basic Open-Hearth Steel Furnace

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Typical Basic Open-Hearth Steel Furnace

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the carbon content, violent boiling results which may cause molten slag from the hearth to splash onto the walls and roof of the furnace. The increasing severity of service conditions in the basic open-hearth has led to a greatly accelerated program of research and development on the application of basic refractories in the roof over the hearth.

Front Walls: The front walls of open-hearth furnaces are subjected to extremely severe service conditions. The piers between doors are exposed to flame impingement and to erosion on the inner face and two sides, to rapid changes in temperature when the doors are raised, and to mechanical abuse when the charge is thrust through the door openings. The refractory material of highest resistance to service of such severity, especially when the charging practice is such as to minimize the conditions of mechanical abuse, is METALKASE. These brick consist of a chemically bonded magnesite-chrome composition, and are provided with sheaths of mild steel. In service, the metal oxidizes for a short distance back from the hot end, and is absorbed by the refractory material, with formation of a monolithic surface high in refractoriness, strength and resistance to spalling.

Additional reinforcement and structural strength are given to the front wall piers by the use of steel plates up to ⅜ inch thick in the horizontal joints, at intervals of one to four courses. These plates are rigidly attached to the furnace buckstays and restrain any tendency of the wall to lean inward.

CHROMEX B, an extremely hard burned chrome-magnesite brick, and CHROMEX, a chemically bonded chrome-magnesite brick, are used advantageously in the front walls of many basic open-hearth furnaces. Reinforcement with light steel plates is recommended, except when water cooling systems are provided for the front wall piers.

Open-hearth doors, most of which are water cooled, are lined with brick or with monolithic material on the face exposed to the heat. High duty fireclay brick have been replaced in many instances by METALKASE brick or by PLASTIC THERMOLITH BATCH rammed over studs which are welded to the doors.

Back Walls: A straight back wall of an open-hearth furnace is usually built of the same material as that used in the front wall of the same furnace, and is reinforced in the same manner.

In a sloping back wall the brick in the entire lower part are kept covered with basic granular hearth material. The only brick exposed to contact with the furnace gases are those in a few courses immediately below the skewbacks. The covered portions of the back wall may be built of CHROMEX B or H-W CHROME — both hard burned brick — without steel reinforcement. The exposed portion of the back wall is built of the same material as the front wall, and in the same manner.

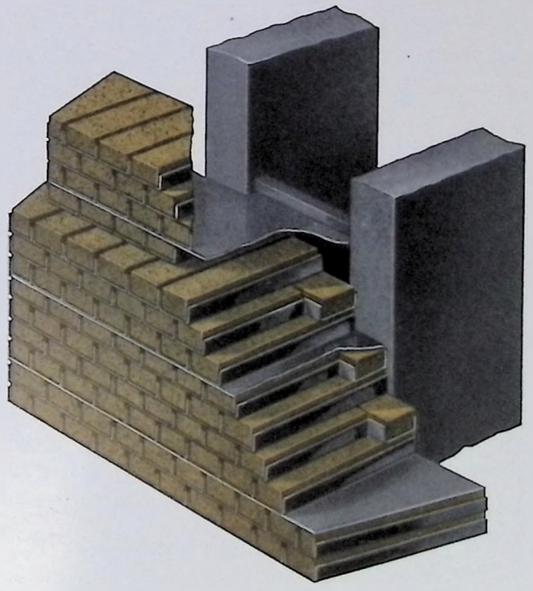
Hearth: Both bottoms and banks of the hearths on which the steel is made are composed of granular basic refractory materials. For the top surfaces, H-W DEAD-BURNED MAGNESITE and H-W FURNACE MAGNESITE are widely used. To these materials, 10 to 15 per cent of open-hearth slag is added to promote sintering. The top surfaces are burned-in, one thin layer at a time.

Prior to World War II grain magnesite hearths were burned-in to a total thickness of 15 to 25 inches. The process required two to three weeks time at maximum operating temperature, before the first charge could be made. Now, high density and homogeneity of the bottom are being obtained with great economy of time, labor, and fuel by the use of H-W MAGNAMIX. Furthermore, damage to the superstructure resulting from the burning-in of a bottom is avoided by the use of this material. It is rammed into place, up to within four to eight inches of the final contours of the bottom and banks, leaving only the top working surface to be burned-in. H-W MAGNAMIX is a cold-setting ramming mixture, prepared from dead-burned magnesite of suitable composition. It requires only the addition of water to bring it to the proper ramming consistency. Its high magnesia content is undiluted by slag additions. At open-hearth furnace temperatures, it develops a strong ceramic bond.

Hearths may be maintained with dressings of H-W DEAD-BURNED GRAIN MAGNESITE, H-W SPECIAL FURNACE MAGNESITE, H-W MAGNAMIX, or refractory dolomite applied between heats.

The sub-bottom under the grain magnesite or H-W MAGNAMIX is of masonry construction. In top courses, H-W MAGNESITE, CHROMEX B or H-W CHROME brick are used. Just above the steel pan, there may be one or more courses of high duty fireclay brick and insulating fire brick; or there may be a layer of insulating concrete beneath the fireclay brick.

Port Ends: With the exception of end wall bulkheads, the port ends of the basic open-hearth furnace are generally built of silica brick. The bulkheads consist of panels of basic brick extending from the top of the end walls down to approximately the level of the charging floor. METALKASE is the outstanding brick for basic end wall construction; the brickwork is reinforced with horizontal steel plates as in the front wall. In many open-hearth furnaces CHROMEX B, CHROMEX, or METALKASE rounds are used in the bulkheads with maximum economy. The last-named consist of refractory magnesite firmly packed and strongly bonded within tubes of soft steel. In laying METALKASE rounds, the spaces between the tubes are filled with H-W SPECIAL FURNACE CHROME or H-W WASHINGTON FURNACE MAGNESITE.



The section illustrated is 18 inches thick from the door sill level to a level 27 inches higher. Above this level, up to the skew line, the wall is 13½ inches thick. Horizontal steel plates are used at every fourth course. These are tack-welded to 1½ by 1½-inch steel bars, which are welded to the solid buckstays. This construction adds rigidity and assists in keeping the plates in place. Special tapered jamb brick provide additional clearance for the charging machine.

Construction of Basic Open-Hearth Front Wall with METALKASE Brick

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An important development in basic open-hearth design is the construction of port ends entirely of basic brick. Suspended arches of CHROMEX B brick with metal casings are installed over the ports. The four port walls down to and including the fantail arches leading into the checker chambers are built with METALKASE or CHROMEX B brick, laid with steel sheets as reinforcement. Because of the weight of such construction, the brick are sectionally supported to relieve pressure upon underlying parts, and to insure stability of the roof, arches and walls.

Basic end construction eliminates silica drip into the slag pocket. As a result, the solid material deposited from basic dust in the outgoing gases is not fluxed, but forms a granular deposit which may be removed readily from the slag pocket after each furnace campaign. Suspension of the climbing arches under the sloping ends of the hearth simplifies and lightens the construction, and makes possible the building of single uptake ports, by eliminating the necessity for arches under the burners.

Fantail Arches: In conventional design, fantail arches leading from the slag pockets to the regenerators may be constructed of STAR silica brick, XX SILICA brick, or ANCHOR brand of high-alumina brick, all of which have adequate mechanical strength to resist the arch stresses.

Regenerators: Regenerator chamber walls and arches are built of high duty or super-duty fireclay brick. The checkers in general consist of high duty fireclay brick, although the top courses may consist of super-duty fireclay or high-alumina brick. Harbison-Walker checker brick are thermally efficient, resistant to spalling and afford a liberal margin in refractoriness. These brick are supplied in a wide variety of sizes and shapes. They are so designed that they may be fitted together into various standard checker arrangements, as well as into special arrangements to meet specific problems of heat transfer or dust accumulation.

Bonding Mortars: In front walls, back walls, and end walls, basic brick other than METALKASE are advantageously laid with THERMOLITH. In the silica portion of roofs, port arches, and uptakes, STARBOND and VEGA BOND may be used. STARBOND is equivalent in refractoriness to STAR silica brick, and VEGA BOND to VEGA super-duty silica brick. For laying fireclay brick in regenerator walls and arches, and high-alumina brick or silica brick in fantail arches, HARWACO BOND is recommended.

ACID OPEN HEARTH

In acid open-hearth furnaces, silica refractories are employed almost exclusively above the charging floor level. STAR silica brick are extensively used in roofs, front walls, and back walls. For maximum economy, VEGA super-duty silica brick are frequently employed in sections where the service is most severe. The furnace bottoms are made up with mixtures of H-W GROUND SILICA GANISTER and fireclay, or with silica sand. The sub-bottoms are built mainly of silica brick. Between these and the steel pan there are one or more courses of high duty fireclay brick and insulating fire brick.

The ports and the end walls are usually built of silica brick, although very satisfactory results have been obtained from H-W CHROME brick and from FORSTERITE brick in the bulkhead panels. The regenerator chambers are usually built of high duty or of super-duty fireclay brick, and the checkers either of brick of the same type and quality as those used in the walls, or of silica brick.

PETROLEUM REFINING

PRESENT day practice in the refining of crude petroleum is extremely flexible, in order to produce the wide variety of finished products demanded by constantly changing market conditions. Although many of the modern processes are of a chemical rather than a physical nature, practically all of them require heat. This is supplied by the combustion of fuel oil, natural gas, or refinery fixed gas.

The crude oil received at the refinery is first subjected to atmospheric distillation and subsequent fractionation. The general fractions or cuts, separated through the differences in their temperatures of vaporization, then receive further processing for the production of gasoline or other marketable products. This processing may consist of vacuum distillation, thermal cracking, catalytic cracking, reforming, polymerization, or isomerization.

Atmospheric distillation is accomplished by means of tubular heaters, which may be of the chamber or box type, the cellular type, or the circular type. Usually, tubes are so arranged in the combustion chamber that they absorb a large percentage of the radiated heat. An economizer or convection section, composed of a bank of closely nested tubes and located between the combustion chamber and the stack, picks up heat by convection from the gases leaving the radiant heating zone.

Tubular heaters are also used in conjunction with reaction chambers or soaking drums in thermal cracking installations. They are employed for thermally reforming low grade gasoline, for preheating the charge to catalytic cracking and polymerization plants, and for preheating and reboiling purposes in the case of isomerization and treating units. The settings of these tubular heaters normally have roofs and walls of supported construction.

The type of refractory employed in tubular heaters depends upon operating conditions. The settings may consist of dense refractory brick, insulating fire brick, or sections of each. In recent years, castable refractory materials have been employed to some extent, principally for heaters operated at relatively low temperatures. The walls and arch are often as little as 3 inches thick where protected by tubes, particularly when sectionally supported. In unprotected sections, they are generally 7 to 9 inches thick. In all cases, the cold face of the suspended construction is covered by insulation. This is protected from the weather by waterproofing material, asbestos board, building brick, or a casing made of steel plate.

Sections of the settings of certain types of tubular heaters are subjected to flame impingement or to high combustion temperature. For such conditions, high-alumina brick are frequently employed. In the remaining portions of the setting, the normal temperature rarely exceeds 2000° to 2400° F. The refractories, however, must be capable of withstanding extreme thermal shock, such as may be occasioned by a sudden shutdown following a tube rupture, when the heater is quickly flooded with steam to extinguish the flames. The high resistance of super-duty fireclay brick to thermal shock renders their use an economy for this service.

Specific uses of refractories in the petroleum refining industry include the following:

Tubular heater settings, which house the combustion zone and the tube bank.

Burner blocks and baffles.

Firing tunnels where ignition and partial combustion of the fuel takes place before it is discharged into the heater setting.

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Shapes for access openings, explosion door openings and peep-holes.

Bridge walls, such as those which separate the radiant and the convection zones in certain types of oil heaters.

Checkered arches and piers, used principally in heaters which employ flue gas circulation.

Linings for chimneys.

Linings for catalytic regenerators and reactors.

Linings for direct-fired air heaters.

Linings for miscellaneous vessels.

High-alumina brick and super-duty fireclay brick serve most advantageously in those parts of the furnaces where the brick are subjected to soaking heats, to heavy loads, or to rapid changes in temperature, or where they are exposed to the action of reducing gases, such as hydrogen or carbon monoxide. In certain thermal reactions there is a tendency for carbon to form within the refractories, causing their disintegration. For such service, brick of an extremely hard burn, such as specially hard-burned VARNON, will give longest life.

Special shapes required for any of the different types of suspended arches and walls are manufactured in high duty and super-duty fireclay material, and in high-alumina material.

The use of Harbison-Walker light-weight insulating fire brick in suspended walls and arches is common practice. It is found that insulating refractories, because of their low heat storage capacity, greatly reduce or even eliminate coking in the tubes, resulting from sudden shutdowns or due to other causes. Insulating fire brick are employed advantageously in service where the operating temperatures are cyclic in character. Ovens designed to supply hot flue gas for process purposes will operate with much more rapid changes in temperature if the linings are constructed of insulating fire brick than if they are built of dense fireclay brick. The saving in fuel is also an important factor.

The oil industry has many uses for refractories which are similar to those in other industries. For example, nearly all refineries or gasoline plants have steam boiler installations, some have calciners for reactivating fuller's earth, and many have chemical equipment such as acid sludge kilns, facilities for producing sulphuric acid by the combustion of hydrogen sulphide, and other facilities.

Harbison-Walker high-alumina brick are widely used in sludge burners and in combustion chambers and walls of boiler settings. The brands best adapted to this service are ANCHOR, in the 60% alumina class, and DIALITE, in the 50% alumina class. These brick are highly resistant to the action of free acids, and to attack by the slag, which usually contains appreciable quantities of lime and potash. VARNON and ALAMO super-duty fireclay brick give superior service where the acid sludge is not neutralized, or where the neutralizing agent is either a sodium compound or ammonia.

The standard or special shapes employed in multiple-hearth or rotary calciners for reactivating fuller's earth must be of superior workmanship and of proper hardness, strength and density. For many years, Harbison-Walker brands of high duty fireclay brick have been accepted standards for this service.

The use of HARWACO BOND or FIREBOND for laying high-alumina or fireclay brick in oil refinery furnaces is recommended.

DURO and W-ACID brick are widely used in equipment employed for the production and recovery of acids, and in the linings of agitators.

PULP AND PAPER MILLS

Sulphite Process: In the sulphite process, refractories are required for boiler settings and for linings of furnaces used in the burning of sulphur or pyrites. Harbison-Walker high duty and super-duty fireclay brick and high-alumina brick are accepted standards of quality.

Dense, impervious, acid-resisting brick are required for the linings of acid towers, accumulators, storage tanks and blow-pits, and for the linings and the packing of acid-reclaiming towers. For these various service conditions DURO and W-ACID acid-proof brick, tile and tower packing partition rings are unexcelled.

Harbison-Walker manufactures special digester brick for the linings of sulphite digesters. These brick are produced in the several textures best adapted to meet the various service requirements in face and back linings.

Soda and Sulphate Processes: In both the soda and the sulphate processes a wide variety of refractories is required for furnaces used in connection with the recovery of sodium salts and other chemical compounds. These furnaces comprise rotary incinerators, recovery furnaces and boilers, shaft lime kilns, rotary lime kilns, and rotary lime sludge kilns.

In the linings of rotary black ash incinerators, Harbison-Walker brands of high duty and super-duty fireclay brick, manufactured in a manner which gives them a dense texture, are giving exceptionally good results.

The smelter or recovery furnace and the modern recovery boiler reclaim sodium salts from waste liquors of the kraft and soda processes of paper making. These furnaces require careful selection of refractories, because of the strongly corrosive action of the molten sodium salts. In the main, the lining problems are similar, since similar furnace conditions exist; that is, high temperatures in the presence of sodium salts, resulting in severe fluxing action upon the lining. In furnaces of the conventional types, H-W CHROME, CHROMEX, and CHROMEX B brick are employed extensively for building the walls and bottoms. However, they should not be used where steam comes in direct contact with the refractory. Dense high duty fireclay brick are generally preferred in the upper portions of the walls, and in the arches. THERMOLITH is recommended for bonding either chrome or fireclay brick. DRY or PLASTIC THERMOLITH BATCH serves very satisfactorily for patching and for making rammed bottoms.

In the newer recovery boilers where black liquor is sprayed into the combustion chamber, the refractories in the upper walls for the most part are set behind water tubes. They usually consist of high duty fireclay tile or brick with a backing of light-weight insulating brick, such as H-W16 or H-W20. The bottoms and lower side walls of the combustion chamber may be built with THERMOLITH BATCH or PLASTIC THERMOLITH BATCH well rammed into place. Also widely used in bottom construction are CHROMEX and CHROMEX B brick, laid with THERMOLITH high temperature bonding mortar to fit the sloping contour of the bottom.

Universal Circle Brick made in DURO and W-ACID brands are widely employed for vertical tank linings which must be resistant to caustic or acid solutions. They are suitable for the linings of tanks used for causticizing, for dissolving tanks, for the storage of the various liquors, and for the storage of acids in bleaching plants. Universal Circle Brick are described and illustrated on page 127.

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ROASTERS—MULTIPLE-HEARTH

Not many years ago, roasters were used almost exclusively for the desulphurizing of ores and concentrates. However, roasters of some types are so flexible and transmit heat so efficiently that they have been widely adapted to other uses. Today, their applications may be for roasting, incinerating, calcining, activating and drying in the metallurgical, chemical, petroleum and other process industries.

The requirements as to workmanship for brick used in roasters are most exacting. This is especially true of shapes used in multiple-hearth roasters to form the hearths, which are dome or cone segments of slight curvature. Harbison-Walker roaster brick are manufactured with a thorough understanding of this important requirement.

A property desirable in any roaster brick, especially for those used in multiple-hearth furnaces, is low thermal expansion. By careful selection of clays, the company produces brick which are outstanding for this service. The high temperature at which the brick are fired minimizes shrinkage in service. Important properties which contribute to their superiority are low porosity and low permeability, high mechanical strength at working temperatures, and ability to withstand changes in temperature.

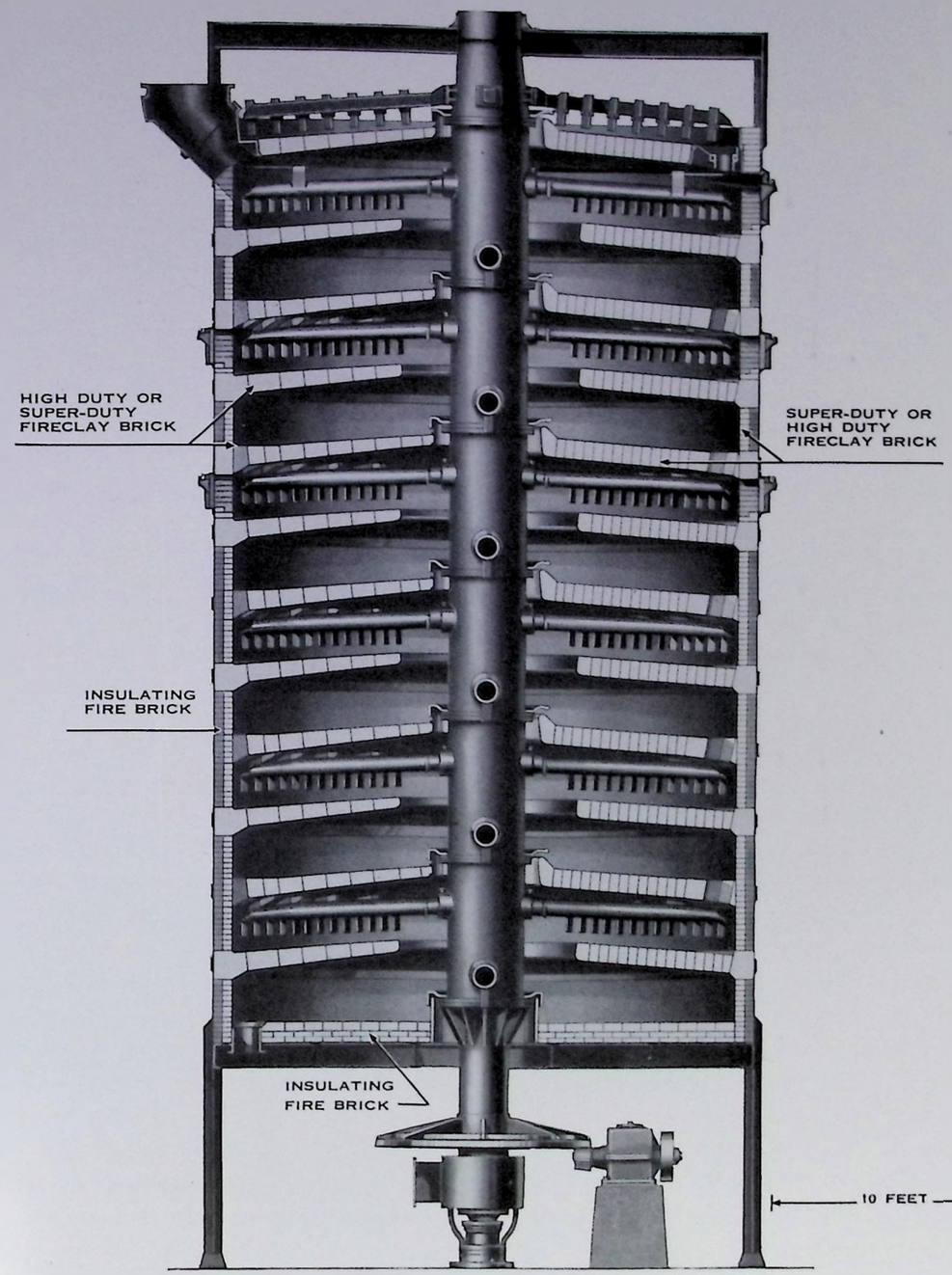
For roasters equipped with auxiliary burners between the hearths, it becomes necessary to make a special selection of refractories other than high duty fireclay brick, having the special characteristics best adapted for the linings, hearths, and shafts. In the operation of some of these roasters, and some used for flash roasting, exceedingly high temperatures and severe fluxing conditions prevail. Depending upon the severity of the treatment to which the refractories in the combustion chambers are subjected, Harbison-Walker furnishes either super-duty fireclay brick or high-alumina brick such as Alcor or Korundal.

In the manufacture of brick to be used in roasting sulphide ores, the clays used must be carefully selected and processed in order to guard against the tendency toward swelling or disintegration due to "sulphating". Sulphating, resulting from the condensation of moisture in the presence of sulphur dioxide or trioxide, is an important factor. The use of Harbison-Walker insulating fire brick has contributed much to the avoidance of this difficulty.

Harbison-Walker produces refractories for roasters in which highly reducing atmospheres are maintained. By special selection of clays, and careful control of firing temperatures and kiln atmospheres, refractories which are practically immune to disintegration over the critical temperature range are produced.

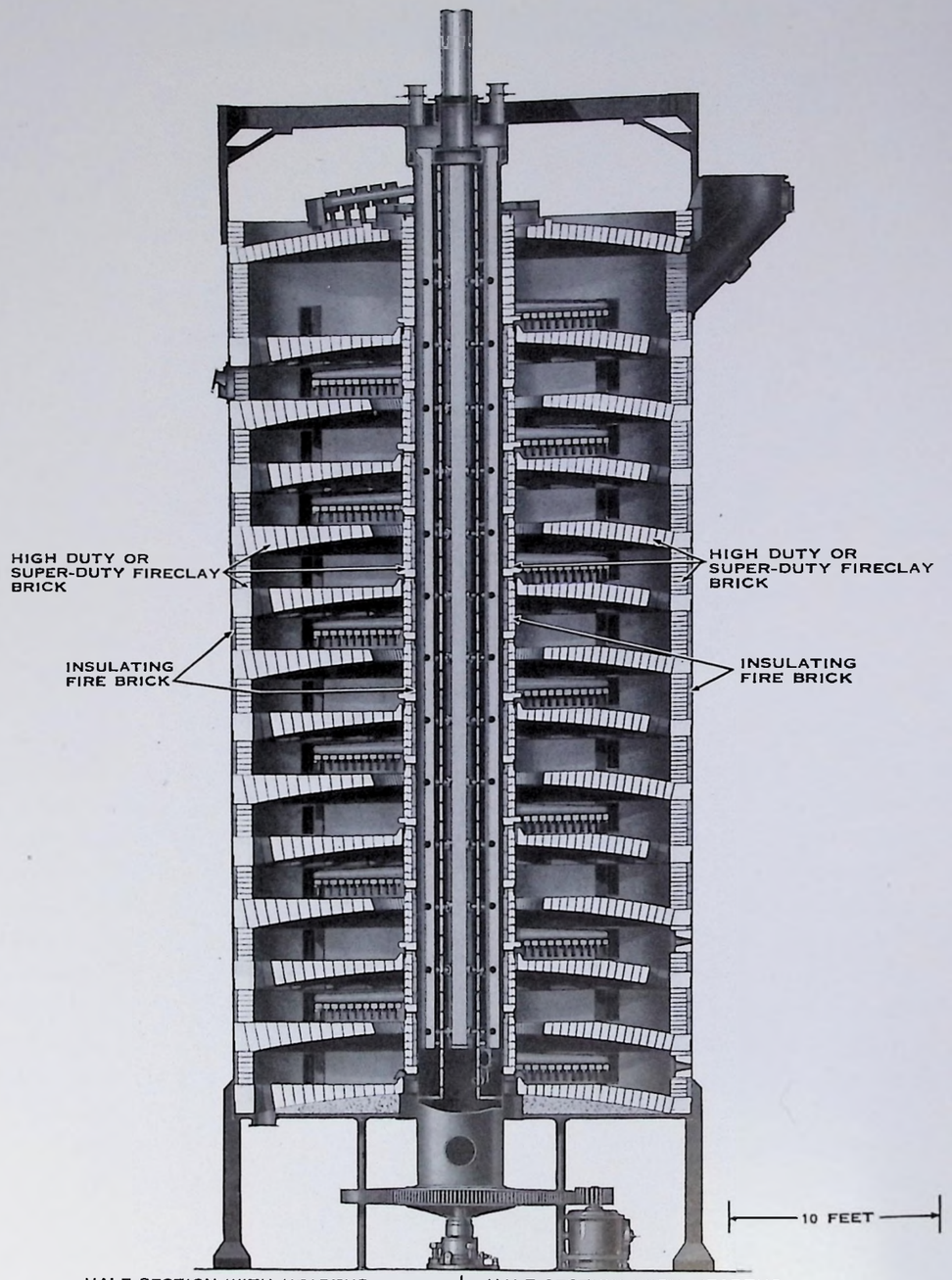
Many roasters are now provided with a course of insulating fire brick between the shell and the refractory lining. The brand H-W 26 is used extensively, primarily because of its high compressive strength. For a higher degree of insulation, H-W 23, H-W 20, and H-W 16 brands may be used, depending upon the specific conditions. H-W 26 is used also with excellent results in door linings.

The high temperature bonding mortars Harwaco Bond and Thermolith, used for laying brick and for coating hearths, effectively bond the shapes, and go far toward preventing calcines from working into joints during periods of unavoidable shut-downs. Accurate measurements of hearths built of Harbison-Walker brick and laid with these bonding mortars have shown no cumulative rise during operating periods extending over many years.



Multiple-Hearth Roasting Furnace

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Multiple-Hearth Roasting Furnace

ROTARY KILNS

IN CEMENT MILL PRACTICE

PROGRESS in the Portland cement industry has been accompanied by improvements in operating technique, higher productivity, development of numerous cements having specific properties, and close adherence to rigid specifications. Evolution in cement mill practice has brought about a trend toward harder burning of the clinker, with increased severity of the conditions which the refractory linings of the rotary kiln must withstand.

The extent to which the linings are corroded is influenced to a considerable degree by the composition of the mix. Even a slight difference in the lime-silica ratio may result in greatly different burning characteristics. Feed relatively high in alkalies may have a severe chemical action upon the lining in the burning zone, even though burned at a temperature lower than that employed for more refractory mixes. High-iron mixes, and high early-strength cements, are generally burned under rather severe conditions.

No one brand or type of refractory can be expected to give the most economical results under all the varied conditions of service. Harbison-Walker brands of rotary kiln blocks cover the entire range of cement kiln requirements. Recommendations as to the brand best adapted to specific requirements will be made promptly upon request.

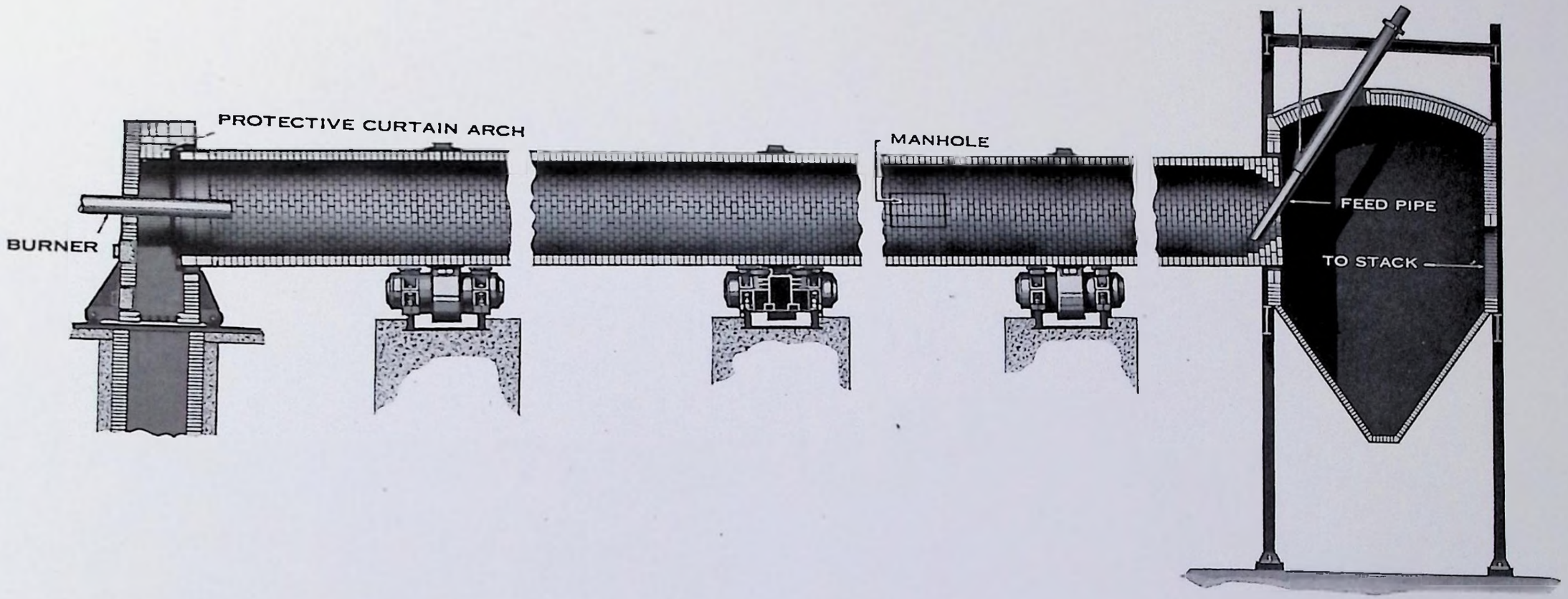
The service imposed upon the lining in the feed end of dry process kilns is relatively moderate. Temperatures are not high, temperature changes are not rapid, and abrasion by the charge is not severe. The brick used should have satisfactory resistance to the spalling conditions, and should have high mechanical strength, especially for linings of shells which have been in service for a long time. In the chain sections of wet process kilns, abrasion may be severe. DURO and WYLAM A brands of extremely hard dense fireclay brick often last three to four times as long as other dense fireclay brick in this service. Under some conditions, they may be used well into the intermediate zone of the kilns.

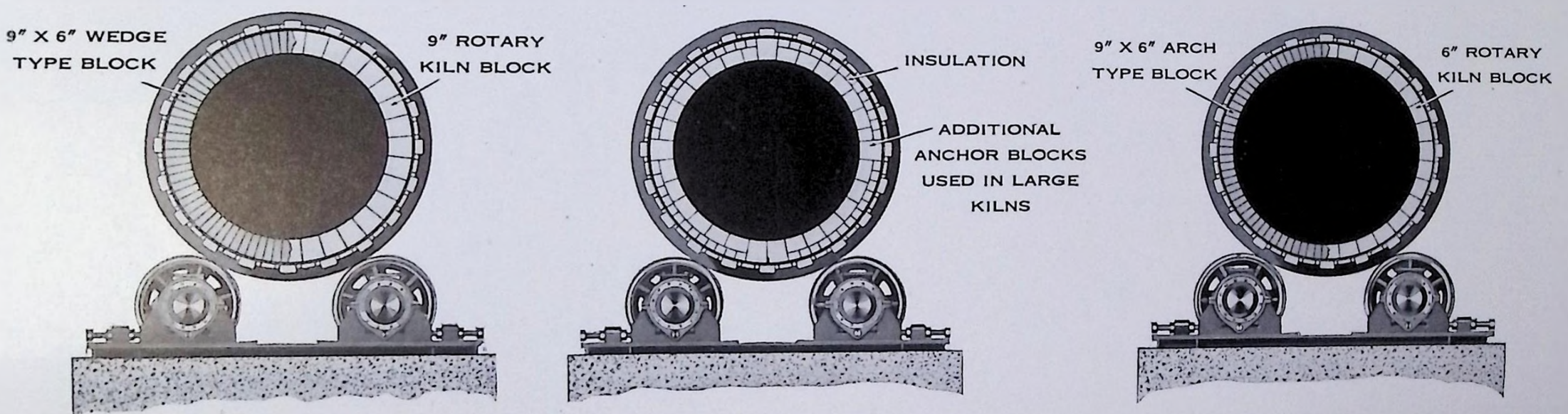
In the intermediate zone the brick are exposed to higher temperatures, with moderate fluctuations in temperature. In the hotter end of the intermediate zone, the linings must withstand chemical attack by the mix. The brick must be mechanically strong, since they are called upon to resist stresses resulting from kiln torsion and deflection.

Throughout the greater part of the intermediate zone, high duty fireclay brick usually give long service, although super-duty fireclay brick are being used to an increasing extent. In the hottest portion of this zone, super-duty fireclay brick and high-alumina brick are often used with excellent economy. The brand which will give best service will depend upon the service conditions. ALUSITE, in the 70% alumina class, is generally used in the intermediate zone when the burning zone has a basic lining.

In the burning zone of the kilns, service conditions vary from relatively moderate to extremely severe. For moderately severe service, brick of the 50% or 60% alumina class may be used. H-W SPECIAL H. A., DIALITE or ANCHOR are recommended. However, service conditions are usually more exacting than such refractories will withstand, and the burning zone refractory most widely employed is

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Typical Rotary Cement Kiln

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high-alumina brick of the 70% alumina class. ALUSITE brick in this class possess all the desirable characteristics for this type of liner. The brick are dense and mechanically strong, highly resistant to chemical attack by the clinker, and yet capable of taking on and retaining the necessary protective coating. For conditions more severe than even ALUSITE can withstand to advantage, the use of CORALITE brick, of approximately 80% alumina content, will provide higher refractoriness. However, even this refractory is not always entirely adequate. For such conditions, basic refractories such as MAGNEX and THERMAG are employed. These brick readily take and hold a coating which protects them from chemical attack.

By laying basic brick with steel sheets or plates between the joints parallel to the axis of the kiln, a high degree of structural stability is obtained. In service, the metal oxidizes for a short distance back from the hot end, combines with the refractory material, and forms a monolithic surface which is highly resistant to corrosion and spalling. The unaffected portion of the metal adds strength to the lining. In the construction of kiln linings of basic material, 9″ x 6″ x 3½″ arch and wedge brick are used in preference to the usual radial rotary kiln blocks, because the smaller brick are more resistant to spalling influences. Between the burning zone and the nose brick the use of ALUSITE is most common practice.

There is a wide selection of Harbison-Walker brands of refractory materials for the linings of the hoods, coolers and waste heat boilers.

The use of THERMOLITH or HARWACO BOND for laying nose ring and feed end blocks, as well as for laying brick in the hoods and waste heat boiler settings, has resulted in marked economies. HARWACO BOND is widely used for grouting fireclay and high-alumina brick linings which are laid dry.

Cement Kiln Coolers: Rotary coolers are lined with a dense, tough, and abrasion-resistant refractory. DURO and WYLAM A brands meet these specific requirements.

Some rotary cement kilns are equipped with integral coolers either as an extension of the kiln shell or in the form of a number of small units attached to the kiln discharge end and revolving with it. In the most vulnerable spots of such coolers, a dense, super-duty fireclay brick such as VARNON, which has good strength and volume stability at high temperatures, is required. At other locations an abrasion-resistant refractory such as DURO is preferable.

Grate type coolers, over which the hot clinker passes and through which secondary air is blown, are now used extensively. The secondary air cools the clinker quickly, becomes preheated, and increases the efficiency of combustion in the kiln. Coolers of this type require a high duty refractory lining for the side walls and roof. WOODLAND, WALSH XX, HIGH GRADE XX, and H-W CROWN brands are used extensively. At the spot where the hot clinker is impacted upon the brickwork, a high-alumina refractory such as KORUNDAL serves best.

ROTARY KILNS FOR LIME PRODUCTION

The rotary kiln is widely employed for the production of lime from limestone and dolomite, and to a lesser extent from marine shell. In most kilns, marked temperature fluctuations exist. Abrasive action of the stone may be severe, especially at the feed end. In the hot zone, the lime tends to flux the refractories, as does ash from powdered coal fuel. Most linings

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are subject to the formation of rings, which are removed periodically. Cooling of the kiln, for removal of a ring, may cause spalling.

In the feed end section, DURO and WYLAM A serve to resist the abrasive action of the stone. In the intermediate temperature zone, high duty fireclay brick are widely employed. VARNON super-duty fireclay brick, when used in this zone, have satisfied the need for brick that are hard and strong and resistant to the spalling influences of rapid temperature change. In the calcining zone, service conditions vary from relatively mild to extremely severe and the most suitable refractory lining material for any particular installation will depend upon the operating conditions. ALUSITE 70% alumina brick are most widely used. However, Harbison-Walker super-duty fireclay brick give entirely satisfactory service in some kilns and DIALITE 50% alumina brick or ANCHOR 60% alumina brick in others.

HARWACO BOND is employed advantageously for laying the nose and feed end blocks, and for grouting the brick throughout the kiln.

ROTARY KILNS FOR LIME RECOVERY

In paper mills, sugar refineries, and chemical plants producing soda, lime is used extensively for causticizing purposes. The spent lime is in the form of thin slurry or sludge. Recovery of lime from the sludge is often important in the economy of the process. In the majority of cases rotary kilns are used for this purpose.

The factors affecting the life of the kiln linings include the amount of water in the sludge, the alkali content of the sludge, the type of fuel and burners, the continuity of operation, and the use of chains in the feed section.

In the feed end, temperatures are moderate. Feed end blocks must be mechanically strong, of homogeneous texture, and resistant to rapid changes in temperature. In the chain section, DURO and WYLAM A brick are unsurpassed in resistance to the impact and abrasive action of the chains.

The charge moving through the intermediate zone is heated to progressively higher temperatures. At the hotter end of this zone, the temperatures may be high enough to cause chemical reaction between the charge and the lining material. The liners should be dense, to minimize penetration by fluxes, and at the same time resistant to rapid temperature changes. High duty or super-duty fireclay brick are used for lining the intermediate zone.

In the burning zone, high-alumina brick of the 50%, 60% and 70% alumina classes are employed. ALUSITE, in the 70% alumina class, is used extensively. In some cases, ALUSITE is used in the burning zone, with ANCHOR (60% alumina class) in the adjacent sections.

Basic refractories serve to advantage in the burning zone to resist the fluxing action of soda. H-W MAGNESITE and FORSTERITE A are used to a considerable extent. These brick are laid with steel plates of 16 to 20 gauge.

For service in which the purity of the reclaimed lime is of primary importance, H-W PERIKLASE rotary kiln blocks are recommended for the burning zone. On account of their high thermal conductivity, they are sometimes laid with a backing of high duty fireclay brick, to avoid overheating the shell.

Nose blocks may be of high duty fireclay, super-duty fireclay or high-alumina material, depending upon operating conditions.

HARWACO BOND and FIREBOND high temperature bonding mortars serve splendidly for laying the nose ring blocks and for grouting linings formed of fireclay or high-alumina brick.

ROTARY KILNS FOR SINTERING BASIC PRODUCTS

In rotary kilns employed for sintering dolomite or dead-burning magnesite, temperatures in the burning zone may be as high as 3100° F. The fluxes added to the charge cause chemical attack of unusual severity on lining materials of most types. Mechanical erosion also must be resisted by the linings in the hot zone, as well as in the intermediate and feed end zones.

Choice of the refractory materials for lining the kilns will depend upon the particular service conditions. Materials used with highly economical results are as follows:

Location	*Refractory*
Discharge End:	ALUSITE (70% alumina class)
Burning Zone:	FORSTERITE A MAGNEX
Intermediate Zone:	ALAMO (Super-duty fireclay) VARNON (Super-duty fireclay) DIALITE (50% alumina class) ALUSITE (70% alumina class) CORALITE (80% alumina class)
Feed End:	High duty fireclay DURO (fireclay) WYLAM A (fireclay)

SILICATE OF SODA FURNACES

THE economical operation of furnaces used in the production of silicate of soda depends in a large measure upon the selection of the refractories of which the furnaces are constructed. In many plants, including those in which all the various commercial grades of silicate of soda are manufactured, Harbison-Walker refractories are accepted standards.

WOODLAND, H-W HIGH GRADE XX and WALSH XX brands of high duty fireclay brick have the chemical and physical properties which are especially desirable for service in furnace bottoms, side walls, roofs and regenerator chambers, including the checkers. ALAMO and VARNON brands of super-duty fireclay brick meet the more severe service conditions where fluxing action tends to destroy the lining.

In a number of plants, STAR silica brick are the standard for roof construction of either the sprung arch or suspended types. Prolonged service is secured by the use of DIALITE, of the 50% alumina class, for the roofs of furnaces in which unusually severe conditions prevail. DIALITE is especially desirable for the portions of the roof surrounding the charging holes.

Special refractories adapted for service in various vulnerable parts of the super-structure are available from the full line of refractories produced by Harbison-Walker. KORUNDAL high-alumina brick, containing approximately 90 per cent alumina, may be used for parts where the service is too severe for refractories of the types used in the major portions of the furnaces, as in the ports and top courses of the checkers, and around the tapping holes.

Increased furnace life is secured by the proper application of the bonding mortars FIREBOND and HARWACO BOND.

Modern Refractory Practice: 3rd Edition (1950)
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SOAKING PITS

While the temperatures at which soaking pits are operated in normal practice are relatively moderate, the service conditions to which the refractories are exposed are frequently severe. Opening of the pit for withdrawing ingots or for charging, especially when cold ingots are charged, may cause a sudden drop in temperature of hundreds of degrees. When the pit is closed, heating is correspondingly rapid. The brick in the lower walls are subjected to corrosive action of molten iron oxide scale. Impact from ingots or charging tongs may cause severe mechanical damage to pit walls or bottoms. At some steel plants, open-hearth capacity has been greatly increased without corresponding increase in ingot heating capacity; consequently, pits are forced to operate on faster heating schedules and at higher operating temperatures.

While in some instances domed pit covers are constructed from rectangular brick sizes, the use of suspended arch shapes has been widely adopted. These may be high duty fireclay brick, such as WOODLAND X DASH, WALSH XX, H-W CROWN, or COLEMAN XX, super-duty brick such as ALAMO or VARNON, or H-W 28 insulating fire brick. Highest standards of workmanship must be met in making the suspended arch shapes, to permit the brick to be fitted closely. Close fitting minimizes mechanical damage to the covers when they are moved for opening and closing the pits. Harbison-Walker special arch shapes are manufactured to provide the maximum resistance to thermal shock. They are laid advantageously with HARWACO BOND.

The upper walls are frequently built with XX SILICA. The hot faces of the brick in service tend to acquire a glaze, which contributes to longer life. The brick do not shrink and they have good resistance to thermal spalling. They should be laid with ample allowance for thermal expansion. STAR silica brick are also used with good results. In some cases, high duty fireclay brick are employed; if operating conditions are particularly severe and temperatures extremely high, super-duty brick are best.

The curb tile, usually consisting of high duty fireclay or super-duty fireclay material, must have adequate strength to withstand impact and abrasion which may result from the handling of ingots. Harbison-Walker standard hearth tile 18″ x 9″ x 4½″, laid with HARWACO BOND, serve admirably for this purpose.

In lower side walls CHROMEX, CHROMEX B, H-W CHROME, METALKASE or ALUSITE brick, laid with H-W SPECIAL FURNACE CHROME or THERMOLITH, serve to withstand the severe corrosive action of iron oxide scale. PLASTIC THERMOLITH BATCH is used in the bottoms and around the burner openings.

In regenerative fired pits, high duty or super-duty fireclay brick are used for the checker chambers and checkers. In the checkers, it is good practice to lay super-duty brick in the top eight to fifteen courses, with high duty brick below. Flue connections are built of intermediate duty fireclay brick such as WEBSTER, SALAMANDER, WYLAM, or COLEMAN.

For recuperative fired pits, Harbison-Walker manufactures tile in various classes of refractories. The excellence of Harbison-Walker workmanship is demonstrated by the various intricate shapes supplied for recuperator construction. Leakage of gases is minimized by laying the brick with HARWACO BOND.

Harbison-Walker bulk insulation and insulating fire brick are widely used in construction of soaking pit walls and regenerator chambers.

ZINC

The many and varied products of Harbison-Walker include refractories well adapted for use in the various types of furnaces employed in the metallurgy of zinc.

The outstanding records established with Harbison-Walker brick in roasters of various types demonstrate how well the requirements for roaster service have been fulfilled.

The division walls of zinc distillation furnaces are subjected to very severe conditions imposed by the combination of soaking heat and heavy load. The Harbison-Walker brands of fireclay brick WALSH T, ALAMO and VARNON, which serve this purpose with excellent results, have rigidity and strength at high temperatures, the refractoriness necessary to endure the long-continued soaking heat, and the high quality of workmanship required. STAR silica brick are well adapted to service in center walls and shelves in zinc distillation furnaces, especially when natural gas is used for firing.

With raw producer gas as fuel, the fluxing action of slag upon brickwork in the combustion chamber may be severe. ALAMO super-duty fireclay brick are highly resistant to this action.

The special dense high duty fireclay refractories in the form of various special shapes required for electrothermic zinc smelting furnaces have been manufactured by Harbison-Walker for many years.

The linings of rotary recovery furnaces must be resistant to the action of the slag and to the destructive influence of carbon monoxide gas. Hard-burned high duty fireclay brick, super-duty fireclay brick and in some cases STAR silica brick are used to advantage.

In zinc oxide furnaces, the superior service given by STAR silica brick in side walls, roofs and bridge walls is recognized. High duty fireclay brick made by the de-aired extrusion process and by the vacuum power press process are also used with gratifying results in many such furnaces. Commonly used brands are WALSH XX, WALSH T and WOODLAND. Harbison-Walker bonding mortars have proved their value for laying brick in bridge walls, doors and other parts of the zinc oxide furnaces.

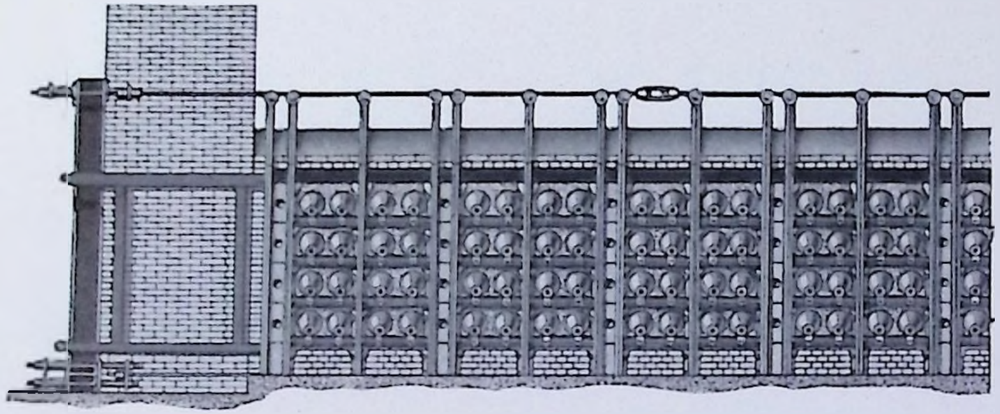
Choice of refractories for zinc melting furnaces involves the selection of several distinct types and classes, in order to secure best service, and to avoid maintenance expense in any part of the furnace in advance of the usual general repairs. High duty dense fireclay brick, such as WALSH T, are used with splendid results for construction of bottoms and lower side walls, with WALSH XX in the upper walls and usually in the roofs. ALAMO gives outstanding service in combustion chambers and, where conditions necessitate, in the roofs as well. HARWACO BOND is used for laying all the brick in the entire furnace structure.

The various brick shapes required for sintering machines, sulphur burners, and gas producers, are supplied in the brand best adapted to the service. In certain high-temperature sulphur burners, ALCOR and ANCHOR brands of high-alumina brick are giving much longer service than other refractories. DURO and W ACID acid-proof brick are widely used for linings and packing of sulphuric acid towers, and for linings and insulators of electrolytic zinc cells.

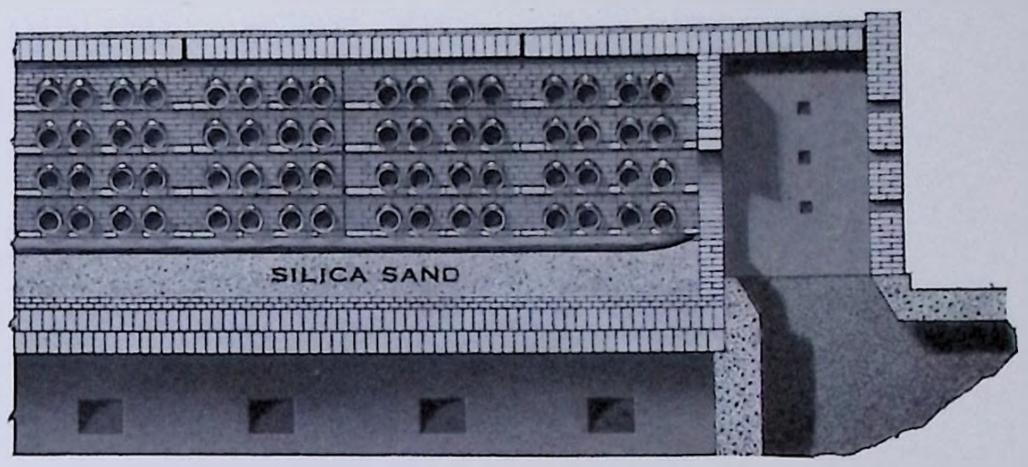
Harbison-Walker special plastic bonding and calcined clays serve as raw materials for the production of zinc retorts and condensers, and tile.

THERMOLITH, FIREBOND and HARWACO BOND bonding mortars are contributing much to the long service obtained from Harbison-Walker refractories in zinc furnaces.

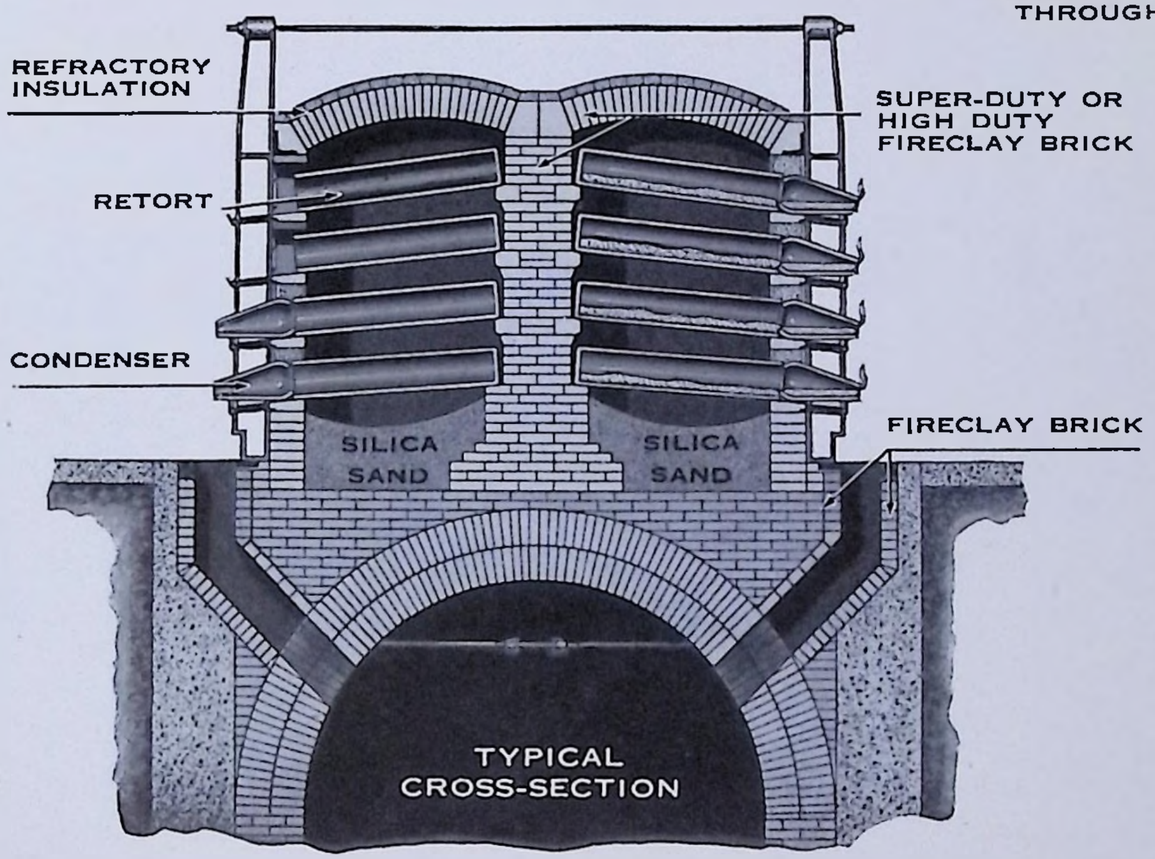
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LONGITUDINAL ELEVATION



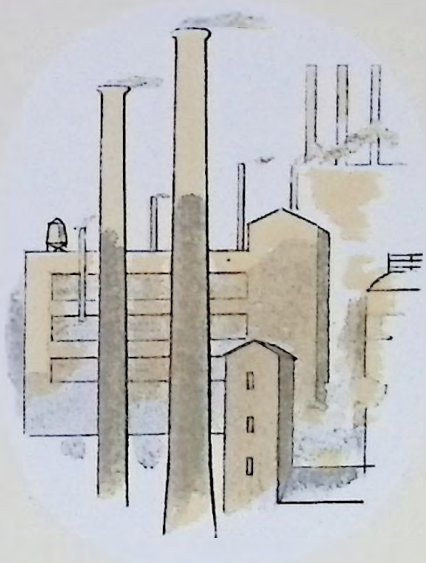
LONGITUDINAL SECTION THROUGH RETORTS



Zinc Distillation or Retort Smelting Furnace

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SELECTION AND USE OF REFRACTORIES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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SELECTION AND USE OF REFRACTORIES

ECONOMY in the use of refractories is governed largely by selection of the kind best suited for the purpose intended. A careful study of furnace design and operating conditions will greatly aid in this selection.

The type and class of refractory most suitable in any particular case will be determined by such factors as the following:

1. **Factors Related to Furnace Design:**
   - Type of construction.
   - Furnace volume for maximum fuel input.
   - Dimensions of walls and arches.
   - Is heat to be confined or to be transmitted?
   - Load imposed upon the lining materials.
   - Method of firing.
   - Conditions of heating:
     - From one side, as in side walls.
     - From more than one side, as in bridge walls, checkers, piers, and muffles.
   - Impinging flames or hot spots.
   - Insulation.
   - Ventilation of furnace parts.
2. **Factors Related to Operation:**
   - The temperature.
   - Continuity of operation.
   - Rapidity and range of temperature changes.
   - Character of raw materials treated.
   - Kind of fuel.
   - Heat release per unit of volume.
   - Rate of heat dissipation.
   - Chemical attack by oxides of metals, by slags or by fuel ash.
   - Chemical attack by dust or fumes.
   - Composition of gases in contact with the refractories.
   - Velocity of gases in contact with linings.
   - Abrasion resulting from moving charges.
   - Abrasion from dust in rapidly moving gases.
   - Mechanical wear.
   - Impinging flames or hot spots.
   - The effects of pulsating flames, explosions, or machinery vibration.
3. **Factors Related to Refractories:**
   a. Properties at atmospheric temperatures:
      - Workmanship, uniformity in size and freedom from warpage.
      - Strength and ability to withstand normal handling.
      - Weight.
      - Porosity and permeability.
      - Chemical and mineral composition.
      - Uniformity in texture and composition.
      - Size and design of brick shapes.

   b. Properties at high temperatures:
      - Refractoriness.
      - Reversible thermal expansion.
      - Resistance to thermal shock.
      - Resistance to chemical attack.
      - Resistance to load, to shearing action, and to cross-breaking stresses.
      - Resistance to abrasion and erosion.
      - Permeability to gases and liquids.
      - Stability of volume, porosity and permeability — as affected by high temperatures, by fluctuations in temperature, by alternate oxidizing and reducing atmospheres, and by melts which are absorbed by or react with the refractory.
      - Stability of mineral composition.
      - Resistance to gases or fumes which tend to cause disintegration.
      - Thermal conductivity.
      - Heat capacity.
      - Electrical resistivity.

   c. Economic factors:
      - Delivered cost.
      - Cost of brick laying.
      - Use of standard sizes vs. special shapes.
      - Salvage value.
      - Life of various types of refractories.

From the large number of factors which possibly may have a bearing upon the choice of refractories, it might appear that selection of the most suitable material in any particular case would be exceedingly difficult. Yet there is usually available a wealth of data from past experience in the use of refractories under similar furnace operating conditions. Moreover, the best refractory material for any particular purpose often depends upon a few requirements so essential that by comparison, other factors appear to be of minor importance. For example, in some cases high refractoriness alone may be the determining factor; in others, high refractoriness together with resistance to thermal shock within a critical temperature range; in still others, resistance to corrosive slags or to disintegration by gases may govern the selection of refractories. In some cases, high thermal conductivity is essential; in others, high insulating value. In the selection of refractories, the more essential properties for the particular service are given greatest weight.

The true cost of refractories is not measured by their cost per thousand. The proper criterion for the value of a refractory material is its effect upon the overall costs of production per unit of output — whether it be a ton of steel, a pound of copper, or a unit of any other product. Actually, in many cases, the furnace operator has been able to decrease the overall costs of production by making changes in operating conditions which shorten the life of the refractories but result in greater furnace output. In other cases, savings have been effected by changing to refractories which cost more but which lengthen the furnace campaign.

The costs of handling and bricklaying, and generally the cost of transportation, amount to as much for inferior brick as for those of high quality. In addition, the use of refractories not best suited to the operating conditions will cause loss of output due to more frequent shut-downs for repairs, and additional expense for making them. When these factors are taken into consideration, it is evident that materials of lowest first cost may prove to be the most expensive in the long run.

When confronted with the necessity of selecting refractories for a type of furnace operation with which he has had little past experience, the operator will find it good policy to obtain competent advice.

The wide experience of Harbison-Walker in recommending the most suitable refractory material for any particular purpose is at the disposal of all users of refractories. To take complete advantage of this experience, the user should supply all pertinent information regarding the service to which the brick will be subjected, including the type of furnace, kind of fuel, and operating conditions.

ESTIMATING QUANTITIES OF REFRACTORIES

Number of Cubic Feet Per 1000 9-Inch Brick in Hacks: 1000 standard 9-inch straight brick, of the 2½-inch series, closely stacked, occupy approximately 60 cubic feet; of the 3-inch series, approximately 71 cubic feet.

Number of Brick Per Cubic Foot of Brickwork: A cubic foot of brickwork requires 17.1 standard 9-inch straight brick of the 2½-inch series, or 14.2 standard 9-inch straight brick of the 3-inch series.

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Table I.
Number of Brick Per Square Foot of Wall

Thickness of Wall	Number of Brick Required	
	9″ x 4½″ x 2½″ Straights	9″ x 4½″ x 3″ Straights
4½″	6.4	5.3
9″	12.8	10.7
12″	17.1	14.2
13½″	19.2	16.0
15″	21.4	17.8
18″	25.6	21.3
22½″	32.0	26.7
27″	38.4	32.0

Number of Brick Required for Rings and for Arches: The combinations of brick required for complete rings of various diameters and various thicknesses will be found in the tables on pages 381 to 404. For arches of various spans and rises the combinations of brick required are given in the tables on pages 405 to 422.

The numbers of brick required for rings or arches not covered by the tables can be determined by calculation from formulas. For rings, the formulas are given on pages 367 and 371; use of the formulas is explained on pages 368 to 370, and 372 and 373. For arches, the formulas and a table of arch constants appear on page 375. Use of the arch formulas and constants is explained and illustrated on pages 376 to 380.

Ordering Extra Straights and Sizes: In placing orders for 9-inch brick, it is customary and good practice to add small percentages to net counts to take care of breakage and cutting. In addition, an adequate number of sizes should be included to facilitate laying. Large 9-inch straights and 13½-inch straights may be used for breaking joints, and 9″ 2-inch brick and 9-inch split brick for leveling courses. The extra amounts shown in the following table will usually be sufficient, although the actual number of extra pieces required for any particular job will depend upon local conditions.

Table II.
Suggested Extra Quantities—Standard Sizes

A. Extra pieces for breaking joints and leveling courses.

Net Amounts of 9″ Straights	Add to Net Amounts of 9″ Straights in Ordering			
	Large 9″ Straights	13½″ Straights	9″ Split Brick	9″ 2-inch Brick
Less than 250	5%	2½%	2½%	2½%
250 to 5,000	4%	2%	2%	2%
Over 5,000	2%	1%	1%	1%

B. Extra pieces to allow for cutting and breakage.

Net Amounts of Standard Sizes	Add to Net Amounts in Ordering
Less than 250	10%
250 to 1,500	5%
1,501 to 5,000	3%
Over 5,000	2%

Overshipments: In filling orders for *special shapes*, it is necessary to mold a slightly larger number of shapes than specified, in order to take care of possible breakage during the firing. Some or even all of the extra pieces may come from the kilns in perfect condition. Therefore, the company will ship a limited quantity of extra pieces, if available, on any given order.

The following overages are allowable on all shipments of shapes that are not standard:

Quantity Specified	Allowable Overage
1 – 100	10%*
101 – 1,000	7%
1,001 – 5,000	3%
5,001 – 10,000	2%
Over 10,000	1%

* Not less than 1 shape. If in sets, 1 complete set.

Table III.
APPROXIMATE AMOUNTS OF MORTAR MATERIALS REQUIRED FOR LAYING BRICK

Mortar Material	Pounds of Mortar Per 1000 Standard 9-Inch Brick (9″ x 4½″ x 2½″)	
	Brick Laid Dry and Grouted	Brick Laid with Dipped or Thinly Troweled Joints
Hot-Setting Bonding Mortars		
H-W Fine Ground Fire Clay	200 – 250	350 – 400
H-W Special Mortar Mixtures	200 – 250	350 – 400
H-W Super-Duty Mortar	200 – 250	350 – 400
Ankorite	250 – 300	400 – 500
H-W Furnace Magnesite	400 – 500	700 – 800
H-W Special Furnace Chrome	400 – 500	700 – 800
H-W Star Silica Fire Clay	200 – 250	350 – 400
Starbond or Vega Bond	200 – 250	350 – 400
Air-Setting Bonding Mortars		
Coralite Bonding Mortar	250 – 300	400 – 500
Firebond	200 – 250	350 – 400
Forsterite Bonding Mortar	300 – 400	500 – 600
Harwaco Bond	250 – 300	400 – 500
Korundal Bonding Mortar	250 – 300	400 – 500
Periklase Bonding Mortar	300 – 400	500 – 600
Thermolith	400 – 500	700 – 800
Insulating Bonding Mortars		
H-W 20	.....	150 – 200
H-W 26	.....	200 – 250

Table IV.
WEIGHTS OF REFRACTORY BRICK AND OF INSULATING FIRE BRICK

Kind of Brick	Pounds Per Cubic Foot	Pounds Per 9-Inch Straight 9″ x 4½″ x 2½″
Acid Proof	137 – 145	8.0 – 8.5
Basic		
Chrome and Chrome-Magnesite	187 – 205	11.0 – 12.0
Magnesite and Magnesite-Chrome	170 – 197	10.0 – 11.5
Forsterite	155 – 168	9.1 – 9.8
Fireclay		
Super-Duty	137 – 154	8.0 – 9.0
Aluminous (Except Super-Duty)	120 – 140	7.0 – 8.2
Siliceous	112 – 120	6.6 – 7.0
High-Alumina		
50 to 70% Alumina Classes	128 – 150	7.5 – 8.8
80% Alumina Class	148 – 160	8.7 – 9.4
90% Alumina Class	165 – 175	9.7 – 10.3
Insulating Fire Brick	30 – 60	1.8 – 3.6
Ladle Brick	130 – 135	7.6 – 7.9
Silica	102 – 115	6.0 – 6.7

The weights of refractory brick depend upon the weights per cubic foot of the raw materials from which they are made, and upon the processes of manufacture and the firing conditions.

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Table V.

WEIGHTS OF BULK REFRACTORY AND FURNACE INSULATING MATERIALS

Material	Approximate Weights Per Cubic Foot
Fireclay Materials (Not Calcined)	
Fine Ground Fire Clay	100
Ankorite	110
H-W Super-Duty Mortar	100
Standard Plastic Fire Brick, undried	135
Super-Plastic Fire Brick, undried	137
Bond Clay B, ground	100
Fireclay (Calcined)	
Lumps of approximately 1-inch diameter, including fines	100
Fine Ground	90
Special Clays	
H-W Crucible Clay	
Dried Dobies	120
Ground	80
H-W D Clay	
Unground	90
Ground	75
H-W Foundry Clay	80
H-W Georgia Kaolin, Crude	
Unground, dry	70
Ground, dry	60
H-W Special Mortar Mixture	100
Moldsand Bond	80
Pugged Sagger Clay	
Undried Dobies	115
Dried Dobies	120
Ground	80
Castables	
H-W Standard Castable, in place, dried	110
H-W Super-Castable, in place, dried	120
H-W Light-Weight Castables, in place, dried	56–85
H-W Chrome Castable	185
Chrome Materials	
Lump Chrome Ore	170
Special Furnace Chrome	160
High Temperature Bonding Mortars	
Harwaco Bond	130
Firebond	95
Thermolith	150
Forsterite Bonding Mortar	100
Periklase Bonding Mortar	115
Coralite Bonding Mortar	130
Korundal Bonding Mortar	130
Insulating Materials	
H-W 20 Bonding Mortar	92
H-W 26 Bonding Mortar	92
Calag	
For Concrete	30
For Fill	26
Diatomaceous Earth Powder	
Coarse	23
Fine	21
Magnesite Materials	
Washington Standard Dead-Burned Grain Magnesite, Burned-in	170
Magnamix, rammed into place	170
Furnace Magnesite	155
Ramming Mixtures	
Plastic Thermolith Batch	
Rammed into place, undried	200
H-W Periklase Batch	
Rammed into place, undried	160
Korundal Ramming Mixture	
Rammed into place, undried	160
Silica Materials	
H-W Coke Oven Fire Clay (H-W Coke Oven Silica Cement)	100
Starbond	100
Star Silica Fire Clay (Star Silica Cement)	100
Vega Bond	110
Ground Silica Ganister	123

ORDERING

When standard sizes of brick are ordered, it is not necessary to send drawings, but complete descriptions and dimensions should be given exactly as they are stated on pages 30 to 48.

A sketch should be sent with an initial order for modified or special shapes. On subsequent orders Harbison-Walker's drawing number or the purchaser's drawing and shape numbers should be shown, and when convenient a reference should be made to the order previously placed for the same material.

When ordering standard circle brick or other brick of the radial type, such as cupola or rotary kiln blocks, it is best to give both the inside and the outside diameter of the lining.

Orders for brick should include sufficient mortar material of the proper kind and quality for laying them.

Ground fire clays and various other ground or crushed refractory materials, ordered in carload quantities, can be shipped either in bulk or in sacks, as preferred, and the order should specify which method of shipment is desired. Less than carload shipments are made in sacks.

If an order calls for more than one carload of material, it is best to specify the rate at which shipments are desired.

It is advisable to anticipate requirements as far in advance as possible in order to provide for the desired delivery.

HANDLING, STORAGE AND SHIPMENT

At all Harbison-Walker plants, the brick are handled with utmost care throughout the different stages of manufacture, and in moving them prior to shipment. Transfer equipment such as the following is used:

a. Dryer cars, which run over level and smooth tracks.
b. Specially designed wheelbarrows, provided with rubber tires and springs.
c. Fork lift trucks provided with rubber tires. Where these trucks are used, the brick coming from the kilns are placed on sturdy wooden trays or pallets and are then transferred to stock sheds, and later from stock sheds to railroad cars. They are usually removed from the pallets before shipment.

In handling shapes of such design that they are easily damaged, a cushion of resilient material is placed between the layers of shapes on the wheelbarrows or on the wooden pallets. The workmen are carefully trained in the handling and packing of brick for shipment. In the railroad cars, the brick are packed in straw, heavy paper or sawdust, as conditions may require. Where necessary, the interior of the railroad car is divided into separate sections by strong wooden bulkheads.

When desired, brick are shipped in railroad cars on pallets. Before loading, the brick are secured to the individual pallets by steel strapping. This practice greatly facilitates their handling by users of brick, in plants equipped with lift trucks. The pallets measure 36 x 48 inches overall, and have three 2½ x 2-inch runners. Each pallet will hold approximately 400 to 500 9-inch equivalent of fireclay or silica brick, or 275 equivalent of basic brick. Pallets may be used for the shipment of any 9-inch sizes or rectangular tile, and of many modified shapes. Loaded pallets are made secure in railroad box cars by means of specially designed end and side gates, which are strapped in place. Pallets and gates are returnable. Brick shipped on pallets are subjected to the minimum amount of

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handling at destination, as they are transported to storage sheds or the point of use by means of lift trucks, without removal from the pallets. Complete details concerning this method of shipment, which is called palletizing, will be given upon request.

Brick should be handled as carefully by the user as by the maker, to avoid scuffing, cracking, breaking, or damaging corners or edges. Such damage cannot be avoided when the brick are thrown into scoop or box wheelbarrows, and later dumped out.

As they are unloaded from the railroad cars, brick not received on pallets should be placed carefully upon the wheelbarrow or other conveying equipment. The provision of smooth runways will enable wheelers to handle heavy loads, and will minimize damage to corners and edges of the brick during wheeling. Neither in the stock shed, nor at the point where used, should the brick be dumped out; instead, they should always be stacked up neatly one or two at a time, to form stable piles or hacks. They should be placed on edge rather than on flat, except in the case of large or irregular shapes. It is often advantageous to separate intricate or large shapes with straw or laths.

Refractories should be kept dry during transportation and storage. This is particularly true of basic refractories. Stock sheds should be weather-proof, with smooth floors which are always kept dry. Wet bonding mortars and ramming mixtures should not be stored where cold weather may cause them to freeze.

BUILDING THE FURNACE

Bonding of Refractory Walls: The building of furnaces is a specialized branch of masonry, and should be entrusted only to bricklayers who have had experience in furnace construction. Walls, arches, and other furnace parts should be so designed and constructed that structural stability is assured, and that full advantage is taken of the desirable properties of the refractories.

The horizontal layers of brick in a wall are called "courses". Those in which the lengths of the brick are parallel to the face of the wall are known as "stretchers", and those in which the lengths of the brick are at right angles to the face of the wall are termed "headers".

Header courses on the hot face of a wall are likely to spall less than stretchers, on account of the smaller area of the exposed sections. However, stretcher courses expose fewer joints than do headers. This is an advantage in any service where the joints tend to wear back more rapidly than the body of the brick. The number of horizontal joints can be reduced by the use of brick 3 inches thick instead of 2½ inches thick.

The Types of Bond: Strength and stability are imparted to a wall by bonding or tying-in the brick through the use of various combinations of header and stretcher courses, and by offsetting or "breaking" the vertical joints. The arrangement of headers and stretchers used in building a wall is called the "bond" of the brickwork.

The type of bond selected for any particular furnace construction will depend upon such factors as the design of the furnace, the thickness of the wall, the necessity for gas-tight construction, the severity of operating conditions, and the ease of maintenance.

One of the most important considerations, in deciding upon the method of bonding, is the fact that the resistance of brick to crushing or deformation under load is less at high temperatures than at low temperatures. For example, any part of a high duty fireclay brick which is heated above approximately 2250° F. has relatively low load-bearing capacity. The wall should be so bonded that stresses resulting from loads are transferred to the outer, cooler part of the wall when the inner, hotter portion loses its power to sustain pressure.

Among the types of bond employed for laying the brick in furnace walls are the following:

1. *Construction in which all brick are stretchers.* This arrangement has little structural stability, and is applicable only to thin walls. Its chief use is in small furnaces, and in furnaces where heat must be conducted through the walls.

2. *Alternate headers and stretchers.* This is probably the most common arrangement in industrial furnaces. Alternate header and stretcher construction, for walls of various thicknesses, and built with standard 9-inch brick, is illustrated by Figures 1, 2 and 3. Large 9-inch brick (9″ x 6¾″ x 2½″ or 9″ x 6¾″ x 3″) are used for breaking joints, for starting ends of walls, and for turning corners.

3. *Construction consisting almost entirely of headers.* This arrangement is often used advantageously in 9-inch and 13½-inch walls subjected to high temperatures and heavy loads and to slag attack, and is usually preferred for walls built of magnesite, chrome or forsterite brick. Walls with this bond have the advantage of stability and of easy replacement, and the disadvantage that most of the expansion joints pass entirely through the wall.

4. *Construction consisting mainly or entirely of headers on the inner face of the wall and mainly of stretchers on the outer face.* This bond is sometimes considered desirable when spalling conditions are severe. (See Figures 4 and 6.)

5. *Construction consisting mainly of stretchers on the inner face, i.e., with three or four stretcher courses to one header course.* (See Figure 5.) This arrangement is sometimes favored because the interior face of the wall can be repaired when necessary by tying-in a "skin wall" 4½ inches thick. However, it should not be used where there is danger of the stretcher courses falling into the furnace.

6. *Composite wall construction with backup courses not tied to inner courses.* This type of bond is desirable when the wall is constructed of different kinds of brick, having marked differences in their rates of thermal expansion. (See Figure 8.)

7. *Construction especially adapted to composite walls.* (See Figures 6, 7 and 8.) In various types of furnaces, it is common practice to build the enclosing walls of two or even three kinds of brick. In such cases, the most refractory brick are used for the face of the wall to be exposed to the highest temperature, and the least refractory brick for the face which will be exposed to the air. Many such combinations are in common use. As examples, high-alumina brick may be backed up by high duty fireclay brick; super-duty or high duty fireclay brick may be backed up by intermediate or low duty fireclay brick, or by insulating fire brick. The more refractory brick of a combination should be the one used for tying-in courses.

Thickness of Walls: While great latitude is allowable in the thickness of walls, it should bear some relation to the height and unsupported length. In walls not tied to the binding at vertical intervals or otherwise supported, a 4½-inch thickness will serve for heights up to 3 feet; 9-inch thickness from 3 to 8 feet; 13½-inch thickness from 8 to 12 feet, and 18-inch or greater thickness for walls higher than 12 feet. Walls with an unsupported length more than one and one-half times their height should be somewhat thicker. Additional thickness may be desirable also if the brick are subjected to conditions which cause spalling.

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BONDING OF WALLS BUILT WITH BRICK OF STANDARD SIZES

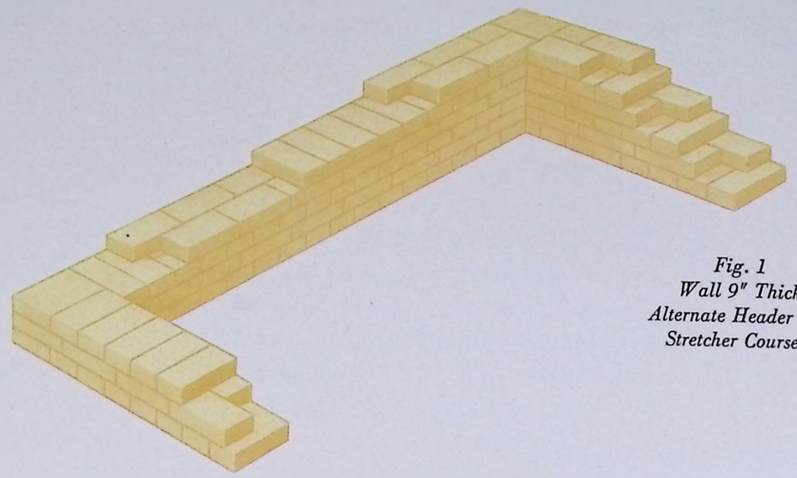


Fig. 1
Wall 9" Thick
Alternate Header and
Stretcher Courses.

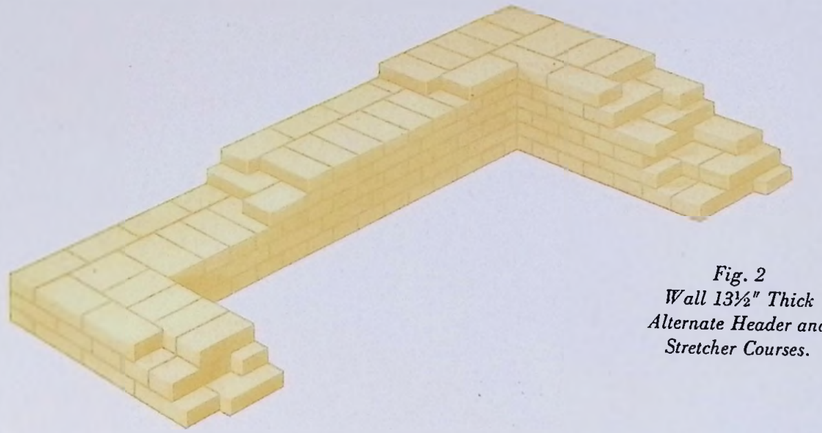


Fig. 2
Wall 13½" Thick
Alternate Header and
Stretcher Courses.

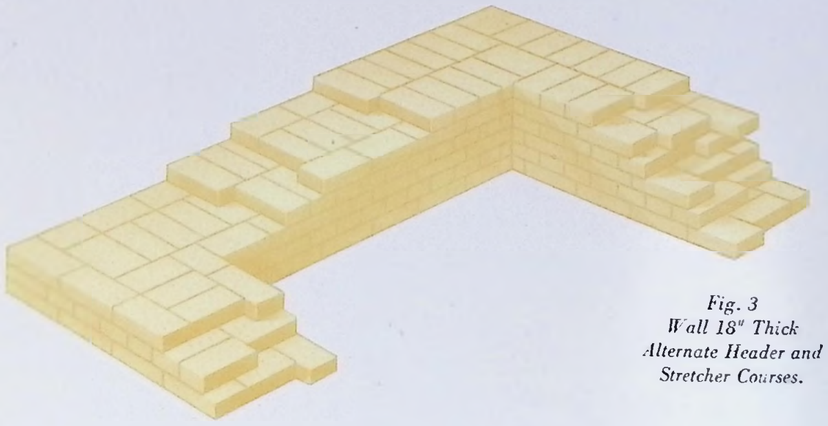


Fig. 3
Wall 18" Thick
Alternate Header and
Stretcher Courses.

BONDING OF WALLS BUILT WITH BRICK OF STANDARD SIZES

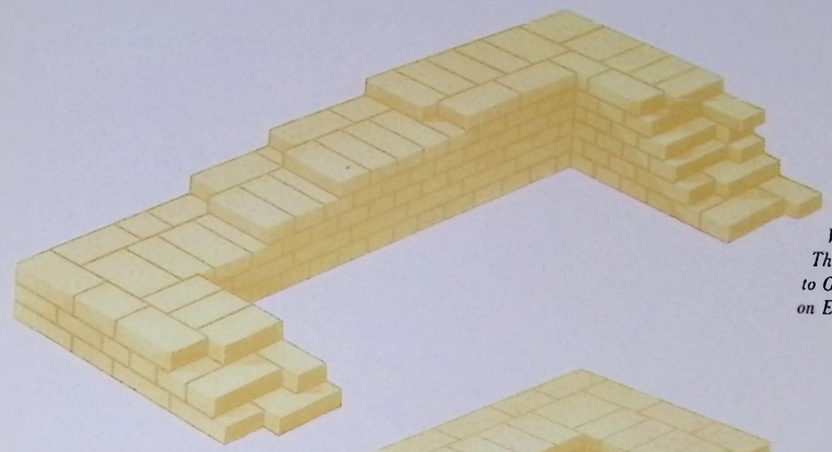


Fig. 4
Wall 13½" Thick
Three Header Courses
to One Stretcher Course
on Exposed or Hot Face.

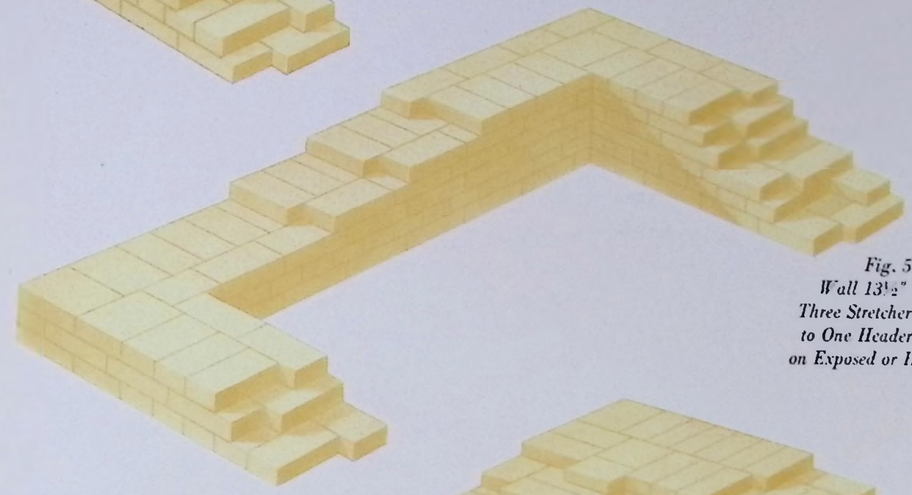


Fig. 5
Wall 13½" Thick
Three Stretcher Courses
to One Header Course
on Exposed or Hot Face.

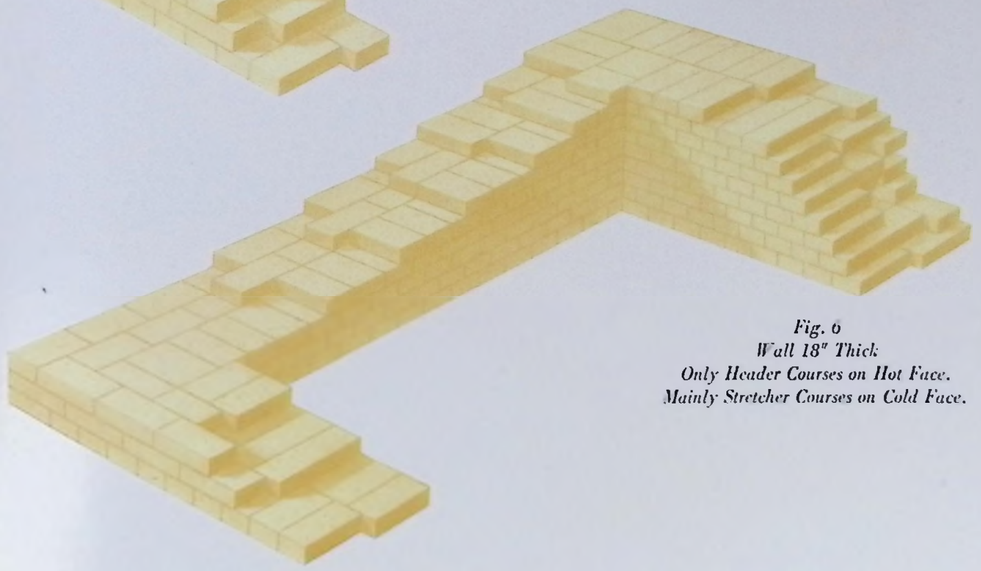


Fig. 6
Wall 18" Thick
Only Header Courses on Hot Face.
Mainly Stretcher Courses on Cold Face.

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BONDING OF WALLS BUILT WITH BRICK OF STANDARD SIZES

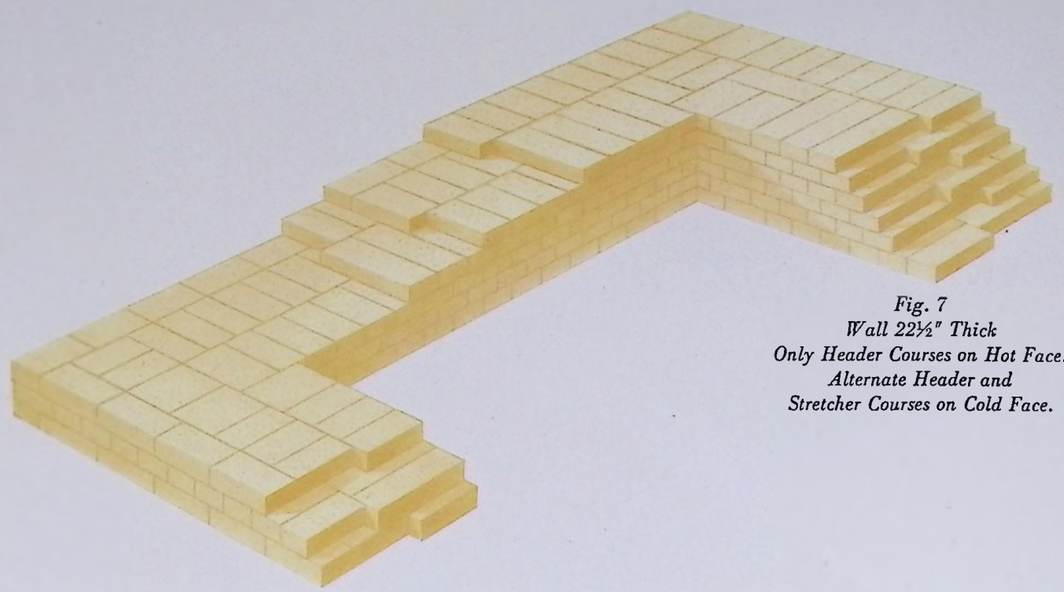


Fig. 7
Wall 22½" Thick
Only Header Courses on Hot Face.
Alternate Header and
Stretcher Courses on Cold Face.

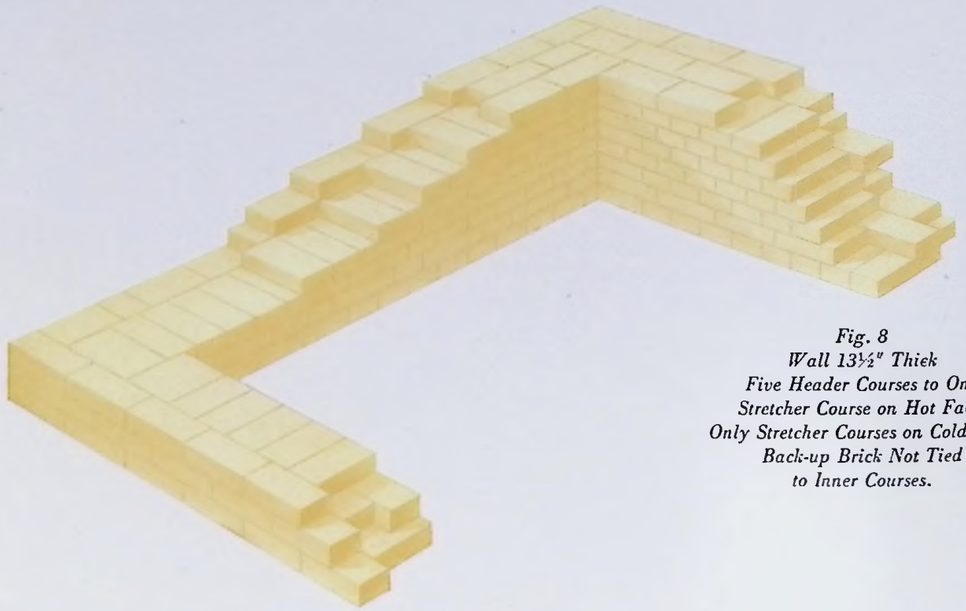


Fig. 8
Wall 13½" Thick
Five Header Courses to One
Stretcher Course on Hot Face.
Only Stretcher Courses on Cold Face.
Back-up Brick Not Tied
to Inner Courses.

The thickness of suspended walls, or of walls which are tied to the binding at vertical intervals, will be determined by the method of support. If adequately supported, walls 30 feet or more in height may not need to be more than 9 inches thick.

Thickness of Joints: The thickness of joints depends upon the character of both the brick and the bonding mortar and the necessity for preventing gas leakage or slag penetration. The thickness of joints is influenced also by the kind of bond employed, and by the manner in which provision is made for the thermal expansion of the brick.

When there is no necessity for guarding against gas leakage or slag penetration, or for bonding the brick strongly together, they are sometimes laid without mortar. However, the use of mortar is generally desirable to level courses and to provide smooth bedding for the brick, or wherever gas leakage through the walls is to be kept to a minimum.

Brick laid with a hot-setting bonding mortar such as finely ground fire clay preferably should have thin joints. Mortars of this kind offer little resistance to penetration by slag. Fireclay mortar should be mixed to a creamy consistency, and the brick should be laid with either dipped or poured joints, and rubbed or tapped into place to secure joints with as nearly brick-to-brick contact as possible. Joints which are made with an air-setting mortar of ample refractoriness and strong bonding properties, generally can be made somewhat thicker. Such joints should be completely filled.

Most rotary kiln linings of alumina-silica refractories are laid without mortar, because of the necessity for securing brick-to-brick joints. The joints are most advantageously sealed by grouting.

A peculiar manner of fluxing in glass tank caps, commonly referred to as "boring", can be avoided by making full bedded joints, except where provision must be made for expansion. The mortar material prevents the infiltration of volatile alkalies in the roofs of tanks operated under positive pressure. Unless the joint is completely filled with the bonding mortar, the fluxing agent has access to the refractories in zones back of the exposed face.

Thermal Expansion: In the construction of a furnace, proper consideration should be given to the thermal expansion of the refractories, and expansion joints should be provided as needed. Usually, the vertical expansion in walls is provided for by allowing them to move freely upward. Horizontal expansion of walls is provided for by means of vertical expansion joints.

Customary allowances for thermal expansion of refractories used at high temperatures are given in Table VI. For more complete data, see charts on page 327.

Table VI.

Usual Thermal Expansion Allowances For Refractory Brick

In high-temperature service

Type of Brick	Expansion Allowance Per Foot
Fire Clay	3/32"
High-Alumina	
50 to 80% Alumina	3/32"
90% Alumina	1/8"
99% Alumina	5/32"
Silica	5/32" to 3/16"
Magnesite and Magnesite-Chrome	1/4"
Chrome and Chrome-Magnesite, fired	1/8"
Chrome-Magnesite, chemically bonded	7/32"
Forsterite	3/16"

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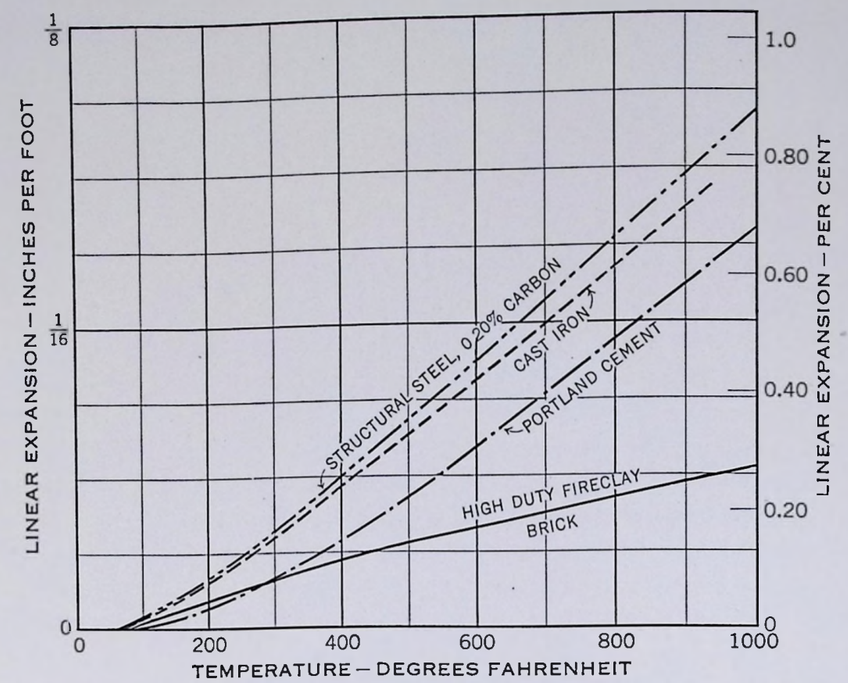


Fig. 9. Thermal Expansion of Steel, Iron, Portland Cement, and High Duty Fireclay Brick

The metal used for the binding of a furnace becomes heated, although to a much lower temperature than the refractory; and when heated it expands, as shown in Figure 9. In many cases, expansion of the binding must be considered in allowing for thermal expansion of the refractories.

Provision for Expansion in Vertical Walls: The methods of making allowance for thermal expansion of refractory brick differ considerably, depending upon such factors as the dimensions of the wall, the thermal expansion of the refractories, the amount and kind of insulation, the kind of bonding mortar, and the operating conditions.

While the allowance for expansion must be adequate, too great an allowance is undesirable as it may cause structural weakness, as well as excessive leakage of gases or air infiltration.

With high or long walls, it is especially important that sufficient provision for expansion be made. The thickness of the wall and the amount of insulation determine the temperature drop from the hot to the cold face. With most refractories, the expansion at the hot face is considerably greater than in the cooler parts of the wall; silica brick attain nearly their full expansion at any point in a wall where the temperature is 1200° F. or higher.

The expansion joints in the different courses of thick walls may be staggered. In thin walls, expansion joints extending through from the inner to the outer face cannot always be avoided. For such cases, leakage of gas can be reduced to a minimum by packing the outside ends of open joints with a compressible inorganic packing material or by covering them temporarily with a loose course of brick.

When the mortar used is of the hot-setting type, the vertical expansion joints may be staggered as desired. However, if the brick are laid with an air-setting mortar, the expansion joints will not function properly unless those in successive courses are in vertical alignment. Brick which are required to move with respect to each other as the material expands under heat, should not be bonded together with an air-setting mortar.

Types of Expansion Joints: Individual preferences generally govern the choice of the type of expansion joints. The types illustrated in Figures 10 to 13 are in common use and are regarded as satisfactory.

Expansion joints in basic brick walls of all-header construction are sometimes provided as shown in Figure 10.

For walls with header-and-stretcher bond, expansion allowance may be made as shown in Figures 11 to 13. The construction with staggered joints shown in Figure 11 may be used when the brick are laid either dry or with a hot-setting bonding mortar. Expansion joints at corners may be made as shown in Figure 12. When the brick are laid with an air-setting bonding mortar, vertical alignment of the expansion joints in successive courses, as shown in Figure 13, is good practice. In the construction of a bridge wall, expansion spaces should always be provided at the ends.

Keeping Expansion Joints Clean: Expansion joints must be kept free from mortar, spalls of brick or other materials. For joints that are not staggered, a good way to accomplish this is by the "movable stick" method, in which each vertical joint is made by a hardwood stick of proper thickness. The stick is not removed at any time until the wall is finished, being merely slipped upward as the wall rises. A second method of keeping joints clean is to pack them to a depth of 1 to 1½ inches with a combustible filler of low ash content.

Filler Materials for Joints: Filler materials are used either to keep the joints free from mortar or other undesirable materials, or to reduce gas leakage or air infiltration. The materials used are of two general types:

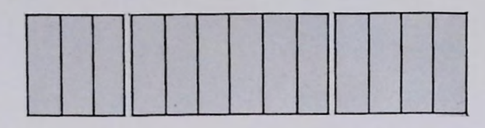
a. Combustible materials which are usually somewhat compressible.
b. Inorganic materials which are not combustible, but which are very compressible.

The combustible materials in common use include softwood strips, shavings, excelsior, sawdust, cardboard, corrugated paper and other heavy paper. When wood strips are used, they should be removed if possible before the furnace is heated, especially with silica brick construction. Wood strips do not burn out at a low enough temperature to provide space for the expanding brick and are not easily compressed. When heated, wood does not begin to char until a temperature of about 525° F. is reached. At this temperature, about two thirds of the thermal expansion of silica brick has already taken place. While corrugated paper and packing paper do not burn out at a very low temperature, they are readily compressed to a small fraction of their original volume.

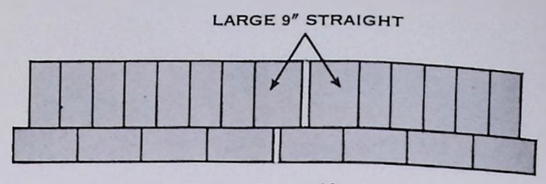
The other class of filler materials includes inorganic materials, such as asbestos fiber, asbestos rope, rock wool, or diatomaceous earth powder. These materials are of relatively low refractoriness, and should therefore be used only in outside joints. If used in parts of a furnace where the temperatures are high, they will melt and may damage the brickwork. Another necessary precaution in using them arises from the fact that after they have been completely compressed, they still occupy an appreciable volume. The actual provision for expansion of the brick is less than the total thickness of expansion joints by the thickness of the compressed filler material.

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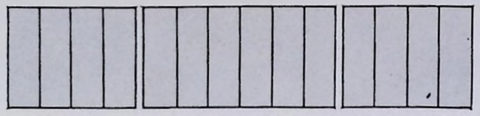
EXPANSION JOINTS



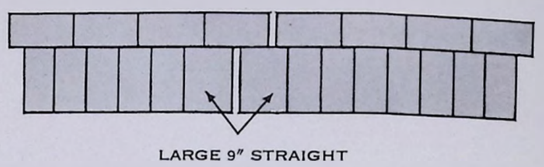
Plan of Course No. 2



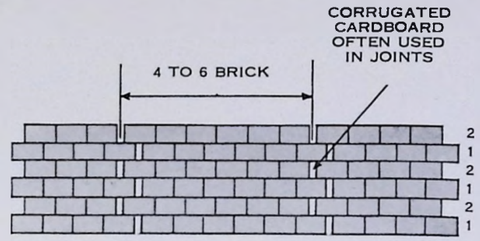
Plan of Course No. 2



Plan of Course No. 1

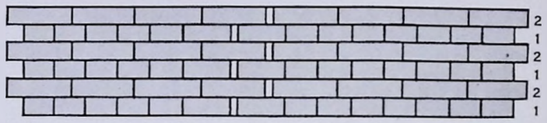


Plan of Course No. 1



Elevation of Hot Face

Fig. 10. Expansion Joint in Basic Brick Wall 13½″ Thick. Header Construction.



Elevation of Hot Face

Fig. 11. Expansion Joint in Wall 13½″ Thick. Alternate Header and Stretcher Construction.

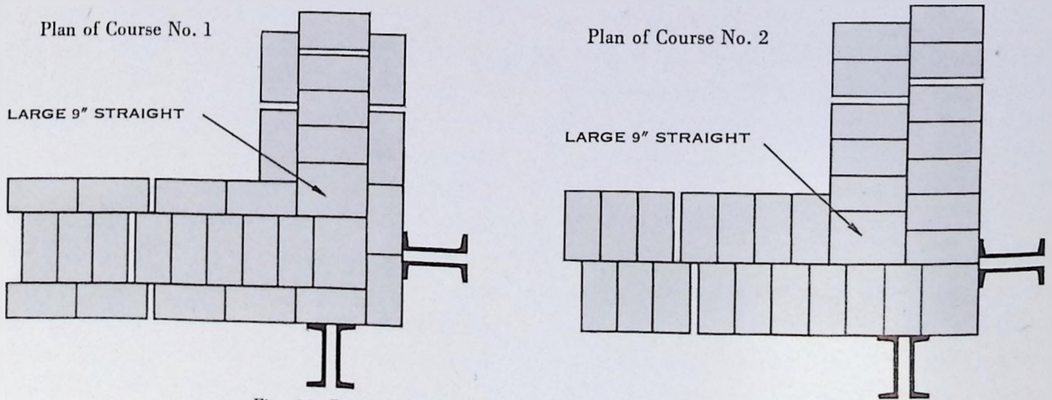


Fig. 12. Double Expansion Joint Near Corner of Wall 18½″ Thick. Alternate Courses Showing Header and Stretcher Construction.

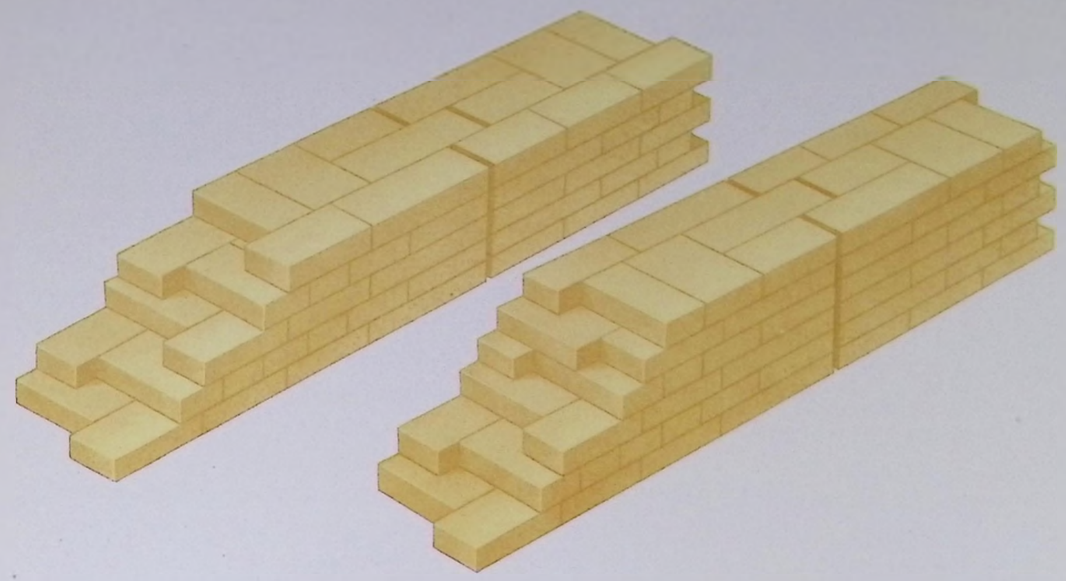


Fig. 13. Expansion Joint in Wall 13½″ Thick. Alternate Header and Stretcher Construction

Expansion Joints for Fireclay Brick: In boiler settings having walls 15 feet or more in length, it is customary to provide staggered vertical expansion joints 4 to 6 feet apart. In other types of furnaces built of fireclay brick, the expansion joints are usually somewhat farther apart, especially if the walls are low. In tunnel kiln construction, for example, the expansion joints are usually 15 feet apart in the high temperature section and 20 to 30 feet apart in the low temperature section.

Expansion Joints for Silica Brick: In the silica brick walls of copper reverberatory furnaces, vertical expansion joints which consist of open spaces or slots extending from top to bottom of the walls are usually provided 10 to 16 feet apart. In glass tank construction, it is customary to provide expansion joints in silica brick walls midway between the ports. In open-hearth furnace walls, probably the most common method consists in merely laying the brick somewhat loosely without definite expansion joints. Some operators prefer to make positive allowance for expansion at suitable intervals.

Expansion Joints for Basic Brick: Magnesite, chrome and forsterite brick in straight walls are usually laid according to one of the following methods:

a. The brick may be laid dry, with sufficient space at each vertical joint or at 18 to 27 inch or wider intervals to take care of the expansion.

b. The brick may be laid dry with a heavy paper or cardboard filler in each vertical joint.

c. A method commonly used is shown in Figure 10. Expansion space is provided at 18 to 27 inch or wider intervals throughout the length of the wall, by means of joints filled with heavy corrugated paper or with cardboard. All other joints between brick are thin and are filled with mortar.

The expansion of basic brick in checker work is allowed for at the full rate, usually by means of a space at each joint between brick.

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In lining horizontal cylindrical furnaces, such as copper converters, provision for expansion may be made by means of a loose fill of grain magnesite between the lining and the shell; and in addition, expansion joints are made longitudinally between the brick at suitable intervals. This practice is illustrated in the drawings on page 187.

In rotary kilns, basic linings are laid with steel sheets in the longitudinal joints, and expansion joints ordinarily are made only between rings. When the lining is insulated, however, provision is made also for circumferential expansion of the brick.

Provision for Expansion in Electric Furnace Roofs: In building a domed electric furnace roof with silica brick, adequate allowance for expansion is necessary. The amount of allowance for expansion varies from about 1/16 inch to 1/8 inch per foot. Proper functioning of the expansion joints is dependent largely upon the way in which they are made. They should be uniformly spaced, and preferably not over 1/16 inch to 1/8 inch thick. It is common practice to use soft wooden strips or heavy paper to form the expansion joints.

Where Expansion Joints Are Not Needed: In some furnaces, the brick are laid loosely enough to provide sufficient expansion space in the individual joints. In certain other furnaces no expansion allowance is made within the walls, but the brick are laid tightly against each other and the lining is allowed to expand as a whole. In such cases, the binding should be so designed that expansion of the brickwork can take place without the development of excessive stresses. In portable furnaces enclosed in rigid cast iron or structural steel casings, usually at least 1/2 inch of bulk insulation is placed between the brickwork and the shell, to take up the expansion. However, skewbacks in such furnaces should be placed against the casing.

In rotary kiln service, thermal expansion of the steel shell compensates sufficiently for the expansion of fireclay or high-alumina brick linings, even though they are laid tightly against the shell. In the case of basic brick linings installed with steel sheets in the joints, provision is made for expansion between rings, but not for circumferential expansion, except for linings which are insulated.

HEATING UP THE FURNACE

A new furnace should be heated slowly, with provision for a sufficient volume of circulating air, since the formation of steam in the pores of the brick or in the mortar between brick may cause damage to the lining. It is best practice to avoid raising the furnace temperature above 400° to 575° F. until all steaming from the drying mortar has ceased.

Careful drying of linings built of magnesite brick, or of other refractory brick containing free magnesia, is especially important to prevent the formation of entrapped steam. These refractories will disintegrate if they are exposed to contact with steam under pressure, because of the hydration of the free magnesia.

A flame which impinges against the brickwork during the heating-up period may cause rapid local expansion with consequent spalling. Special care should be exercised in the heating of either silica brick or magnesite brick because of their tendency to spall when subjected to rapid changes in temperature.

In low temperature furnaces, it is often good practice to subject the structure to an initial heating for a short period, at a temperature higher than that required during operation. This preliminary heating develops the ceramic bond of the mortar material in the joints.

FACTORS AFFECTING THE LIFE OF REFRACTORIES

When the life of a furnace lining is shorter than is regarded as normal, a study should be made of the governing factors, including furnace design and construction, selection of the refractories, and operating practice.

Furnace Design: A change in furnace design, in some instances, will be the most effective means of securing longer life from the refractories. This may be the case, for example, when the volume of a combustion chamber is insufficient or the heat is too confined, when the walls are too thin or inadequately supported, when the amount of insulation is excessive, when the brickwork is subjected to heavy load, or when ventilation or cooling of parts of the furnace obviously is desirable.

The combustion temperature of most fuels exceeds 3000° F. when they are burned rapidly with the amount of air theoretically required or with a slight excess. If the heat is liberated within an enclosed space, and if it is not utilized but is confined because of insufficient conduction and radiation, the refractories will be exposed to a temperature almost as high as the temperature of combustion. Under such service conditions, it may be possible to lengthen the life of the refractories appreciably by a change in furnace design which will prevent excessive confinement of the heat.

Brickwork exposed to high temperatures on two sides, without provision for ventilation, cannot be expected to give as long life as that which is heated from one side only.

The life of a brick wall or roof exposed to the action of an impinging flame may often be increased by a redesign of the furnace, by adjustment and control of the burners to secure a longer flame and avoid localized overheating, or by the use of brick of higher refractoriness.

Proper size and placement of burners is important. When burners are placed too close to side walls, the refractories in the walls are subjected to localized high temperatures, and usually to the fluxing action of fuel ash. Back walls opposite burners should be placed far enough from the burners that they are beyond the zone in which heat is liberated most rapidly, and also beyond the range of flame impingement. A thin coating of high temperature bonding mortar which will adhere strongly to the brick will reduce penetration by gases and by molten ash.

Ash deposited upon the openings of powdered coal burners may deflect the flame and cause it to impinge upon portions of the brickwork with resultant fluxing and erosion.

The height of combustion chambers is often of great importance, as a small difference in roof elevation may cause a considerable difference in roof life. For example, the life of the combustion arch in a boiler setting can sometimes be lengthened by increasing its height above the grate.

High walls should always be anchored, even when 18 or 22½ inches thick. Anchors prevent buckling and permit the use of thinner walls. Various methods of anchoring and suspending walls are in common use.

Operating Conditions: Operation at greatly increased furnace output will necessarily impose more severe service upon the refractories. A lining material which is capable of withstanding the normal furnace temperature without fusion or appreciable softening may be badly damaged at higher operating temperatures. Refractories in intensely heated localized areas, even though the heating be of short duration, may be damaged considerably. At times when a greater output must be secured from a furnace than that for which it was designed, it may

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be necessary to rebuild the most vulnerable portions of the construction with materials which have higher refractoriness.

A change in the kind of fuel or in the nature of the charge will often cause a marked difference in the behavior of the refractory linings.

Rapid changes in temperature should be avoided if possible, to prevent spalling. This is particularly true in heating or cooling silica brick in the temperature range below 1200° F.

Reaction Between Refractories: When no single kind of refractory material is suitable for withstanding all the varying conditions prevailing in the different parts of a furnace, several different kinds of refractories necessarily are employed in the construction. Some refractories of different chemical compositions, such as fireclay and magnesite brick, tend to react chemically with each other at high temperatures. The approximate temperatures of reaction, as determined in laboratory tests, are given on pages 333 and 334. In service, damaging reactions between two refractories can be prevented either by the use of an intermediate course of brick which will not react with either of them to an appreciable extent at the temperature of operation or by means of a joint made with a non-reactive high temperature bonding mortar. In the cooler parts of the furnace, such a buffer course usually is not necessary.

Charging and Cleaning: The lining materials may be damaged during the charging of a furnace. This may occur as a result of excessive temperature change during the charging period, through bumping by charging machinery, or through the impact of large and heavy pieces of cold stock.

Damage to furnace hearths and walls is often caused by tools used for the manipulation of material placed in the furnace for heat treatment. When this occurs, the life of the refractories can sometimes be lengthened by a change in the design of the tools, or by the exercise of greater care in their use.

Hearth cleaning operations are sometimes very severe, as for example when a furnace is quenched with water to loosen scale or slag. The necessity for quenching can often be avoided by the use of a refractory to which the scale does not readily adhere.

Other frequent causes of damage to furnace linings are vibration from hammers or other machinery, pulsating flames, and gas explosions.

In a furnace with water-cooled parts, any water leaks which develop should be given prompt attention because of their harmful effect upon the refractories.

Effect of Stresses: In most cases, refractories can withstand relatively high compressive stresses up to a critical temperature, which varies for different types of refractories; above that temperature, their strength rapidly decreases. Refractories have much lower resistance to transverse, shearing and tensile stresses than to compression. Furnaces should be so designed that stresses imposed upon the brick are kept as low as possible.

In spanning wall openings or narrow flues, a sprung arch is generally better than a flat tile, for the arch brick are under compression, while the lower face of the tile is under tension. Moreover, a tile spanning an opening between two parallel walls may shear or spall, if the walls are heated and cooled at different rates.

In furnace operation, there is generally a temperature drop of hundreds of degrees between the inner and the outer faces of walls and arches. In a wall built of fireclay refractories, the hot ends of the brick may be somewhat viscous, and unable to support a load, while at the same time the cooler portions of the brick may have many times the

strength necessary to sustain the entire weight of the super-imposed brickwork. The mechanical strength of most high duty fireclay brick begins to decrease at about 1800° to 2000° F., depending upon the grind, process of manufacture, burn and density, being highest for hard-burned brick. Super-duty brick retain their strength at somewhat higher temperatures.

The effect of the temperature gradient upon the strength of walls built of fireclay brick and subjected to high furnace temperatures is illustrated in Figures 14A, 14B and 14C. In the cooler portion of the walls the brick are strong and rigid, while in the hottest portion they are pyroplastic and will deform if subjected to heavy pressure. In the figures, the temperatures which mark the limits of these portions or zones of the brickwork are approximate mean values used merely for purposes of illustration.

Figure 14A shows a section through a high duty fireclay brick wall 18 inches thick with a hot face temperature of 2700° F. It is assumed that the pressure of the gas inside the furnace and that of the air outside the furnace are equal. Under these conditions the brickwork would be strong and rigid for a distance of about 14½ inches from the cold face, while the remainder of the wall would be hot enough to deform under heavy pressure. However, the hot ends of the brick would not deform appreciably, since the slight softening of this hotter portion of the wall would transfer all the load to the cooler, stronger portion.

Effect of Insulation: The loss of heat from the wall illustrated in Figure 14A would be about 1250 B.t.u. per hour per square foot. A considerable proportion of this heat could be saved by insulating the wall. However, insulation can be excessive, as illustrated by Figure 14B, in which the fireclay brick in the outer 4½ inches of the wall are represented as having been replaced by insulating brick of the 2000° F. class. Under these conditions, the temperature at the interface between the insulating fire brick and the high duty fireclay brick would be about 1980° F. The fireclay brick in this wall would be overheated, since they would be hot enough to deform under pressure for a distance of about 8½ inches from the hot face, and would remain rigid for only about 5 inches of the 13½-inch thickness. The wall might have insufficient structural stability, and could not be expected to give maximum service.

A considerable degree of insulation could be obtained by the better method illustrated in Figure 14C, in which high-fired super-duty fireclay brick are used instead of high duty fireclay brick, and insulating brick of class 26 instead of class 20. The heat loss would be about 760 B.t.u. per hour per square foot of wall. With this construction the interface temperature would be about 1800° F. About 8 inches of the length of the super-duty fireclay brick would remain rigid, and only about 5½ inches would tend to deform under pressure. These conditions represent a heavy but not necessarily an excessive degree of insulation. A factor of safety could be provided by the use of high-alumina brick instead of high-fired super-duty fireclay brick.

How can the safe maximum degree of insulation be determined for any particular installation? No definite answer of general applicability can be given to this question, because the answer depends upon various furnace operating conditions, as well as upon the properties of the particular refractory and insulating materials chosen. The following figures provide a rough guide to the maximum permissible temperatures in furnace walls which are not sub-

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jected to spalling, slagging or abrasion, and into which hot gases are not forced by positive pressures. The data are based on the assumption that the load upon brick is not greater than 25 pounds per square inch. For either an insulated or an uninsulated furnace wall, the *mean temperature* between the hot and the cold face of the refractory portion of the wall should not exceed approximately the following values:

Hard-burned or medium-to-hard-burned high duty fireclay brick 2100° F.
Normally-fired super-duty fireclay brick..... 2200° F.
High-fired super-duty fireclay brick..... 2250° F.

For higher temperatures, high-alumina brick or silica brick might be chosen. High-alumina brick in walls may be subjected to a mean temperature of about 2300° to 2800° F. depending upon their composition; conventional silica brick to about 2800° F., and super-duty silica brick to about 2875° F. For long and high walls which are insulated, the use of suspended construction is often good practice.

In most cases, an insulated furnace wall should be so designed that the insulating fire brick will not be subjected initially to its maximum working temperature, since the interface temperature rises as a wall wears thinner. Conservative practice suggests limiting the interface temperature to 100° or more below the maximum safe working temperature of the insulating fire brick. This is not done under the conditions illustrated by Figure 14B, in which insulating fire brick of class 20 are shown exposed to an interface temperature of 1980° F. This temperature allows no margin of safety for the insulating fire brick. Should the fireclay brick portion of the wall wear thinner in service, the temperature at the interface would rise, possibly with disastrous effects upon the insulation. In the construction shown in Figure 14C, insulating fire brick of class 26 are used. The calculated interface temperature is 1800° F., which would not have a damaging effect upon insulating fire brick of class 26.

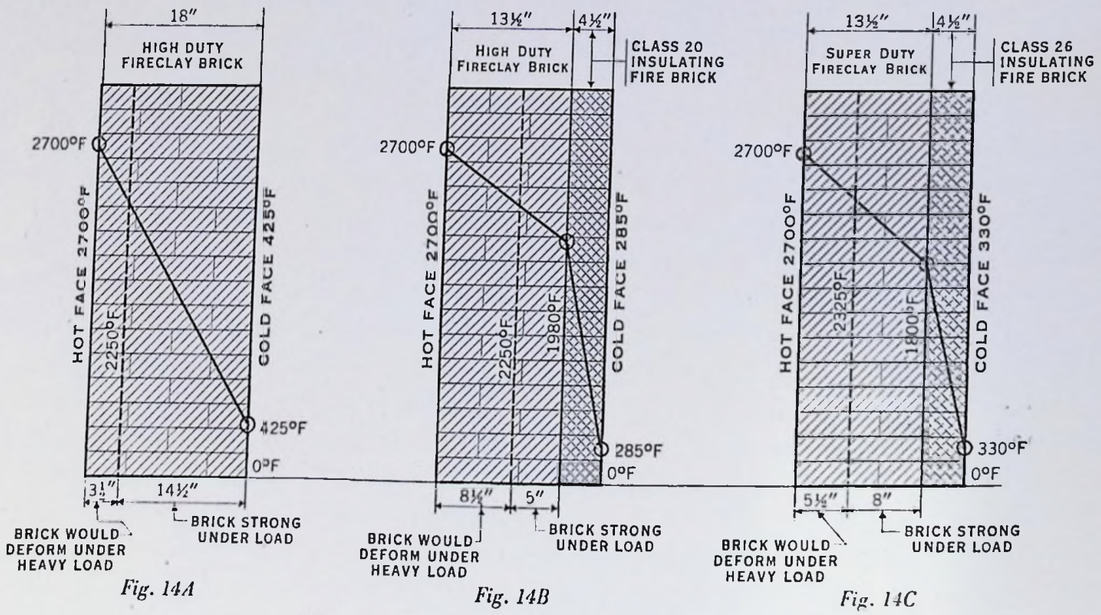


Fig. 14A *Fig. 14B* *Fig. 14C*

Fig. 14. Temperature Gradients Through Furnace Walls

SUGGESTIONS REGARDING DETAILS OF CONSTRUCTION

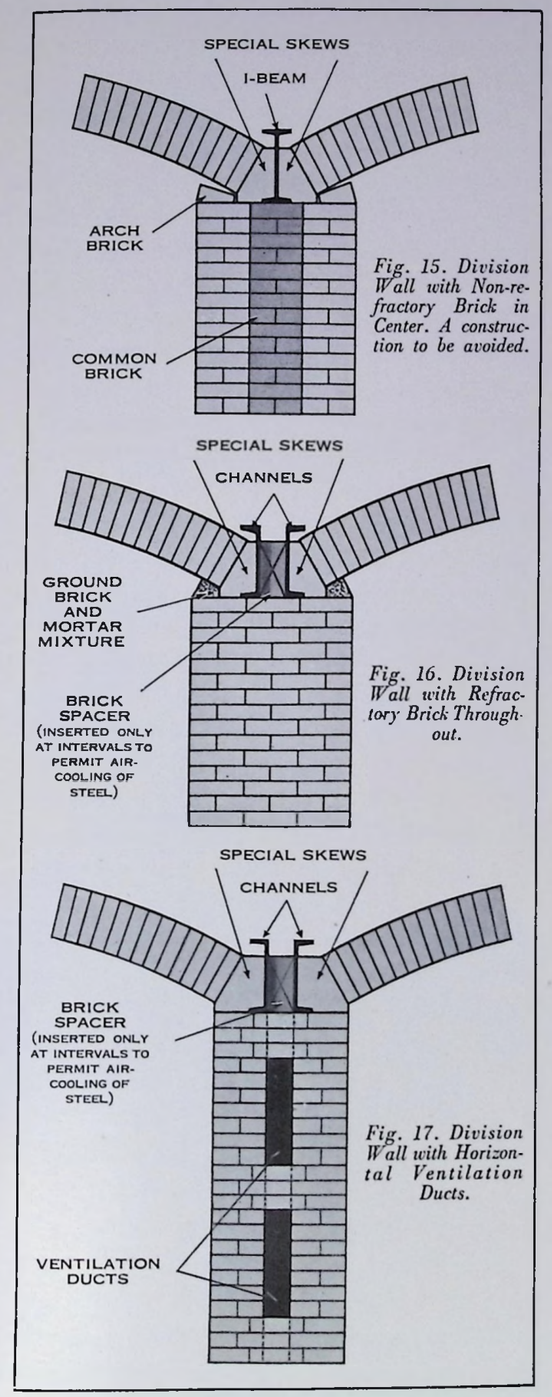


Fig. 15. Division Wall with Non-refractory Brick in Center. A construction to be avoided.

Fig. 16. Division Wall with Refractory Brick Throughout.

Fig. 17. Division Wall with Horizontal Ventilation Ducts.

Center or Division Walls: For high-temperature service, it usually is best practice to build all furnaces as individual units. For less severe temperature conditions, however, it may be advantageous to build two adjoining furnaces of certain types as a single structure divided into two parts by a division wall. The single structure requires less space, costs less for brickwork and metal binding, and has lower heat loss by radiation.

The mean temperature of the side walls of a furnace is normally much lower than the temperature at which the furnace is operated. However, division walls are heated on both sides and if not ventilated, attain practically the full furnace-operating temperature throughout. At high operating temperatures, such walls may deform unless built of material having higher refractoriness than that which is adequate for uninsulated side walls exposed to the same temperature. For example, solid division walls between furnaces operated at about 2200° F. should preferably be built of super-duty fireclay brick, although the side walls may be built of high duty brick.

If brick of inadequate refractoriness are used in the center of a division wall such as that shown in Figure 15, they may soften or completely melt at relatively low temperatures. The construction illustrated in Figure 16, in which the wall is built of refractory brick throughout, permits operation at higher temperatures.

In the construction illustrated by Figure 15, the skewbacks rest against an I-beam. With this construction, repairs can be made to one arch independently of the other; however, there is danger that the I-beam may become overheated. In the wall shown in Figure 16, the skewbacks are supported by two channels separated by brick. The steelwork will not

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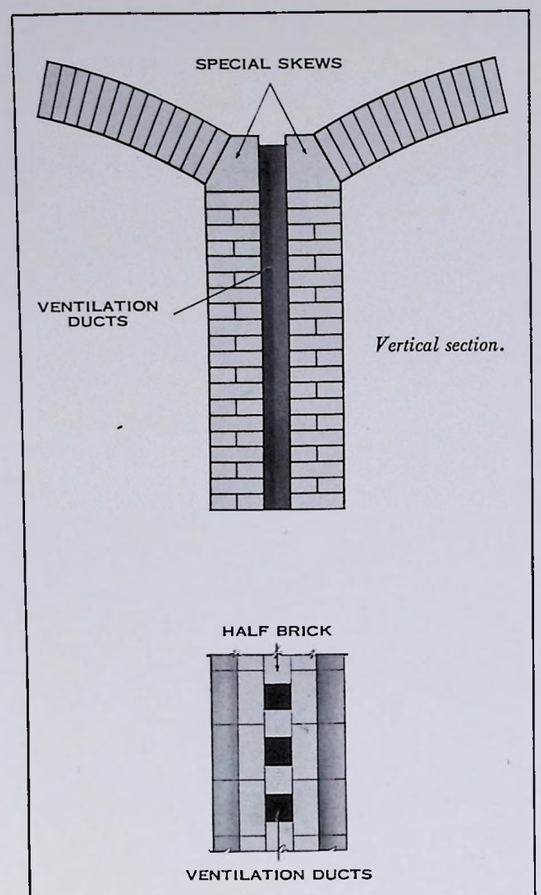


Fig. 18. Division Wall with Vertical Ventilation Ducts

become overheated since the brick between channels are inserted only at required intervals, and for the greater portion of their length the channels are exposed to the air on one side.

Figure 17 shows a ventilated center wall, which is cooled to some extent by means of air circulating through horizontal ducts. Bridge walls may be similarly ventilated. Continuous flow of cooling air is insured by the stack action of a short vertical flue which connects the horizontal ducts at one end. The other end of each of the ducts is wholly or partly open to the outside air.

Figure 18 shows a ventilated wall with vertical air ducts which are interconnected at the bottom.

Suspended Walls and Arches: For many kinds of service, the use of suspended arches and walls is highly economical. Various types of suspended constructions are available from the designs of engineering companies who specialize in this work.

The first cost of suspended construction is greater than that of solid walls and sprung arches. In suspended arches, the pressure on the sides of the brick is much lower than in sprung arches. Suspended construction affords certain definite advantages. Repair costs are generally lower, both because of the ease with which brick can be removed and replaced, and because replacement can be limited to the brick which are actually damaged, and in some cases there is the further advantage that hot repairs can be made without loss of production.

In suspended construction the refractories carry negligible load, and therefore have little tendency to deform at high temperatures. Definite allowance can be made conveniently to take care of thermal expansion, both horizontally and vertically. Provision can easily be made for ventilation, for water-cooling, or for insulation, as conditions may require. Suspended construction permits a latitude in design of furnaces, which otherwise would not be possible. One example of this is the greatly increased spans of many suspended arches, as compared with the spans of sprung arches.

If the weight of the roof is supported by suspended construction, the top courses of the walls should be tied to the furnace binding by metal hangers or clips to keep the walls from bowing in.

Heating Furnace Hearths: Conditions which may affect the durability of hearths are penetration by slag, floating of the brick by liquid pressure, and abrasion and loosening by movement of the charge over the hearth.

In the construction of many furnaces, the brick in the hearths should be laid with expansion joints. In some cases it is advisable to provide additional expansion space for the hearth under the side walls. As it is extremely difficult to keep expansion joints free from accumulations, they should be kept covered while the furnace is being heated to working temperature. Hearths of large furnaces resting directly on concrete foundations may become overheated unless they are ventilated by means of open cross-flues. These are located in the lowest courses of brick in the furnace bottom.

Solid hearths of rammed plastic material are

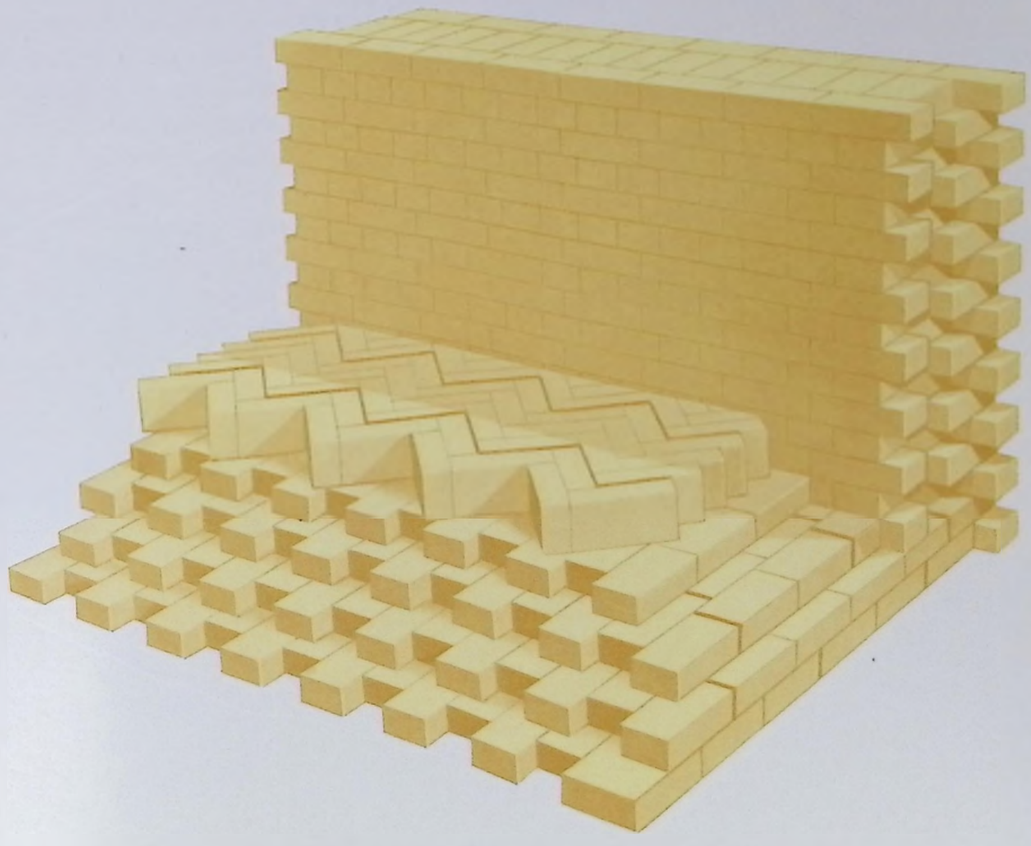


Fig. 19. Heating Furnace Bottom of Herringbone Construction with Expansion Joints

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often used, since with this construction slag penetration is kept to a minimum and the hearths may be maintained by hot patching. Ramming mixtures of various compositions and dead-burned grain magnesite are excellent materials for the construction of furnace hearths.

In the hearths of reheating furnaces, the lower courses of brick are usually laid on flat, and the top courses on edge. Regular rowlock bond is often used with the length of the brick laid parallel to the axis of the furnace. However, the rows of brick in the top course are often set in place with a herringbone pattern, as shown in Figure 19. During construction, expansion joints are made by the insertion of laths. These are removed after construction is completed and before the furnace is heated.

In some reheating furnaces, a layer of silica sand is used as a covering over a fireclay brick hearth; it absorbs the scale and forms a liquid slag which is easily drained off, but it may cause pick-up of adhesions.

In pipe-welding furnaces, the slightly sloping hearth usually consists of sand placed above crushed ganister or pebbles, forming a "French drain" through which the liquid slag can escape.

CONCRETE FOUNDATIONS

Concrete foundations of furnaces in many instances are subjected to temperatures up to 500° F. or even higher. The concrete may be considered to be constituted of two parts — first a binder of partially hydrated Portland cement, and second, the aggregate, consisting of crushed stone.

At 500° F. the Portland cement binder begins to lose its water of crystallization; at 700° F. dehydration has proceeded to the point where the cement begins to weaken; and at 900° F. dehydration has progressed to such an extent that the concrete has little mechanical strength. Under average conditions, concrete made with ordinary Portland cement can be used safely for furnace foundations up to a temperature of about 700° F. Refractory concrete made of castable material can be used safely at temperatures which would cause Portland cement concrete to disintegrate. In general, standard castables may be used up to 2400° F. and super-castables up to 2700° F. Refractory concrete loses its hydraulic bond at high temperatures but develops a ceramic bond which imparts mechanical strength.

Calcined refractory clay in lump form, when used as the aggregate in Portland cement mixtures, provides an insurance against the shortcomings of some of the conventional aggregate materials. Its thermal expansion is low, and it does not shrink at the highest temperatures to which concrete will be subjected. An aggregate made of quartz pebbles or silica gravel will expand sufficiently at relatively low temperatures to set up stresses within the concrete, or even to cause appreciable weakening. Limestone or dolomite rock used as the aggregate, while better than quartz or silica, will become calcined and may weaken considerably if overheated.

For high temperature furnace operation it is often advisable to ventilate the lower courses of brickwork or the concrete foundation. This may be done by designing the furnace so that it rests on plates or girders or on low brick piers between which air can circulate. The piers and separating flues may be of any convenient dimensions; frequently 9-inch piers 5 to 10 inches high, separated by 4½-inch flues, are most practicable. Sometimes, cross-flues for ventilation are formed in the top of the concrete foundation itself. Another means of ventilation is obtained by embedding, in the foundation, pipes 3 inches in diameter or larger, which are kept open to the air.

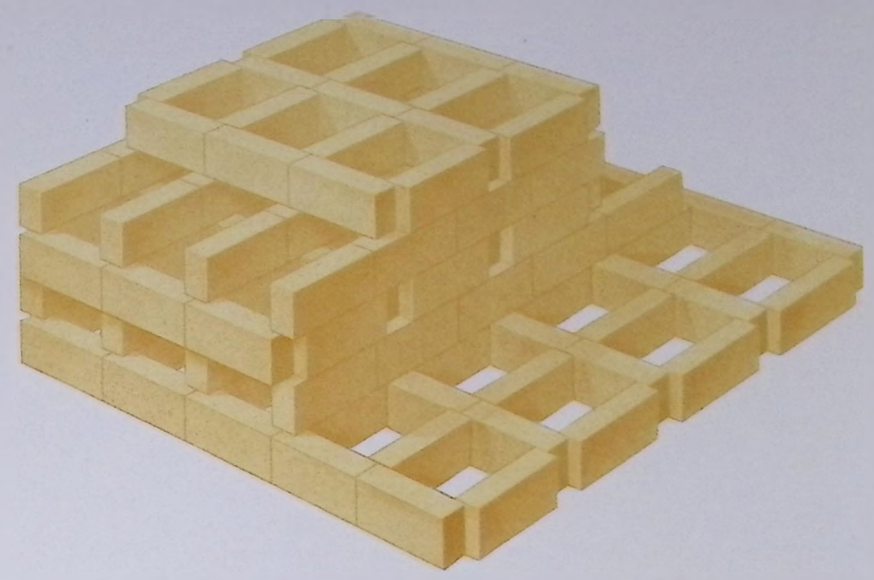


Fig. 20. Alternate Chimney and Open Flue Checker Assembly — 9" x 4½" x 2½" Straights

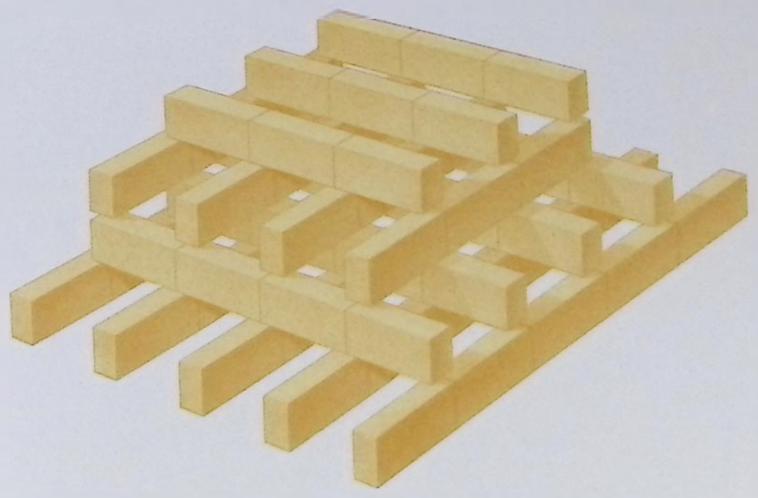


Fig. 21. Open Flue Checker Assembly — 9" x 4½" x 2½" Straights

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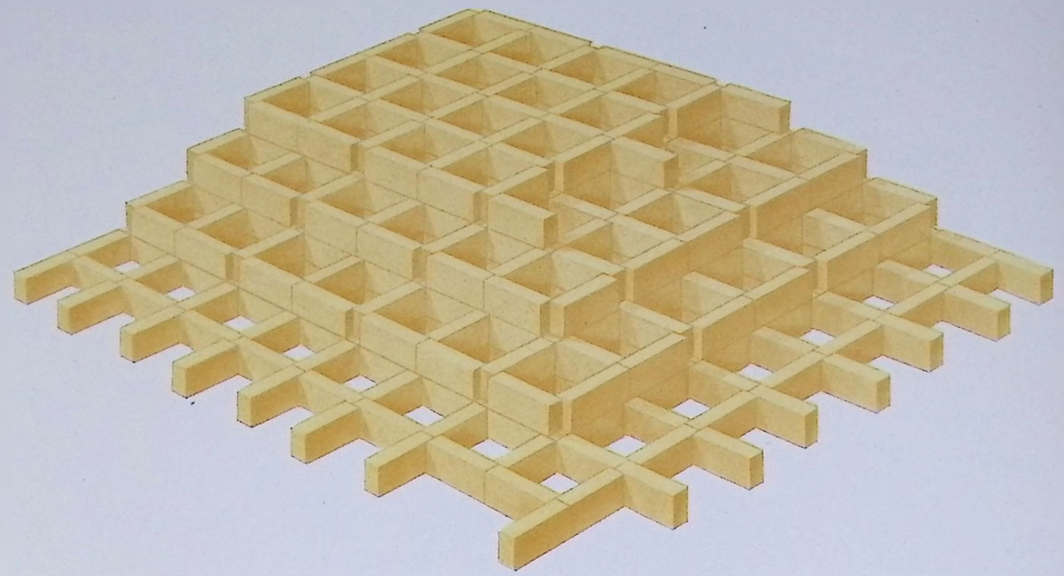


Fig. 22. Chimney Flue Checker Assembly — 9" x 4½" x 2½" Straights

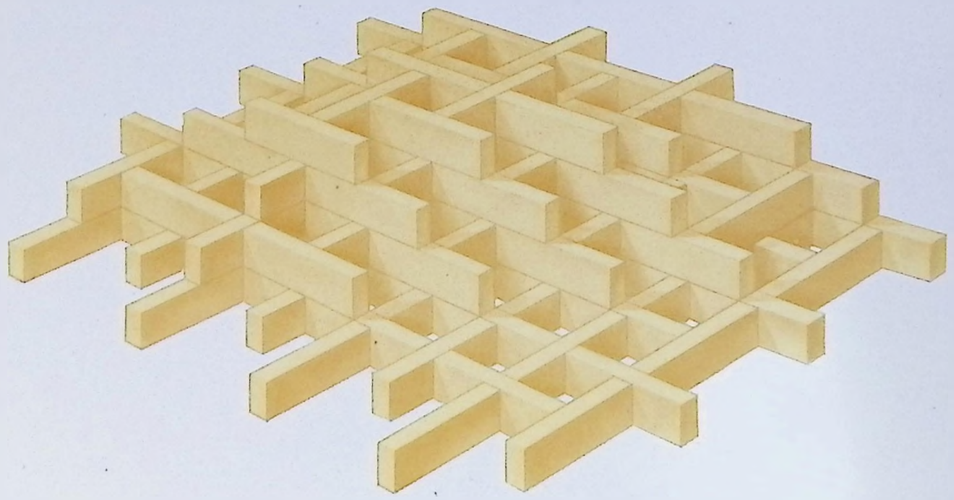
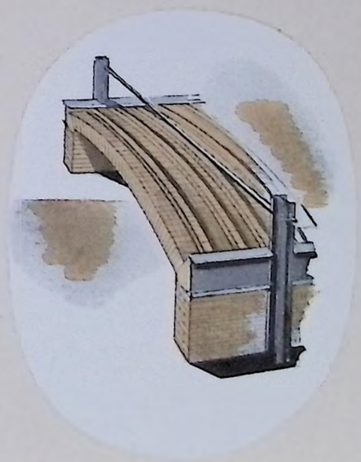


Fig. 23. Basket Weave Checker Assembly — 18" x 6" x 3" Straights

FURNACE ARCHES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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FURNACE ARCHES

Arches form the roofs of furnaces, of combustion chambers, and of flues; they span wall openings; and they are sometimes used to support the weight of superstructures such as walls and checkerwork. In no position of a refractory structure are proper design and construction more important than in the arch.

In a true arch, each block or structural unit has a shape which is determined by the design of the whole. An arch is not self-supporting until all the structural units required to bridge the span between supports have been fitted together. Arches are built with radial joints, and usually with the interior surface following a curved line. At each end of an arch there are masonry units known as skewbacks, with sloping faces from which the arch rises.

An arch exerts upon its skewbacks not only the downward force of its own weight and the weight of any loads carried by it, but also an outward or horizontal force, which tends to make the skewbacks spread farther apart. The vertical component of the arch stress may be supported by the furnace walls, or it may be carried by steel beams. The horizontal component of the arch stress also must be resisted, as otherwise the skewbacks would slide outward and deprive the arch of its support.

The horizontal thrust of a roof arch is transmitted through the skewbacks to a steel supporting system known as the furnace "binding". The outward thrust of flue arches above ground is supported by metal binding; the thrust of flue arches below ground is usually supported by concrete outer walls backed up by earth or rock. In arches spanning wall openings, the stresses are supported by resistances within the wall.

ROOF ARCHES

The roofs of furnaces are commonly formed by sprung arches consisting of combinations of refractory brick shapes supported at the sides only, by skewbacks. As shown in Figure 24, a cross-section taken at right angles to the axis of the arch usually consists of a segment of a circular ring in which the outer and inner arch surfaces are represented by arcs of concentric circles, and in which the inner chord is horizontal. Throughout the present discussion, an arch of such design will be referred to as a simple sprung arch, or as a simple arch.

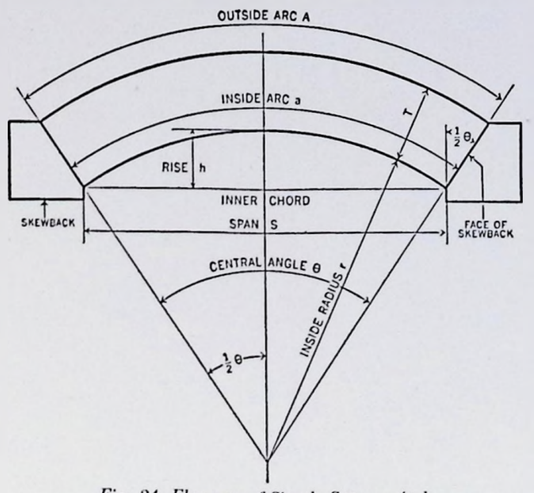


Fig. 24. Elements of Simple Sprung Arch

The furnace binding consists of (1) horizontal buttress beams placed lengthwise of the furnace directly back of the skewbacks; (2) vertical beams known as "buckstays", spaced at intervals along the furnace walls, and generally with their lower ends set in the concrete foundation; and (3) horizontal members consisting of tie-rods, I-beams, or channels. These extend across the furnace above the roof, and connect the upper ends of opposite buckstays. Such binding is illustrated in the drawing of a copper reverberatory furnace on page 186.

The sloping surface of a skewback brick is termed its "face". The deviation of the face from a vertical plane is known as the "slope" of the skewback. The "rise" of an arch is the distance between the inner chord and the inner arc of the arch at their centers.

The stability of the arch depends upon its rise and thickness, upon the weight, strength and thermal properties of the material of which it is composed, and upon the strength, placement and structural support of the skewbacks.

Usually, in the design of a furnace arch, the span and the thickness are established first. When, in addition, the rise has been decided upon, all the other arch dimensions, as well as the slope of the skewback, are definitely fixed and can be calculated. The arch dimensions may be calculated in simple manner by use of the constants given in the table on page 375.

ROOF THICKNESS

Factors which determine the most desirable thickness of a roof arch are the span, stability considerations, the type of refractory, the strength of the brick at operating temperatures, the kind of service, the permissible heat loss, and the normal life of the roof as related to that of the rest of the furnace structure.

In general, the thickness of a roof arch should be not less than 4½ inches for spans up to 5 feet, 9 inches for spans between 5 and 12 feet, and 12 or 13½ inches for spans from 12 to about 20 feet. For low temperature operation the thickness may be somewhat less, and for roof arches subjected to severe corrosive action the thickness may be somewhat greater.

The thickness of a silica roof arch over a high-temperature furnace of wide span is rarely less than 0.05 S, and generally not less than 0.06 S, where S represents the span. Stress considerations suggest that such roofs should preferably be not thicker than about 0.06 S for a rise of 1 inch per foot of span, about 0.085 S for a rise of 1.25 inches per foot of span, or about 0.10 S for a rise of 1.5 inches per foot of span. For rises greater than 1.5 inches per foot of span, the maximum practical limit is about 0.10 S.

If a roof arch is relatively thick and its rise is low, excessive stresses may develop unless care is taken to compensate in some manner for the expansion of the brick which occurs on heating. In some constructions, the abutments are so designed that they yield sufficiently to compensate for this expansion.

RISE OF A ROOF ARCH

The rise of an arch is commonly expressed either directly in inches per foot of span, or indirectly in terms of the central or included angle. In a simple sprung arch, when either of these two values is known, the other is definitely fixed. For example, regardless of the span, any such arch having a rise of 1½ inches per foot of span has a central angle of 56 degrees 8.7 minutes.

Experience has shown that a simple roof arch should have a rise of not less than about 1 inch nor more than about 3 inches per foot of span. A roof which is too flat will be subject to excessive stresses; one which is too steep will tend to buckle.

Silica brick roofs, in furnaces of wide span operated at high temperatures, rarely have a rise of less than 1 inch or more than 2 inches

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per foot of span. They usually have a somewhat lower rise than fireclay brick roofs, because of their greater strength at high temperatures.

A roof built of fireclay brick will usually be given a rise of not less than 1½ inches nor more than 3 inches per foot of span. The higher figure is to be preferred for roofs which are sub jected to extremely high temperatures or to conditions of soaking heat.

Insulating fire brick have much lower resistance to compression than fireclay or silica brick; therefore, roofs built of insulating fire brick are given a rise of not less than 2 inches per foot of span. Conditions of stability, however, require that the rise should be not more than 3 inches per foot of span.

A logical standard for many applications is the arch with a central angle of 60 degrees, corresponding to a rise of about $1\frac{19}{32}$ inches per foot of span. This 60-degree arch meets all the normal requirements for strength and stability. The number of brick required for such -arches can be calculated easily and quickly, since the inside radius is equal to the span, and the arch includes exactly one sixth of a circle.

When the skewbacks are built with standard 9-inch feather edge brick of the 2½-inch series, a rise of 1½ inches per foot of span is obtained; and when standard 9-inch side skew and end skew brick of the 2½-inch series are used, the rise is $2\frac{5}{16}$ inches per foot of span. Both these constructions are illustrated on page 57.

Table VII.

TYPICAL DIMENSIONS OF SILICA BRICK FURNACE ROOFS

Kind of Furnace	Type of Roof	Typical Span	Typical Rise	Typical Rise Per Foot of Span	Typical Thickness
Copper					
Reverberatory Smelting	Bonded	25′ 0″	27½″	1.10″	20″
Anode and Wirebar	Bonded	16′ 0″	18″	1.12″	15″ to 20″
Glass Tanks	Bonded	21′ 0″	33½″	1.608″	12″ and 13½″

Table VIII.

TYPICAL DIMENSIONS OF OPEN-HEARTH STEEL FURNACE ROOFS

Furnace Charge	Type of Roof	Tonnage	Typical Span	Typical Rise	Typical Thickness		Typical Number of Courses Between Ribs
					Roof	Ribs	
Hot Metal	Ribbed	Below 100	14′ 6″	27½″	12″	15″	6
Hot Metal	Ribbed	100 – 150	17′ 0″	30″	15″	18″	5
Hot Metal	Ribbed	150 – 200	19′ 6″	32″	15″	18″	5
Hot Metal	Ribbed	Above 200	20′ 6″	34″	15″	18″	4
Hot Metal	Bonded	100 – 150	17′ 6″	28″	13½″	....	....
Hot Metal	Bonded	150 – 200	20′ 0″	36″	13½″ to 18″	....	....
Hot Metal	Bonded	Above 200	20′ 6″	36″	13½″ to 18″	....	....
Cold Metal	Ribbed	Below 100	14′ 0″	24″	12″	15″	3 – 4
Cold Metal	Ribbed	100 or over	17′ 0″	27″	15″	18″	3 – 4
Cold Metal	Bonded	60 – 70	13′ 0″	18″	12″	....	....

About 10% to 12% of open-hearth roofs are of the bonded type.
About 10% of the open-hearth furnaces are charged with cold metal only.

SELECTION OF BRICK SIZES FOR THE ARCH

Furnace arches are formed either of tapered brick only, or of tapered brick used in combination with straights. The tapered brick employed are standard sizes or special shapes of wedge, arch or key design. Wedge brick and sometimes key brick are used for wide spans; wedge brick or arch brick for narrow spans.

Construction of an arch with units all of the same size and shape generally would require the use of special shapes. In order to obtain a required radius with standard brick sizes, it is usually necessary to use a combination of tapered and straight brick, or of two tapered brick having different slopes. When the proportion of straight brick in an arch is too high, the arch cannot be properly keyed, and lacks stability. The number of straights should not be greater than twice the number of tapered brick. In arches having relatively wide spans, a much more desirable ratio of straight to tapered brick is obtained with sizes of the standard 3-inch series than with those of the 2½-inch series.

Tables showing the quantities and kinds of brick for arches of various rises and spans are given on pages 405 to 422.

ABUTMENTS

The supports or abutments of a roof arch consist of two parts: first, the brick skewback, and second, a horizontal steel member or "buttress" which supports the skewback. The buttress may be either a channel, an angle or an I-beam. It is protected from the effects of excessive temperature by the brickwork. The abutments must not only support the cold thrust of the arch, but they must also withstand additional horizontal stresses due to thermal expansion of the roof brick. The vertical load may be supported either by the abutments or by the walls, depending upon the design.

Solid support for the skewbacks, to withstand the arch stresses, is vitally important. Movement of the skewbacks may result from insufficient strength or rigidity of the metal binding, or from overheating of the binding. Skewbacks resting upon side walls may sag because of softening or wearing away of the side walls, or because of defective or inadequate foundations.

SKEWBACKS

The skewbacks may be built-up combinations of standard brick sizes or they may be one-piece special shapes. The built-up skewbacks can be used satisfactorily for roofs of narrow spans. The sizes used in their construction are available as needed from stocks regularly carried by manufacturers. Built-up skewbacks are illustrated on page 57.

The one-piece skewback is generally to be preferred for furnace arches having spans greater than 4 feet. It is stronger than the built-up skewback because of its freedom from joints, and it can be supported more completely by the metal buttress.

It is important that the face of a skewback be given the proper slope, as determined by the rise and the span of the arch. When the skewback is carried on a channel or an angle, it is preferably designed and placed so that the line of thrust will pass through or slightly above the corner of the supporting channel or angle. If a one-piece skewback is so designed that its

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face forms an acute angle with the base, the sharp edge formed may crack or shear off. It is best practice therefore to design the skewback with a square toe, as shown in the drawings of skewbacks for arches with included angle of 60 degrees on page 58.

In most cases, the dimension of a skewback brick lengthwise of the wall upon which it rests may advantageously be 9 inches for arches 4½ inches thick, and 3 or 4½ inches for arches 9, 12 and 13½ inches thick.

The skewbacks of ribbed arches should be high enough to support the ribs over their entire length.

The slope of the skewback, or angle between its face and a vertical plane, is equal to one-half the central angle of the arch. In plants where it is possible to standardize on the same central angle for the roofs of all furnaces, there will be no necessity for carrying in stock skewback shapes other than those which fit the central angle selected. Skewbacks for 60 degree arches are shown on page 58. One series shown has no cutouts; a second series has cutouts to fit angles; and a third is designed to fit channels. From the illustrations, skewbacks can be selected for arches which are 4½, 9, 12 and 13½ inches thick.

The skewbacks without cutouts are suitable for roof arches when the supporting angle or channel can be placed with its flange outward, or when a buttress block of brick separates the skewback brick from the metal buttress. They may be used also for arches over openings in walls, and for arches of flues which are set in steel or concrete.

The skewback brick illustrated are designed to fit the heaviest angles and channels which are likely to be used. When thinner angles are employed, proper bonding of the skewback brick may be secured by the use of ground brick or of mortar material. It is sometimes desirable to provide an air space under the angle or channel, to permit air-cooling.

PLACEMENT OF SKEWBACK BRICK

Protection of skewback brick from the destructive influences of furnace conditions is important, since wearing away of the skewbacks may cause failure of the roof. Skewbacks set flush with the inner faces of walls will be deprived of their support, if these inner faces soften or wear away. Any sagging of the face of a wall which causes the skewbacks to tilt will impose severe stresses upon the arch brick, and may cause the roof to buckle. Skewback brick should not be separated from the metal buttresses by insulating fire brick or other compressible material, as these may crush through inability to support the arch stresses.

In the construction shown in Figure 25, the wall is thicker than the arch, the skewback is in a protected position, and damage to the interior face of the wall will not affect the skewback. For constructions in which the walls are 4½ inches thicker than the roofs, the special skewbacks shown on page 58 may be used. When this is done, a 4½-inch roof will rest on 9-inch side walls, a 9-inch roof on 13½-inch side walls, and a 13½-inch roof on 18-inch side walls.

Figures 26 and 27 illustrate a 9-inch arch resting on a 13½-inch wall and supported by a built-up skewback formed of standard brick. In Figure 26, the better arrangement, the skewback is placed on the outer or cooler portion of the wall in such a manner that softening or wearing away of the inner 4½ inches of the hot face of the wall would not deprive the arch of its support. Repairs can be made to the inner

DESIGN AND PLACEMENT OF SKEWBACK BRICK

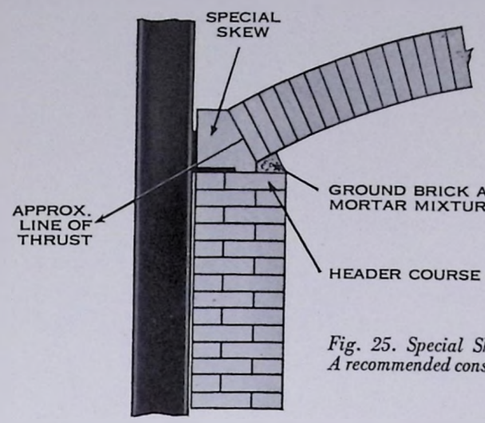


Fig. 25. Special Skewback. A recommended construction.

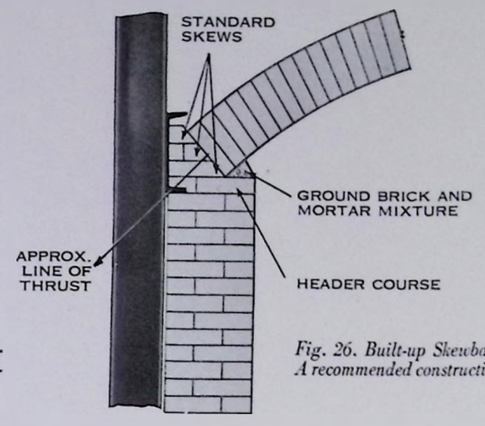


Fig. 26. Built-up Skewback. A recommended construction.

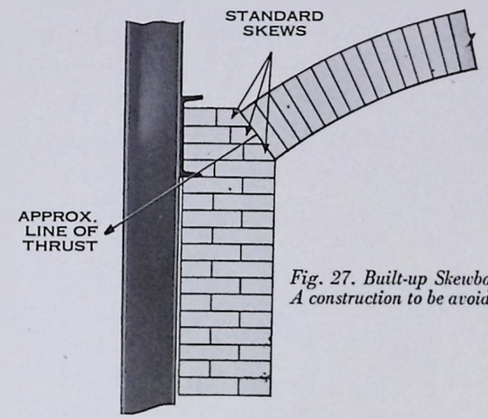


Fig. 27. Built-up Skewback. A construction to be avoided.

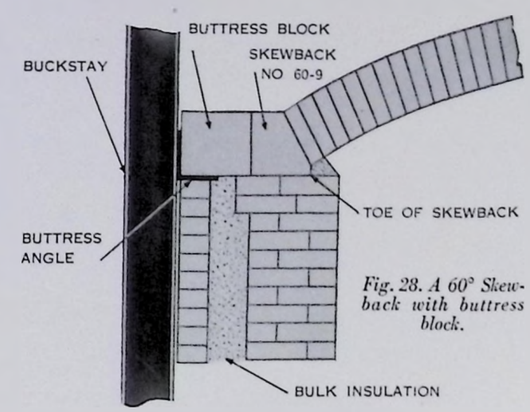


Fig. 28. A 60° Skewback with buttress block.

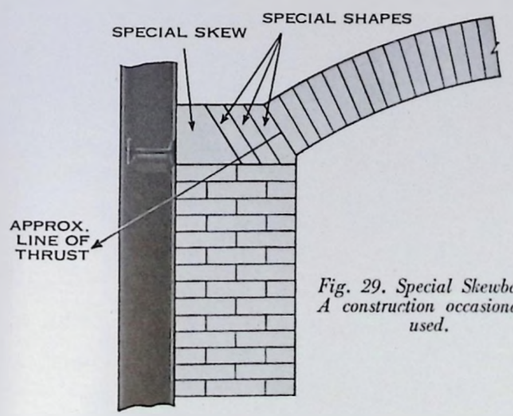


Fig. 29. Special Skewback. A construction occasionally used.

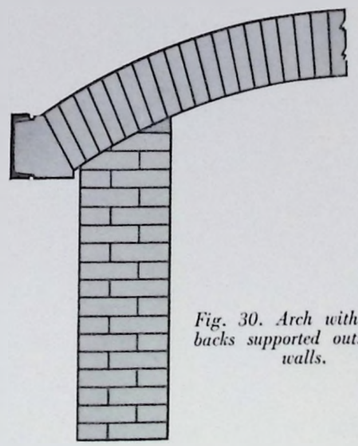


Fig. 30. Arch with Skewbacks supported outside of walls.

A stretcher course should never be used immediately below the skewback.

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4½ inches of the wall without disturbing the arch. With a skewback placed as in Figure 27, damage to the hot face of the wall will weaken the support of the skewback brick and affect the stability of the roof.

When there is a narrow ledge on top of the side wall, as shown in Figures 25 and 26, the space between it and the arch sometimes is filled with feather edge or other thin brick. Since these may fall off, it is usually better practice to fill the space with plastic fire brick or a refractory ramming mixture.

In Figures 25, 28, 29 and 30, special skewbacks are employed. In each case, the skewback is placed on the cooler part of the wall and is thereby protected. However, in Figure 29 the special shapes between the skewback block and the ends of the arch may be damaged by any wearing away of the wall and the arch thereby weakened. The construction shown in Figure 30 is sometimes used when there are relatively large openings in the roof.

In Figures 25 and 26 the line of thrust comes within the channel or angle. This is a desirable condition, since it is conducive to stability of the arch.

TYPES OF ARCH CONSTRUCTION

Arches formed of separate courses or rings, not bonded together, are called "ring arches"; those in which the transverse joints are staggered, to tie the construction together, are known as "bonded arches".

Among the relative advantages and disadvantages of the two types of arches are these:

Ring Arch (Figure 31)

Somewhat less labor for initial construction.

Ease of cold repairs.

Less strain longitudinally.

Better resistance to spalling conditions.

Requires support at end of furnace to prevent buckling outward.

A ring may fall in if it is worn thin in spots.

Bonded Arch (Figure 32)

Stronger construction.

Better adapted to hot repairs.

Requires greater uniformity of brick, greater skill in construction.

More chance of single brick falling in.

Bearings of brick less positive.

Bonded roof arches of wide span are frequently built of brick 6 inches wide. Breaking of joints is accomplished by the use of brick 9 inches wide in the first and last courses. In a somewhat less desirable method of construction sometimes followed, the arches are built of brick 9 inches wide, and brick 6 inches wide are used in the first and last courses.

In the usual sprung arch roof, all courses or rings are of uniform thickness. In a rib ring arch the rings are of two different thicknesses, as shown in Figure 33. The thicker rings, generally called "rib rings", are separated by three to six of the thinner or "valley rings". The rib brick usually are 3 to 4½ inches longer than the brick in the valley rings. The ribs project above the outer surfaces of the other rings, and the inner surface of the roof is smooth. Bonded arches are sometimes provided with ribs constructed of special wedge shapes.

Ribbed ring arches are used mainly in the roofs of open-hearth steel furnaces. In service, as the roof gradually wears thinner, the brick in the ribs remain strong even after the intervening rings have become too thin for stability. The stability of the ribs is especially advantageous if the roof wears away much more rapidly in some places than in others. Their additional strength is very helpful when roofs must be patched.

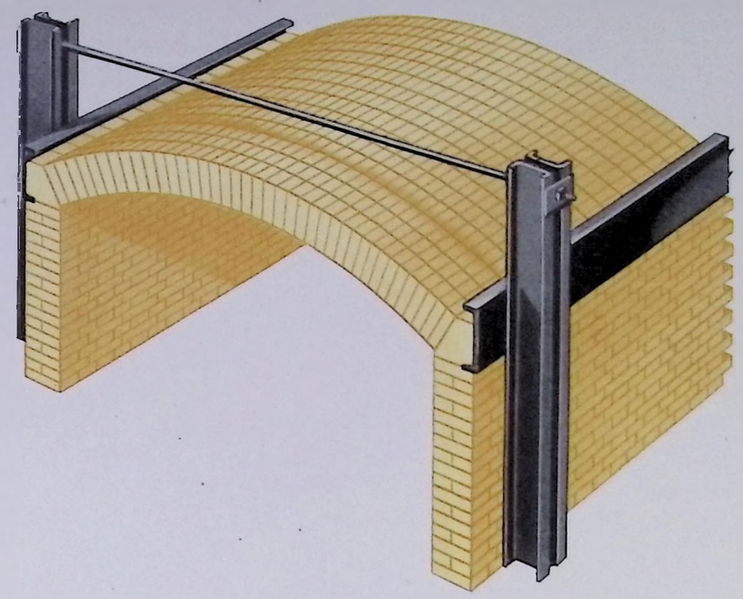


Fig. 31. Ring Arch

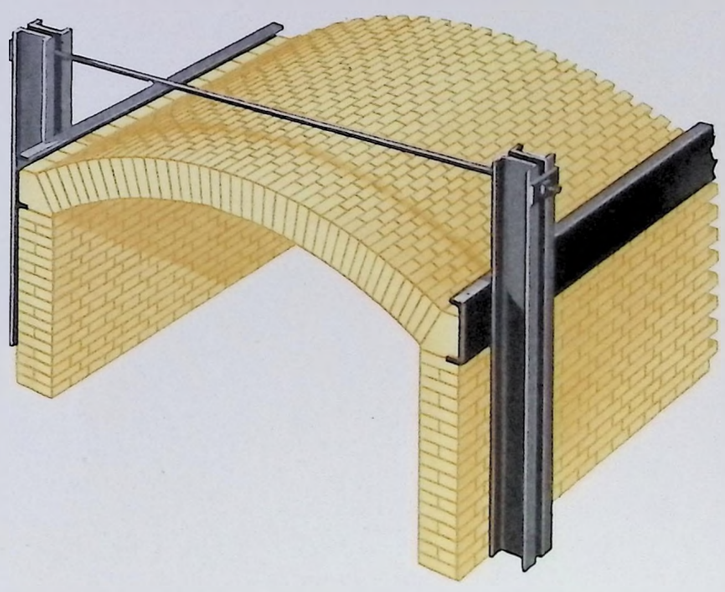


Fig. 32. Bonded Arch

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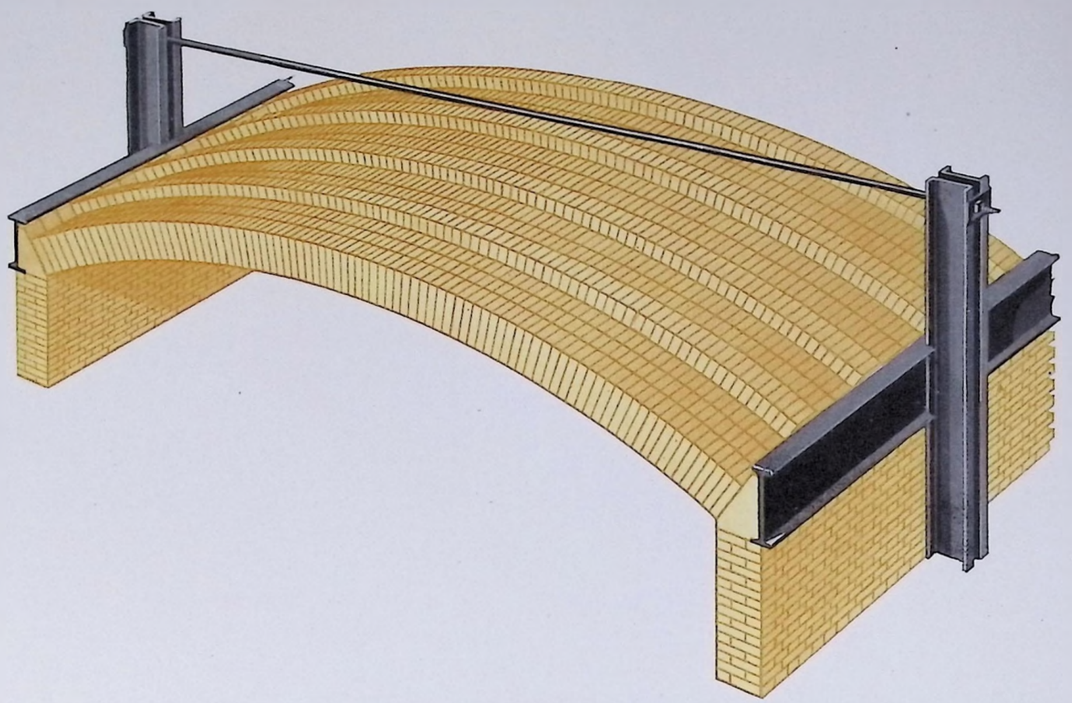


Fig. 33. Ribbed Arch

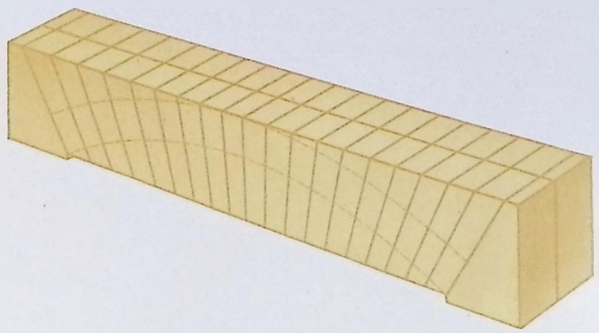


Fig. 34. Flat or Jack Arch

JACK ARCH

The flat or jack arch is formed by special wedge shapes, which may be designed by first laying out a radial sprung arch of proper rise and thickness for the given span; then extending all lines representing joints between brick upward to the level of the highest part of the arch and downward to the level of the spring line. This construction is shown in Figure 34.

A wall opening spanned by a flat arch has a rectangular cross-section, which is desirable for certain purposes. Arches of this design sometimes are used to conserve space. A jack arch such as illustrated is structurally weak and should be used only for narrow spans. For best construction, a large number of special shapes is required.

WALL ARCHES

The term "wall arches" may be used to designate relieving arches, and arches over firing door and charging door openings, ports and the like. The rise of wall arches can safely be made higher than that of roof arches, because the tendency to buckle is resisted by the weight of the overlying brickwork. Consequently wall arches are frequently made semi-circular.

In furnaces operated at high temperatures, it is often advantageous to span an opening through a wall with two or more sprung arches one above the other. The lower arches serve to withstand the brunt of the severe furnace conditions, while the upper or relieving arch thus protected supports the weight of the wall, and also facilitates repairs and renewals to the lower arches. This construction is illustrated in Figure 35.

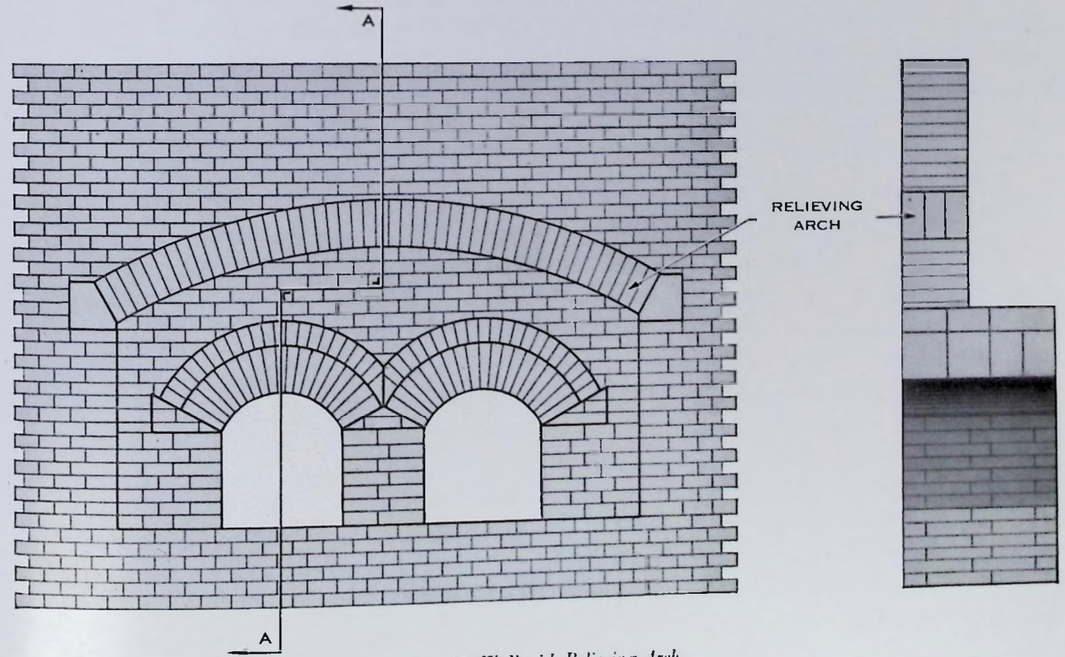


Fig. 35. Wall with Relieving Arch

BUILDING A FURNACE ROOF

During the time a sprung arch roof is being built, the brick are supported by a temporary structure or form called a "center". This usually consists of a number of wooden arcs or "ribs" set vertically a few feet apart at right angles to the length of the furnace, and covered with wood lagging. The span of the "center" is slightly less than that of the arch, as otherwise the form could not be readily removed after the roof is built.

In the construction of an arch, the laying of brick begins at the skewbacks and progresses toward the middle. The operation of closing the space at the middle is known as "keying the arch". This is done by driving one or more brick into place. Wooden blocks set on top of these brick protect them from damage while being keyed. If the arch is keyed too tightly, it will be subjected to high compressive stresses; later, when the furnace is heated, and thermal expansion of the brick imposes additional stresses, there may be a tendency toward pinch spalling at the inner arch surface. All arch rings should be keyed uniformly; otherwise, some rings will rise higher than others when the furnace is heated. In building a roof arch, it is considered good practice to use two or three brick for keying. It is best not to drive them too tight.

Roofs built of silica brick frequently are laid without mortar, and grouted with a silica cement after the furnace is heated. However, there is a trend toward the more extensive use of highly refractory mortar for laying the silica brick.

Sprung arch roofs constructed of fireclay or high-alumina brick are almost always laid with dipped mortar joints, which give an even bedding. For high-temperature arches, a hot-setting bonding mortar is usually satisfactory. In some arch constructions air-setting mortar is preferable, as for example in many flues, muffle-type arches, thin arches or arches of narrow span, or in other constructions where the arch is not subjected to a temperature high enough to develop a ceramic bond in the mortar.

DIFFERENTIAL THERMAL EXPANSION OF ROOF BRICK

During the operation of a furnace, the temperature of the inner surface of the roof arch is usually very little below that of the furnace gases. The temperature of the outer surface of the roof arch is much lower and consequently its thermal expansion is less. The "cold surface" temperature of a furnace roof depends upon the "hot surface" temperature, the thickness of the arch, and the thermal conductivity of the refractory used in its construction. The cold surface temperature is influenced also by the porosity of the brick, by the extent to which the brick are impregnated with fluxes, by the gas pressure within the furnace, by the temperature of the outside air, and by exterior air currents which may have a cooling effect.

The distance an arch will rise when heated depends upon the thermal expansion characteristics of the brick used, the difference between the expansions of the inner and outer surfaces of the arch, the arch dimensions, the closeness of fit of the brick surfaces, the elastic and pyroplastic properties of the brick, and the rigidity of the furnace binding. Rising of an arch may cause joints to open at the outer surface of the arch near the point of mid-span, with concentration of the entire arch stress upon very small bearing surfaces at the inner ends of the brick. The unit stresses may become great enough to break off the inner ends of the brick.

PROVISION FOR EXPANSION IN ARCHES

In building a roof arch, provision may be made for the expansion lengthwise of the furnace by the use of strips of combustible material such as cardboard in each transverse joint, by leaving an open space at each joint, or by leaving open joints or slots across the roof at desired intervals. Usually, provision for the transverse thermal expansion is not made in the arch itself. This expansion generally is compensated for by rising of the arch, by slight compression of the hot ends of the brick, or by adjustment of tie-rods. In the case of silica or basic brick arches compensation for expansion is sometimes made by the use of steel springs at the ends of the tie-rods.

At high temperatures, slight softening of the heated ends of fireclay roof brick will transfer the arch stresses to the cooler ends of the brick, which will provide solid bearing surfaces of ample strength to withstand the stresses. Usually sufficient compensation for the transverse expansion of a fireclay brick arch is provided automatically by bedding-in of brick surfaces, stretching of tie-rods, rising of the arch, and compression of hot ends of the brick.

In some roof arches of wide span, such as those of glass melting tanks and copper reverberatory furnaces, compensation for thermal expansion of silica roof brick is made by manual adjustment of tie-rods, sometimes accomplished by the use of force-limiting springs. However, springs cannot be very effective unless the skewbacks are so supported that they offer little or no frictional resistance to horizontal movement, and unless they are protected from excessively high temperatures.

In open-hearth steel furnaces, buckstays often are tied together rigidly with channels, and outward movement of skewbacks is usually prevented. In some cases, provision for transverse thermal expansion of the roof is made by the insertion of cardboard in the joints; in others, by the insertion of thin narrow strips of soft wood at the inner ends of the joints at intervals of approximately two feet across the furnace. In still other cases, compensation for transverse thermal expansion is provided by driving the key brick just hard enough, based upon experience, to permit the roof to drop slightly when the forms are removed, with the opening of small gaps between brick along the inner surface. If the brick have been laid properly, thermal expansion will close the gaps between brick and cause the arch to rise until it has assumed approximately the lines for which it was designed or slightly higher.

MATERIALS OF ARCH CONSTRUCTION

Fireclay and silica brick are the materials most commonly used for furnace arch construction; high-alumina, magnesite, chrome or forsterite brick are employed for special conditions.

The fireclay brick most commonly employed in roof service are those of the high duty and super-duty classes. They find application in the roofs of tunnel kilns, heating furnaces, malleable and air furnaces, and the like. They are indispensable for service in which there are rapid fluctuations of temperature, and in many furnaces which are heated and cooled daily, or which are operated intermittently.

In metallurgical furnaces operated continuously at high temperatures, sprung-arch roofs of wide span usually are constructed of silica brick. The properties which make these brick so valuable for arch construction are their great mechanical strength and rigidity at high temperatures, their lightness of weight, with

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consequent low arch stresses, and their constancy in volume above 1200° F.

For temperatures higher than those which silica brick will withstand, basic refractories in some cases are applicable. Some types are available which have high strength at high temperatures and adequate resistance to spalling. Forsterite brick and high-fired chrome-magnesite brick give good results in sprung arch roofs of furnaces operated at high but relatively constant temperatures.

In furnaces of various types, the roof brick may be consumed more rapidly, in localized small areas near the side walls, than in the main portion of the roof. The life of such a roof can be extended by the use of more refractory brick in the critical zones. It often is good practice to provide conventional silica brick roofs of metallurgical furnaces with shoulders or sections built of super-duty silica, high-alumina, or basic brick. In basic open-hearth furnaces the shoulders may consist of narrow panels of super-duty silica brick or of basic brick, usually adjacent to the back wall. Basic brick shoulders frequently vary in width in adjoining rings.

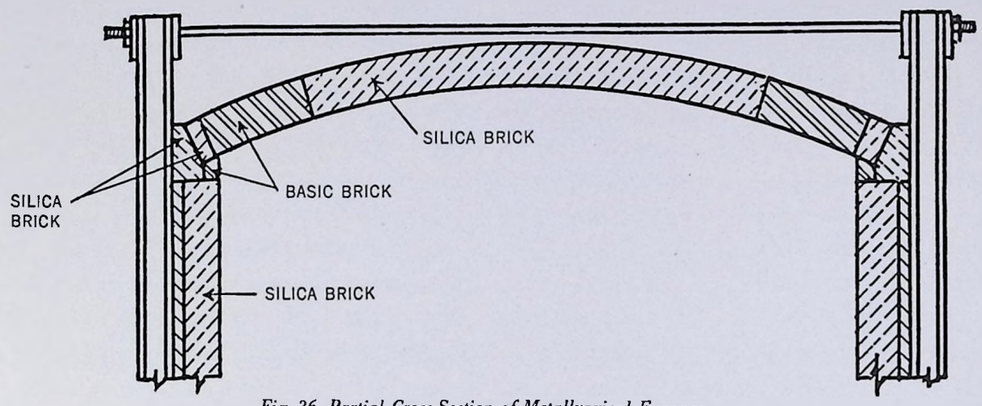


Fig. 36. Partial Cross-Section of Metallurgical Furnace, Showing Silica Brick Roof with Basic Brick Shoulders

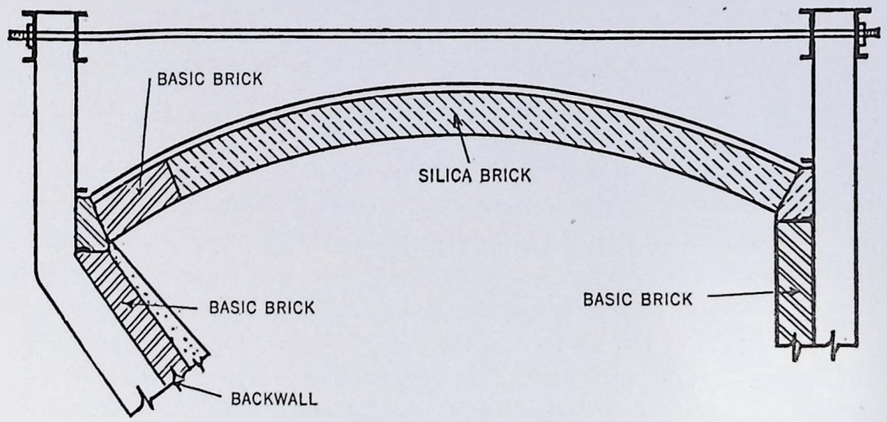


Fig. 37. Partial Cross-Section of Basic Open-Hearth Steel Furnace, Showing Silica Brick Roof with Basic Brick Section at Backwall Side

ARCH STRESSES

Every brick in an arch is subjected to stresses resulting from the weight of the brick. In a section taken across an arch, the point through which the resultant of all outer forces acts at each surface of contact between adjacent brick is known as the "center of pressure", and the line joining the centers of pressure is called the "line of thrust". The positions of the centers of pressure and of the line of thrust are indicated in Figure 38.

In an arch of uniform thickness, the line of thrust would follow a catenary curve, if the curved line connecting the centers of gravity of the individual brick were also a catenary. In the usual simple sprung arch, however, the line through the centers of gravity is an arc of a circle. Nevertheless, the actual line of thrust coincides so closely with a catenary curve that the latter may be assumed to be correct for practical purposes.

Although the shape of the line of thrust in a simple sprung arch is known, its position is indeterminate, since various positions are possible. In order to make a solution of arch problems possible, various hypotheses have been advanced. The one which seems to be accepted most generally is known as Winkler's Theorem, which leads to the conclusion that for arches in which contact occurs over the whole face of each brick, the line of thrust in nearly every case will lie within the middle third of the arch thickness.

The conditions which must be met in order that an arch will be stable and that no joints will open are these:

1. a. The line of thrust must lie within the brickwork which makes up the arch ring; if not, the arch will collapse.
   b. The line of thrust should lie within the middle third of the thickness of the arch ring, or joints may open.
2. The angle between the line of thrust at any joint and the normal to that joint must not be greater than the angle of repose of brick upon brick, or of brick upon mortar, otherwise brick will slide past each other.

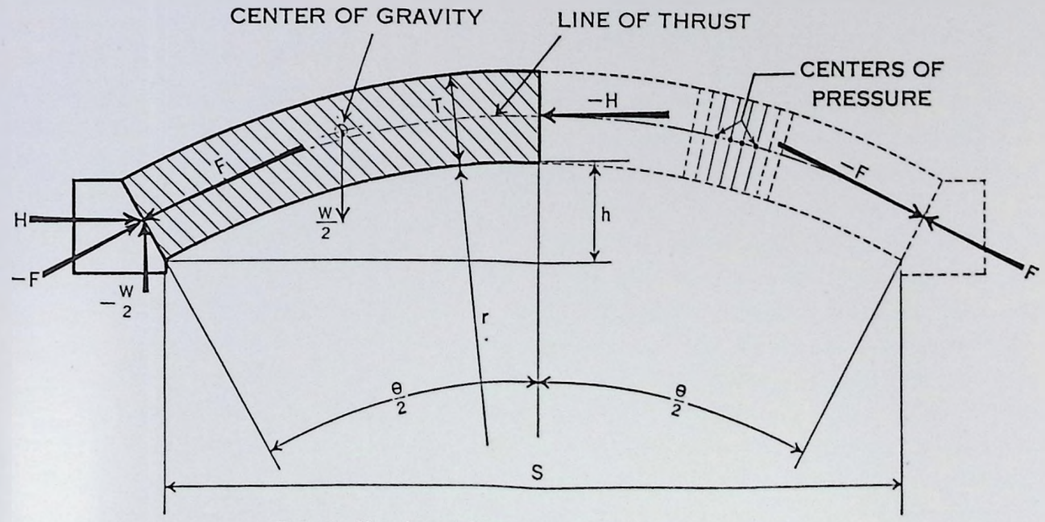


Fig. 38. Hypothetical Position of Line of Thrust in a Simple Sprung Arch, when the Brick are in Full Contact at Joints

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The maximum resultant force occurs when the line of thrust is the flattest one possible through the arch ring; the minimum resultant force occurs when the line of thrust is the steepest one possible.

Pinch spalling, shearing or deformation will occur if the pressure at any point in the arch exceeds the stress which the arch materials will withstand at furnace operating temperatures.

At atmospheric temperatures the angle of repose of brick upon brick varies from 31° to 38°; the corresponding coefficients of friction are 0.60 to 0.68. These values are so high that normally there is little danger of brick in an arch sliding past each other. However, the coefficient of friction may vary to some extent with the pressure, and in some cases will be reduced by the presence of mortar between the brick surfaces. Moreover, vibration caused by machinery or resulting from pulsating flames or slight explosions may cause a temporary decrease in the coefficient to such an extent that brick may slip past each other and portions of the arch may settle.

Arch stresses are affected by the weight of material which adheres to the surface of the brick in service, or which is absorbed by the brick. In open-hearth practice for example, it has been found that silica roof brick may increase in weight as much as 20 pounds per square foot of exposed surface.

Severe localized erosion or melting of the under side of an arch may cause it to buckle and collapse, because the line of thrust cannot stay within the thickness of both the eroded part and adjacent unaffected parts.

CALCULATION OF ARCH STRESSES

The amount of stress in a furnace arch can be determined only approximately for the following reasons:

1. The exact position of the line of thrust, even when the arch is cold, is not known.
2. The position of the line of thrust is altered when the furnace is heated.
3. Workmanship in building the arch may be imperfect.
4. Tie rods may stretch and supporting walls or foundations may settle.

The force exerted against the skewbacks per unit of arch length depends primarily upon the span, rise and thickness of the arch, and upon the unit weight of the brick; and secondarily upon the temperature of the furnace.

Thrust in a Cold Arch: Adjoining surfaces of all brick forming an arch ring may be in full contact before the furnace is heated. For this condition, the thrust in a cold arch of uniform thickness and having opposite skewbacks at the same level can be calculated closely enough for most engineering purposes.

The resultant thrust of an arch at the skewback can be resolved into horizontal and vertical components. The vertical force at each skewback per foot of arch length is equal to one-half the weight (W) of the arch per running foot. The horizontal force (H) per foot of arch length depends upon the weight of the arch per running foot, and upon the span and rise. The resultant thrust (F) is equal to the square root of the sum of the squares of the horizontal and vertical forces; that is,

$$F = \sqrt{H^2 + \left(\frac{W}{2}\right)^2}.$$

The thrust is least at the center of the span, where it equals the horizontal force (H).

The stresses in an unheated arch in which all adjoining brick are in full contact with each other may be determined approximately from the constants given in Table IX.

MAXIMUM THRUST IN A HEATED ARCH

When a furnace is heated, the arch brick expand. The amount of expansion is greatest at the hotter inner surface and least at the cooler outer surface of the arch. Unless full compensation is made in some manner for the expansion, changes will occur both in the position of the line of thrust and in the magnitude of the thrust. The arch will rise, and the outer ends of some of the joints near the middle of the span will open.

At the instant when joints are just about to open, if the skewbacks do not tilt the line of thrust will pass from a point near the outside arch surface at each skewback, to a point near the inside arch surface at midspan. The arch stresses at this instant will assume the maximum values which are possible. Later, as the arch rises, the amount of stress will decrease slightly. Even when the line of thrust comes so near the ends of the joints that the ends of the brick are sheared off, the stability of the arch is not necessarily endangered.

If the rise of the arch is low, and if no compensation for thermal expansion is made, the line of thrust may become almost a straight horizontal line when the furnace is heated. Under these conditions, the horizontal stress may become so great that one of two things must happen: (1) either plastic flow or pinch spalling must occur at the inner ends of the brick, automatically moving the line of thrust to a higher position and giving it greater curvature; or (2) the binding must yield.

The value of H_{max} (the limiting value which the horizontal thrust approaches) can be determined approximately from Table X.

The factor of safety used in designing furnace binding ordinarily is higher than that used in the conventional design of steel work, because of the possibility that the binding of a furnace may become overheated. For ordinary structural steel bindings, many designers limit the stress to 12,000 pounds per square inch. One reason for keeping the stress low is to provide adequate rigidity, since yielding of the binding would allow the arch to flatten.

MAXIMUM PRESSURE IN AN ARCH

For any brick surface supporting the thrust of an arch, the average pressure over the entire surface is given by the following formula:

$$P = \frac{F}{12 \times 12\ T}$$

Where P = Average pressure in pounds per square inch.

F = The resultant thrust of the arch in pounds per running foot.

T = Thickness of arch in feet.

While the average pressure can be calculated, there is usually no way of determining maximum pressure at any point, because the position of the center of thrust is not known. When the center of thrust is near the lower edge of the brick, the maximum pressure may amount to many times the average pressure.

If the line of thrust were to pass through the extreme lower edge of any brick in the arch, the pressure would at that point theoretically become infinite. Actually, the pressure would build up until one of three things would occur: (1) the hot ends of the brick would be deformed by compression, (2) the hot ends of the brick would be pinched off, or (3) the abutments would move outward. In any one of these three cases, the pressure would be lower after the adjustment had taken place.

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Table IX.

CONSTANTS FOR CALCULATION OF STRESSES IN UNHEATED ARCHES

Rise in Inches Per Foot of Span	Central Angle Θ	Forces Per Foot of Arch Length		
		W Weight	H Horizontal Thrust	F Resultant Thrust at Skewback
1″	37° 50.9′	1.05 DST	1.49 W	1.57 W
1¼″	47° 4.4′	1.07 DST	1.18 W	1.28 W
1½″	56° 8.7′	1.09 DST	0.98 W	1.10 W
1.608″	60° 0.0′	1.10 DST	0.91 W	1.04 W
1¾″	65° 2.5′	1.11 DST	0.83 W	0.97 W
2″	73° 44.4′	1.14 DST	0.72 W	0.88 W
2¼″	82° 13.4′	1.17 DST	0.64 W	0.81 W
2.302″	83° 58.5′	1.17 DST	0.62 W	0.80 W
2½″	90° 28.8′	1.19 DST	0.57 W	0.76 W
2¾″	98° 29.7′	1.22 DST	0.51 W	0.71 W
3″	106° 15.6′	1.25 DST	0.46 W	0.68 W

D = Weight of brick per cubic foot. S = Span in feet. T = Thickness of arch in feet. W = Weight of brick per foot of arch length.

The constants given in Table IX are based upon the assumption that the line of thrust passes from the center of arch thickness at the point of midspan, to the center of arch thickness at the skewbacks.

For sketch showing hypothetical position of line of thrust in a sprung arch, see Figure 38.

For table showing weights of refractory brick per cubic foot, see page 247.

Table X.

LIMITING (MAXIMUM) VALUES APPROACHED BY HORIZONTAL THRUST IN A HEATED ARCH FREE TO RISE

Rise in Inches Per Foot of Span	Central Angle Θ	H_{max} Per Foot of Arch Length — Thickness of Arch						
		0.04 S	0.05 S	0.06 S	0.07 S	0.08 S	0.09 S	0.10 S
1″	37° 50.9′	2.8 W	3.6 W	4.9 W	7.5 W	17.5 W*	*	*
1¼″	47° 4.4′	1.9 W	2.2 W	2.7 W	3.3 W	4.4 W	6.3 W	11.0 W*
1½″	56° 8.7′	1.44 W	1.6 W	1.9 W	2.1 W	2.5 W	3.0 W	3.8 W
1.608″	60° 0.0′	1.30 W	1.45 W	1.6 W	1.8 W	2.1 W	2.5 W	3.0 W
1¾″	65° 2.5′	1.15 W	1.26 W	1.39 W	1.6 W	1.8 W	2.0 W	2.3 W
2″	73° 44.4′	0.96 W	1.03 W	1.12 W	1.22 W	1.34 W	1.47 W	1.6 W
2¼″	82° 13.4′	0.82 W	0.88 W	0.94 W	1.01 W	1.09 W	1.18 W	1.28 W
2.302″	83° 58.5′	0.80 W	0.85 W	0.91 W	0.98 W	1.05 W	1.12 W	1.21 W
2½″	90° 28.8′	0.72 W	0.76 W	0.81 W	0.86 W	0.91 W	0.98 W	1.04 W
2¾″	98° 29.7′	0.63 W	0.66 W	0.70 W	0.74 W	0.78 W	0.83 W	0.88 W
3″	106° 15.6′	0.56 W	0.58 W	0.61 W	0.65 W	0.68 W	0.72 W	0.75 W

W = Weight of brick per foot of arch length. S = Span in feet.
* Stress excessive.

EXAMPLE OF STRESS PROBLEMS

Consider a silica brick roof arch 15 inches thick, with a 20-foot span and a central angle of 60°, as illustrated in Figure 39.

S, the span = 20.0 feet
T, the thickness = 1.25 feet
r, the inside radius = 20.0 feet
D, the weight of brick per cubic foot, = 110 pounds
Θ, (the central angle) = 60°
h, (the rise of the arch)
= 1.608 inches per foot of span = 32.16 inches or 2.68 feet
R, the outside radius = r + T = 21.25 feet

The following calculations are based upon the assumption that the line of thrust passes from the center of the arch thickness at midspan to the center of arch thickness at the skewbacks.

Weight of Roof Per Foot of Arch Length:

From Table IX, the weight of the arch per foot of length is equal to 1.10 DST. That is, 1.10 × 110 × 20 × 1.25 = 3025 pounds.

NOTE: The weight could have been calculated more accurately from the exact formula

$$W = \frac{\Theta}{360}\,\pi\,(R + r)\,TD$$

$$\frac{\Theta}{360}\,\pi = 0.5236$$

$$R + r = 21.25 + 20.00 = 41.25$$

Exactly, therefore, W = 0.5236 × 41.25 × 1.25 × 110 = 2970 pounds. Obviously, the weight of 3025 pounds, as determined by use of Table IX, is sufficiently accurate for calculation of the arch stress.

Horizontal Thrust in Cold Arch:

From Table IX, the horizontal thrust H = 0.91W. Therefore H = 0.91 × 3025 = 2750 pounds per foot of arch length.

Resultant Thrust in Cold Arch:

From Table IX, the resultant thrust F = 1.04W. Therefore F = 1.04 × 3025 = 3150 pounds per foot of arch length.

Maximum Value Approached by Horizontal Thrust in Heated Arch:

From Table X, for an arch with a central angle of 60°,

When T = 0.06 S, H_{max} = 1.6 W
When T = 0.07 S, H_{max} = 1.8 W

By interpolation, when T = 0.0625 S, H_{max} equals approximately 1.65 W. Therefore H_{max} = 1.65 × 3025, or 4990 pounds per foot of arch length.

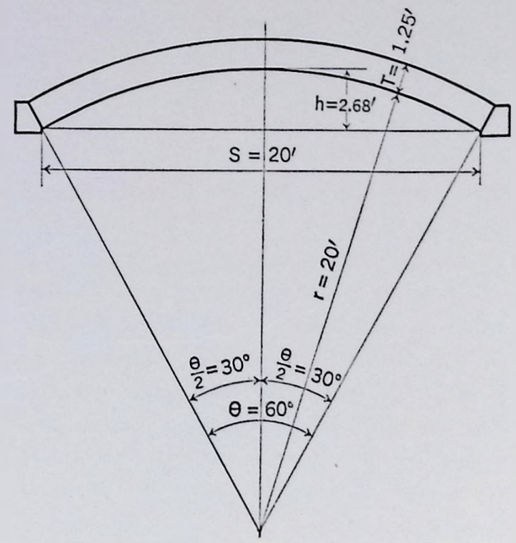


Fig. 39. Silica Brick Arch — illustrative example

Maximum Pressure:

If the line of thrust should pass through the center of the face of the skewback, the maximum pressure P would be

$$\frac{F}{12 \times 12\,T} = \frac{3150}{12 \times 12 \times 1.25},$$ or 17.5 pounds per square inch.

However, the actual position of the line of thrust cannot be determined and the pressure therefore cannot be calculated. It would be very high if the line of thrust were to come near the inner edge of the brick.

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COMPOUND ARCHES OF HIGH RISE

A circular segmental sprung arch with a rise greater than 3 inches per foot of span lacks stability. Greater stability will be secured if the arch is of catenary form, since the line of thrust tends to follow a catenary curve. A true catenary arch would require a large number of special shapes, and the mathematics of design is somewhat complicated. These difficulties may be avoided by the use of a compound arch which approximates a catenary in its lines. For arches with a rise of 3 to 6 inches per foot of span, this can be accomplished by a compound arch having two radii; for arches with a higher rise, three radii are required.

Great care needs to be observed in the design and construction of arches of high rise, especially if they should be built of materials having high thermal expansion, such as basic refractories. A compound arch or a catenary arch which is entirely stable when cold may become unstable at operating temperature, because of the change in the lines of the arch resulting from the thermal expansion. The higher the ratio of rise to span, the greater the danger of instability when hot. However, catenary-type arches built of silica brick in most cases will remain stable when heated. Those made of fireclay or high-alumina brick may remain stable when heated because elastic or plastic deformation may occur sufficiently to take care of the thermal expansion, especially as some of it is taken up by bedding-in of the brick surfaces at the joints. Insulation in all cases would increase the stability, since it would decrease the differential in expansion between the inner and the outer arch surfaces.

Arches of high rise are not used to any great extent except in constructions where they support superimposed brickwork, as for example in furnace walls and in checker chambers. In such construction, the arches generally are semi-circular in form. Arches of the catenary type are used relatively little. However, their greater stability, as compared with circular segmental arches of high rise, suggests the probability that they may be utilized advantageously in the design of furnaces for specialized service which must operate at extremely high temperatures. Furnaces may be designed in which both the side walls and the roof are replaced by a catenary-type sprung arch of high rise.

The potentialities of the commercial application of catenary-type arches may have become greater since refractories which retain strength and rigidity at extremely high temperatures have become more readily available. Among these refractories are corundum and periclase.

The design of catenary-type compound arches with a high rise is simplified by use of the constants given in Table XI, page 291.

EXAMPLE ILLUSTRATING DESIGN OF A COMPOUND ARCH

Assume that a compound arch is to be designed with a span (S) of 12.0 feet, and a rise of 9 inches per foot of span.

Arch Dimensions: The arch dimensions are calculated from the constants given in Table XI, as follows:

$h = 0.750S = 0.750 \times 12' = 9.0' = 9'\text{-}0''$

$R_1 = 0.265S = 0.265 \times 12' = 3.180' = 3'\text{-}2\ 3/16''$

$R_2 = 0.574S = 0.574 \times 12' = 6.888' = 6'\text{-}10\ 5/8''$

$R_3 = 1.801S = 1.801 \times 12' = 21.612' = 21'\text{-}7\ 3/8''$

$m_1 = 0.1947S = 0.1947 \times 12' = 2.3364' = 2'\text{-}4\ 1/16''$

$n_1 = 0.5055S = 0.5055 \times 12' = 6.0660' = 6'\text{-}0\ 13/16''$

$m_2 = 1.266S = 1.266 \times 12' = 15.192' = 15'\text{-}2\ 5/16''$

$n_2 = 1.103S = 1.103 \times 12' = 13.236' = 13'\text{-}2\ 13/16''$

Lay-out of Arch:

A. Lay off the base line, the vertical center line, the skewback center points (1) and (2), and the apex (3) of the arch center line, as shown in Figure 41.

B. From point (3), measure downward on the vertical center line a distance of 3'- 2 3/16", equal to R_1. This locates the first center (4).

C. Locate the second center, point (5), from its coordinates m_1 and n_1; and locate the third center, point (7), from its coordinates m_2 and n_2.

D. Draw a line from the second center, point (5) through (4), a total distance equal to R_2 (6'- 10 5/8"), locating the point (6); and draw a line from the third center, point (7) through (5), a total distance equal to R_3 (21'- 7 3/8"), locating the point (8).

E. With (4) as a center, and radius R_1, describe an arc from (3) to (6); with (5) as a center, and radius R_2, describe an arc from (6) to (8); and with (7) as a center, and radius R_3, describe an arc from (8) to (1).

The layout has now been completed for the half of the arch on one side of the vertical center line. The other half may be drawn in the same manner.

Table XI.

CONSTANTS FOR COMPOUND ARCHES WHICH ARE APPROXIMATELY CATENARIES

See Figures 40 and 41

Rise in Inches Per Foot of Span	No. of Radii	h	R_1	Θ_1 (Degrees)	R_2	Θ_2 (Degrees)	R_3
3	2	0.250S	0.559S	27° 0.0′	0.851S	21° 1.2′	.....
4	2	0.333S	0.449S	33° 24.0′	0.848S	24° 38.4′	.....
5	2	0.417S	0.384S	39° 0.0′	0.929S	26° 6.6′	.....
6	2	0.500S	0.347S	43° 42.0′	1.031S	26° 57.6′	.....
7½	3	0.625S	0.286S	35° 39.0′	0.565S	20° 46.2′	1.448S
9	3	0.750S	0.265S	39° 0.0′	0.574S	21° 52.2′	1.801S
12	3	1.000S	0.244S	47° 6.0′	0.717S	21° 54.6′	3.095S
15	3	1.250S	0.231S	54° 33.0′	1.016S	19° 22.2′	4.794S
18	3	1.500S	0.221S	55° 15.0′	0.968S	20° 7.8′	5.853S

Rise in Inches Per Foot of Span	No. of Radii	Θ_3 (Degrees)	β (Degrees)	m_1	n_1	m_2	n_2
3	2	.....	48° 1.2′	0.1328S	0.8194S	.....	.....
4	2	.....	58° 2.4′	0.2196S	0.7823S	.....	.....
5	2	.....	65° 6.6′	0.3428S	0.8077S	.....	.....
6	2	.....	70° 39.6′	0.4729S	0.8415S	.....	.....
7½	3	18° 31.8′	74° 57.0′	0.1624S	0.5125S	0.898S	1.001S
9	3	17° 50.4′	78° 42.6′	0.1947S	0.5055S	1.266S	1.103S
12	3	13° 13.8′	82° 14.4′	0.3466S	0.5661S	2.567S	1.418S
15	3	10° 18.0′	84° 13.2′	0.6397S	0.6864S	4.270S	1.733S
18	3	10° 54.0′	86° 16.8′	0.6134S	0.6465S	5.341S	1.880S

NOTE: In the above table, the span S and rise h are taken to the center line of the arch thickness, as shown in Figures 40 and 41, and not to the under surface as is customary with circular segmental arches.

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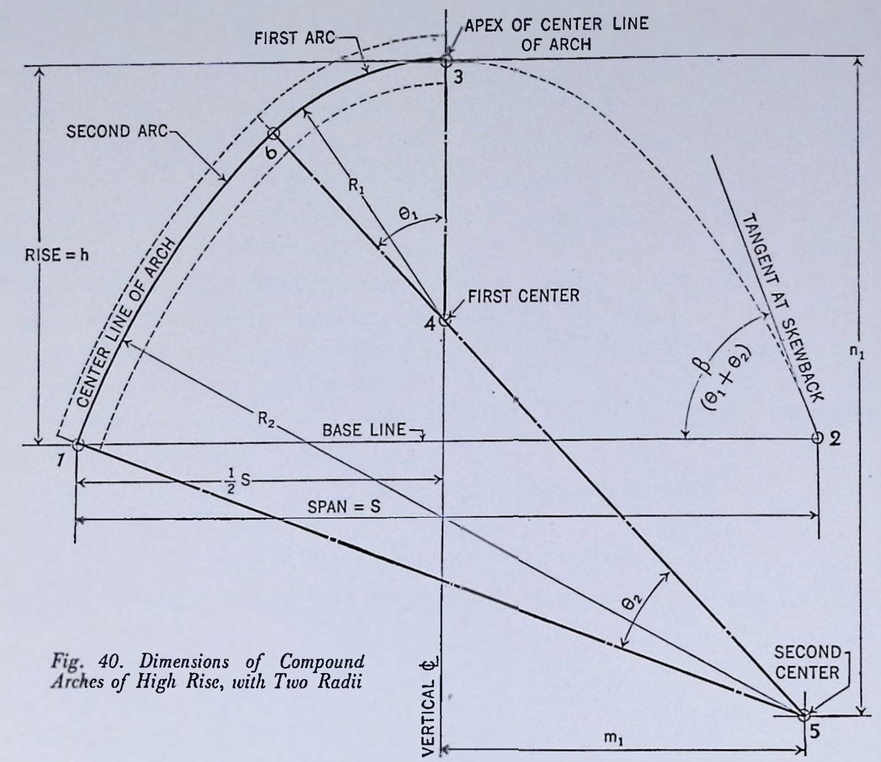


Fig. 40. Dimensions of Compound Arches of High Rise, with Two Radii

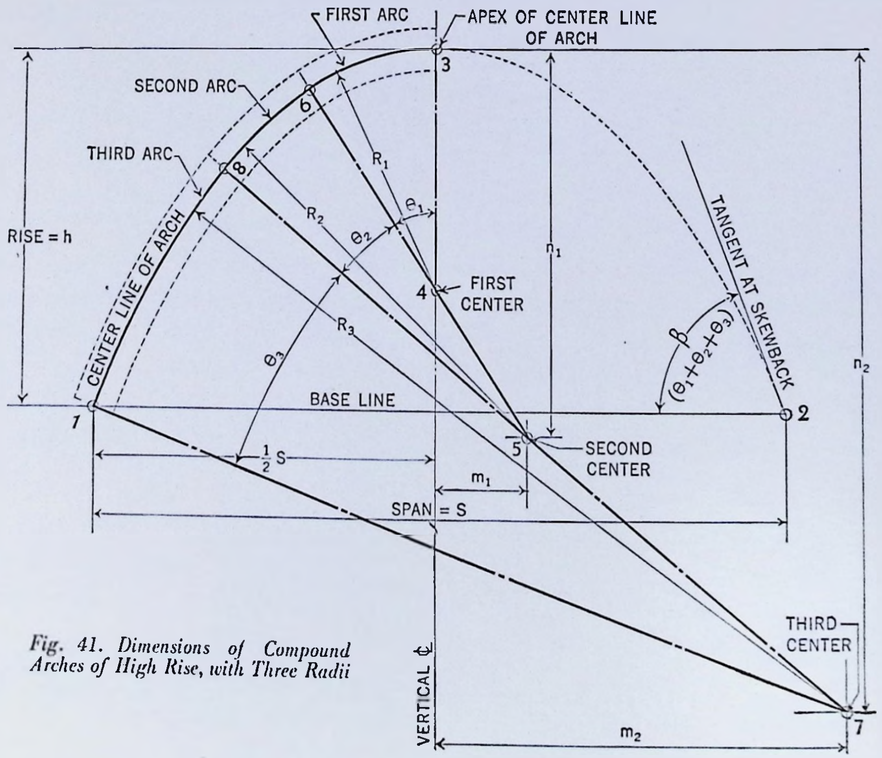
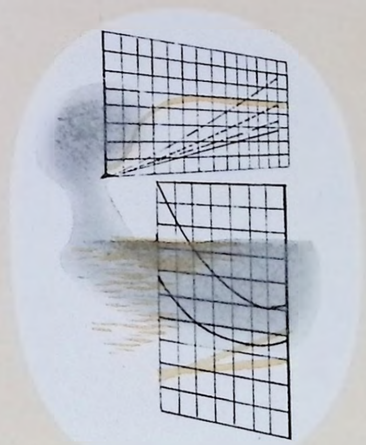


Fig. 41. Dimensions of Compound Arches of High Rise, with Three Radii

PROPERTIES OF REFRACTORIES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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PROPERTIES OF REFRACTORIES

In this review of the properties of refractories enough theory has been included to illustrate some of the basic principles which relate to the development, manufacture and applications of refractory materials. Special emphasis has been placed upon high-temperature mineralogy, and upon the development of the liquid phase under the influence of heat, because these are factors which primarily determine the utility of a refractory material in service. In the discussion which follows, the data are presented in the following order:

Part I. The Mineral Compositions of Refractory Materials. Special reference is made to changes which occur during heat treatment and to stability relations at high temperatures.

Part II. Other Chemical and Physical Properties of Refractories. Greatest emphasis is placed upon the particular properties which are most closely related to the utility of commercial refractory products.

The temperatures given, up to 3470° F. (1910° C.) are based upon the International Temperature Scale of 1948. Higher temperatures, in general, are given on the earlier scale of Day and Sosman.

Technical articles and books referred to in the text are listed on page 346.

Part I. MINERAL COMPOSITION

MINERALS AND GLASSES

All refractory products bonded by firing consist of crystalline mineral particles, or of crystalline mineral particles and glass. When the brick is again heated to high temperatures, as in service, a liquid develops also, in proportions which depend upon the composition of the refractory and upon the temperature. The physical properties of a refractory at any given temperature are fixed by the amount and character of the minerals, the glass and the liquid of which it is composed.

A mineral species is defined[42-1] as "a natural inorganic substance which is either definite in chemical composition and physical characters, or varies in these respects within natural limits". A mineral usually has a definite crystalline structure. When heated, a mineral having a true melting point will pass completely from the crystalline condition to the liquid state at a definite temperature. When cooled slowly, the liquid formed will crystallize or freeze at the same definite temperature, and will again assume the crystalline form.

A mineral is said to have an incongruent melting point when it does not change from a completely solid to a completely liquid condition at a definite temperature, but dissociates, forming a solid crystalline phase and a liquid phase. When the temperature rises above the temperature of dissociation, the solid material dissolves gradually in the liquid. As an example, the mineral mullite ($3Al_2O_3 \cdot 2SiO_2$) melts incongruently (dissociates) at 3317° F. (1825° C.), to form a mixture of about 38% of corundum (Al_2O_3), and 62% of liquid having the composition 45% silica (SiO_2), 55% alumina (Al_2O_3). As the temperature rises above 3317° F. the corundum gradually dissolves in the liquid, and is completely dissolved at approximately 3500° F. or 1925° C.

A glass differs from a mineral in several important respects. It does not necessarily have a definite chemical composition, it lacks crystalline structure, and it has no melting point. When a glass is progressively heated, the change from the apparently solid state to the fluid state is gradual and continuous. When a molten glass is cooled, the change from the fluid state to the apparently solid state is likewise gradual and continuous. Theoretically, at least, a glass is not a solid at all, but an undercooled liquid which has gradually stiffened as it cooled, until the viscosity has become so great that the body conforms to the generally accepted concept of a "solid".

A glass will change into the crystalline condition or "devitrify" if kept for a sufficient time within a critical temperature range. Some melts crystallize even with very rapid cooling. Others must be maintained at a critical temperature for a considerable length of time before any crystals are formed. Alkali-silicate melts high in silica are extremely viscous and do not crystallize readily upon cooling. This immunity to devitrification is an essential attribute of commercial glass compositions.

THE CERAMIC BOND OF BRICK

One of the most important purposes for which brick are fired is to give them permanent mechanical strength, by causing adjacent particles to adhere. The bond between particles, developed by the heat treatment, is known as a "ceramic bond".

Unfired or "green" brick consist of mixtures of particles of refractory material which usually vary from coarse through intermediate to very fine sizes. The coarser particles in some cases have a diameter of ¼ inch or more. The fines, which may be regarded as the particles which will pass a 200-mesh screen, often amount to as much as 30 per cent of the total. After having been fired, the borders of the larger particles are usually distinct; the fines generally form a more or less vitrified groundmass, which bonds together the particles of larger size. The character and continuity of this groundmass, and its degree of adherence to the larger particles, have a very important effect upon the physical properties of a fired product.

The strength of the ceramic bond is dependent upon the character of the brick mix as well as upon the time and temperature of firing. In many cases, the constituents of a refractory which occur in only small amounts (the so-called impurities) play an important role in the development of the bond. With some types of refractories small amounts of reactive materials are intentionally added; the bond is formed by chemical reaction of the material added with a portion of the refractory. In the manufacture of silica brick for example, about 1.8 to 3.5 per cent of lime is added for bonding.

During the firing of refractory brick, mineral dissociation or transformation occurs; such minerals as kaolinite or diaspore dissociate, and quartz is transformed wholly or in part into other forms of silica. Crystal growth and chemical reactions may occur also in the solid state, resulting in the formation of a strong ceramic bond between particles in contact. However, solid-state reactions are believed to have less influence upon the bonding of most refractory brick than does the formation of a liquid phase. In the case of brick molded wholly or in part from calcined or dead-burned materials, some of the changes described above in this paragraph have already occurred in the original heat treatment.

A small amount of liquid can be expected to form in the groundmass of a refractory brick at a temperature some hundreds of degrees below that at which complete fusion would occur. With rise in temperature, this liquid takes other materials present into solution and thereby increases in amount. The liquid becomes a

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medium suitable for the transport of material which it dissolves, and for the formation and growth of crystals, especially at interfaces between liquid and solid particles.[35-1] The brick mass is bonded together and given strength by the adhesive power of the glass, and by adherence and interlacing of the crystals. Elongated crystals, like those of mullite, may tend to interlace; crystals of the cubic form, like periclase (MgO), obviously cannot interlace.

The liquid formed at high temperatures may become a rigid glass upon cooling, or it may devitrify and become crystalline, wholly or in part. Whether the bond of a refractory is glassy or crystalline may depend upon the rate of cooling; with rapid cooling the bond which was liquid at high temperatures might persist as a glass, while with relative slow cooling, crystallinity might develop.

A brick containing a large amount of glass will usually have high strength in the cold condition; but if the glass is of low viscosity at operating temperatures, the brick may deform readily under pressure. For a brick to withstand pressure at high temperatures without deformation, its content of glass must be low, or the viscosity of the glass must be high, or both; in general, the brick should have been fired under conditions which are favorable to the growth of crystals.

Certain types of refractories have their load carrying capacities at high temperatures materially increased by incorporation in the brick mixes of finely ground materials which effect changes in the body. The added material may function in one of several ways: it may react chemically with the glass and transform it into highly refractory crystalline material; it may make the glass more viscous at furnace operating temperatures; it may cause or accelerate solid state reactions; or it may cause improvement merely by dilution of the glass. A change which reduces the amount of glass or liquid in the refractory would usually be more beneficial in service than a change which makes the glass more viscous.

EQUILIBRIUM DIAGRAMS

Melting of mixtures of two or more minerals or oxides takes place over a range of temperatures. The temperatures at which melting is complete depend upon both the relative amounts of the materials present and their compositions. The melting behavior of such mixtures and the nature of the equilibria between the solids and the liquids formed by melting have engaged the attention of many investigators. Since the early years of the twentieth century, many papers on the subject have appeared in the scientific literature. The papers published by the staff of the Geophysical Laboratory of the Carnegie Institution, Washington, D. C., have contributed in no small measure toward placing the study of refractories on a scientific basis.

The data are presented mainly in the form of drawings known as phase equilibrium diagrams. A compilation of these diagrams was published in 1933 by F. P. Hall and Herbert Insley; a more complete compilation appeared in 1947 under the title "Phase Diagrams for Ceramists".[47-2] Both papers include diagrams and their interpretation. A clear explanation of phase equilibrium diagrams applicable to systems which contain no solid solution is given in the paper entitled "The Ternary System $CaO–Al_2O_3–SiO_2$", by G. A. Rankin and Fred E. Wright.[15-1]

ALUMINA-SILICA SYSTEM

The equilibrium diagram for mixtures of alumina and silica is reproduced in Figure 42. The heavy curved line which extends across the width of the diagram represents the temperatures of complete melting of all possible mixtures of pure silica and pure alumina, under conditions of complete equilibrium.

The alumina-silica diagram is based upon the memorable paper by Bowen and Greig,[24-1] which appeared in 1924. It swept away various misconceptions and for the first time gave a clear and accurate picture of equilibrium conditions in alumina-silica compositions. Because of the importance of this diagram to the technology of alumina-silica refractories, it will be described in some detail.

THE ALUMINA-SILICA DIAGRAM

The relationships discussed under this heading apply literally only to (1) mixtures of alumina and silica which are entirely homogeneous, and (2) to conditions of complete equilibrium. Practically, neither of these conditions is met in working with refractory materials, as shown on page 300 for fire clay. Consequently, the theoretical considerations outlined here need to be amplified by other data, for a complete understanding of the behavior of refractory clays and other alumina-silica materials at high temperatures.

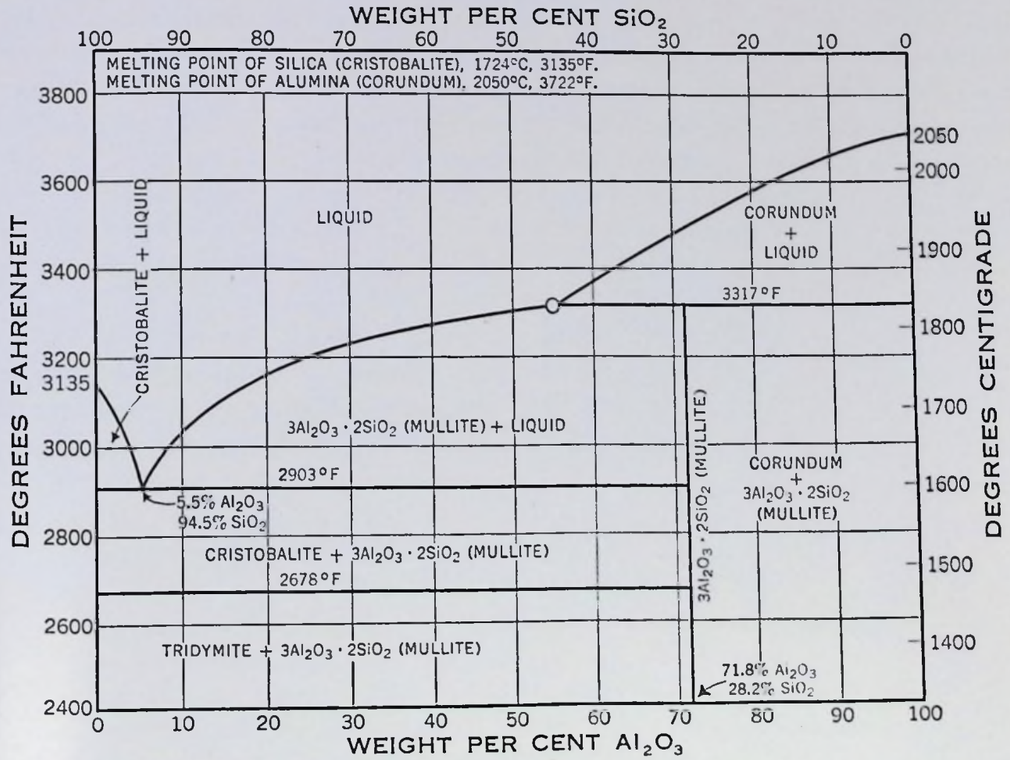


Fig. 42. Equilibrium Diagram of the System Alumina-Silica ($Al_2O_3–SiO_2$) (By Bowen and Greig, with Correction by Schairer)

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General Description: As shown in Figure 42, the melting point of pure silica is 3135° F. (1724° C.). With increasing amounts of alumina, complete melting occurs at successively lower temperatures, reaching a minimum of 2903° F. (1595° C.), at a composition of 5.5% alumina and 94.5% silica, and then the melting temperature rises as the alumina content exceeds 5.5%. Such a composition of lowest melting point is known as a "eutectic composition", and the temperature at which it melts is known as a "eutectic temperature".

Consider any composition which consists of finely divided and uniformly mixed particles of alumina and silica with *less than 5.5% alumina* (Al_2O_3). Upon being heated to progressively higher temperatures, the entire mass will remain solid until a temperature of 2903° F. (1595° C.) is reached. At this temperature a portion of the batch will melt, forming an exceedingly viscous liquid of the eutectic composition (5.5% Al_2O_3, 94.5% SiO_2). All of the alumina will enter into the formation of this liquid, and if equilibrium conditions obtain, excess silica above the eutectic ratio will remain in the solid form as cristobalite. With further temperature rise above 2903° F. the amount of solid silica will decrease, and the amount of liquid will increase through solution of the solid, until the entire mass has melted. The temperature at which complete melting occurs for any specific mixture is indicated by the heavy curved line.

Any composition of alumina and silica which contains *more than 5.5% and less than 71.8% alumina*, will melt in part at the eutectic temperature 2903° F. (1595° C.). The initial liquid phase will have the same composition as the eutectic, and the unmelted solid will consist of crystals of the mineral mullite. This mineral has the chemical formula $3Al_2O_3 \cdot 2SiO_2$, corresponding to 71.8% alumina, 28.2% silica. When the temperature rises above 2903° F. the liquid takes mullite into solution. The amount of liquid thereby increases and its composition changes. With compositions up to 55% alumina, all of the mullite will dissolve in the liquid. However, in compositions containing an amount of alumina between 55% and 71.8%, any mullite remaining at 3317° F. (1825° C.), dissociates at that temperature, forming corundum (Al_2O_3) and a siliceous liquid. As the temperature rises above 3317° F. the corundum gradually dissolves in the liquid.

Any solid mixture of mullite and corundum (necessarily containing more than 71.8% alumina) will remain solid at any temperature below 3317° F. (1825° C.). With rising temperatures the mullite will dissociate at 3317° F. into corundum and liquid, and with progressively higher temperatures, the corundum will gradually dissolve.

Table XII.

COMPONENTS IN THE ALUMINA-SILICA SYSTEM WHICH COEXIST IN EQUILIBRIUM

Components	Temperature Range		Composition Range
(1) Quartz (SiO_2) and mullite	Up to 1598° F.	Up to 870° C.	Up to 71.8% Al_2O_3
(2) Tridymite (SiO_2) and mullite	1598° to 2678° F.	870° to 1470° C.	Up to 71.8% Al_2O_3
(3) Cristobalite (SiO_2) and mullite	2678° to 2903° F.	1470° to 1595° C.	Up to 71.8% Al_2O_3
(4) Corundum (Al_2O_3) and mullite	Up to 3317° F.	Up to 1825° C.	Above 71.8% Al_2O_3
(5) Cristobalite (SiO_2) and liquid	2903° to 3135° F.	1595° to 1724° C.	Up to 5.5% Al_2O_3
(6) Mullite ($3Al_2O_3 \cdot 2SiO_2$) and liquid	2903° to 3317° F.	1595° to 1825° C.	5.5 to 71.8% Al_2O_3
(7) Corundum (Al_2O_3) and liquid	3317° to 3722° F.	1825° to 2050° C.	Above 55.0% Al_2O_3

Relative Amounts of Components: By a simple calculation, based upon the so-called "lever principle", the amount of each component present under conditions of equilibrium can be determined for any composition and any temperature. Consider, for example, *a mixture of 40% alumina, 60% silica*. At all temperatures included in Figure 42 below 2678° F. (1470° C.), tridymite and mullite coexist in equilibrium. The relative amounts of tridymite and mullite are determined as follows:

$$\% \text{ tridymite} = \left(\frac{71.8 - 40.0}{71.8 - 0}\right) 100 = 44.3\%$$

$$\% \text{ mullite} = 100 - 44.3 = 55.7\%$$

At 2678° F. (1470° C.) the tridymite changes to cristobalite. With further heating, no other changes occur until the eutectic temperature of 2903° F. (1595° C.) is reached. At that point all the cristobalite melts, with some of the mullite, forming a liquid with the composition 5.5% alumina, 94.5% silica. At the eutectic temperature, the amount of each component is calculated thus:

$$\text{Amount of liquid} = \left(\frac{71.8 - 40.0}{71.8 - 5.5}\right) 100 = 48.0\%$$

$$\text{Amount of mullite} = \left(\frac{40.0 - 5.5}{71.8 - 5.5}\right) 100 = 52.0\%$$

With further rise in temperature above 2903° F. (1595° C.) progressive solution of the mullite in the liquid occurs. The composition of the melt changes, as indicated by the curved line on the equilibrium diagram. All of the mullite is dissolved at 3275° F. (1802° C.) and the material is then completely melted.

Upon cooling, the mass would undergo the same changes as described above, in reverse order, if complete equilibrium were attained at every stage. Between 3275° F. (1802° C.) and 2903° F. (1595° C.) mullite would crystallize from the liquid, and just above 2903° F. (1595° C.) the composition would be 48% liquid, 52% mullite. At the eutectic temperature, 2903° F. (1595° C.), the entire mass would solidify abruptly, and would become a mixture of crystals of cristobalite and mullite, 44.3% of the former to 55.7% of the latter. These changes are illustrated in Figure 43.

As shown by the above discussion, under conditions of equilibrium, a fired product composed solely of 40% alumina and 60% silica would consist of 55.7% mullite and 44.3% cristobalite just before any melting would occur. At 2903° F. (1595° C.) melting would begin and if that temperature were maintained, 48% of the mixture would melt to a very viscous liquid. The remainder would consist of crystals of mullite. With rise in temperature above 2903° F. (1595° C.) the liquid would become less viscous, and there would be a progressive solution of the mullite in the liquid. The last trace of mullite would be dissolved at 3275° F. (1802° C.), at which temperature the material would become completely melted.

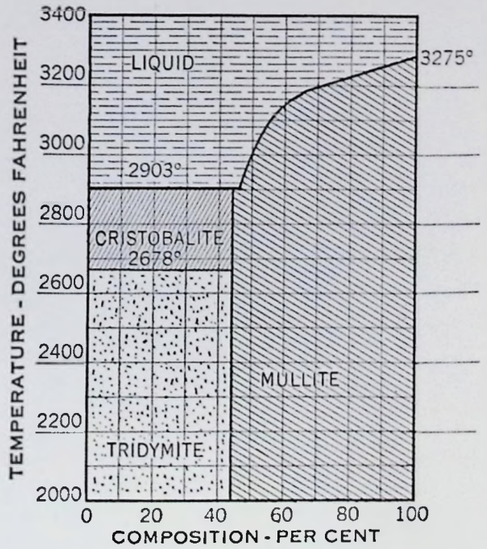


Fig. 43. Equilibrium Diagram for Composition 40% Alumina, 60% Silica

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The Sillimanite Minerals: The minerals sillimanite, kyanite and andalusite all have the theoretical composition $Al_2O_3 \cdot SiO_2$, corresponding to 62.9% alumina, 37.1% silica. There is a common misconception to the effect that all of these minerals may be converted by appropriate heat treatment to mullite, and mullite only. Dissociation of these minerals can be effected by a heat treatment at a sufficiently high temperature and for a long enough time to provide the necessary energy to alter their crystal structure. By such heat treatment, any of the sillimanite minerals can be converted into a mixture of 87.7% mullite, and 12.3% free silica. In this mixture, no melting would occur below 2903° F. (1595° C.), at which temperature the composition would change to 86.6% mullite, 13.4% liquid.

Sillimanite begins to decompose into mullite and free silica at about 2785° F. (1530° C.), kyanite at 2415° F. (1325° C.), and andalusite at 2460° F. (1350° C.).[33-2]

MINERAL CHANGES DURING THE BURNING OF FIRECLAY BRICK

In the commercial burning of fireclay brick, the mineral changes which occur do not follow as simple a pattern as that described on the preceding page. The main reasons are that the ground clay mixtures are not homogeneous either as to mineral composition or as to particle size, and firing temperatures are not held long enough to attain equilibrium. The mineral compositions may vary over a wide range and the grains may vary all the way from pieces ¼ inch or more in diameter to particles much finer than 300 mesh.

Even clays of highest quality contain significant amounts of constituents other than kaolinite. Many clays contain relatively large amounts of mica of a form which has more combined water and less potash than is found in muscovite ($3Al_2O_3 \cdot 6SiO_2 \cdot K_2O \cdot 2H_2O$). The hydrous mica in clays is somewhat variable in composition, but apparently averages about 6% in potash (K_2O). In some clays the accessory mineral present in largest amount is quartz (SiO_2); in others it is diaspore ($Al_2O_3 \cdot H_2O$). Nearly all clays contain small percentages of rutile (TiO_2); other common accessory minerals are pyrite (FeS_2), siderite ($FeCO_3$) and limonite ($2Fe_2O_3 \cdot 3H_2O$).

Some of the changes which are believed to take place in heating a fire clay are outlined in the following paragraphs.[35-3] The rate of heating has an important effect upon the temperatures at which the changes occur.

At about 840° to 1255° F. (450° to 680° C.) dehydration of the kaolinite occurs with the formation of an intimate mixture of amorphous (non-crystalline) alumina and amorphous silica.

At about 1560° to 1725° F. (850° to 940° C.) gamma-alumina crystallizes from the amorphous mixture, leaving the silica in the amorphous form.

At about 1800° F. (980° C.) mullite begins to form through combination of the amorphous silica and amorphous alumina. The formation of mullite probably continues to about 2190° F. (1200° C.), at which temperature most or all of the amorphous alumina has recombined with silica. The mullite crystals formed are sub-microscopic in size, but can be identified by means of X-rays. The crystals grow at higher temperatures and after heat treatment at 2600° F. or 1425° C. are large enough to be identified by microscopic examination.

At about 2190° to 2460° F. (1200° to 1350° C.), the excess amorphous silica remaining after the crystallization of mullite changes to cristobalite.

At about 2280° F. (1250° C.) quartz present as an accessory mineral begins to change to cristobalite. However, residual quartz remains in the centers of large quartz crystals even in bodies which have been heated to about 2700° F. (1480° C.).

Up to this point little has been said regarding the effects of the accessory minerals at high temperatures. Some of the oxides other than silica and alumina lower the temperature at which liquid begins to form and increase the amount of liquid at any given temperature. The alkalies soda and potash are especially potent, reacting to form a highly viscous liquid at temperatures several hundred degrees below the temperature at which liquid would begin to form if the body consisted wholly of alumina and silica. In this alkali-alumina-silica liquid, accessory minerals containing lime, magnesia and iron oxide would dissolve wholly or in part, as would both amorphous and crystalline silica; and at very high temperatures even mullite would dissolve. The temperature of complete melting would depend upon the alumina-silica ratio, and upon the compositions and amounts of the accessory minerals.

In a single ground clay, most of the larger particles have nearly the same composition as the groundmass. However, there is probably some concentration of accessory minerals in the groundmass. For this reason, and because of its greater fineness, the groundmass will develop more liquid than the larger particles in the commercial firing of clay ware. The firing temperature, even for highly refractory clays, usually will not exceed 2625° F. (1440° C.), and generally will lie within the range of 2200° to 2500° F. (1205° to 1370° C.).

When fireclay refractories are cooled from the firing temperature, some crystalline material, especially cristobalite and mullite, may separate from the liquid. However, much of the liquid cools to a rigid glass, which bonds the mass together and gives it strength.[35-1] Additional strength is imparted by the interlacing and adherence of crystals.

MINERAL COMPOSITION OF FIRECLAY AND HIGH-ALUMINA BRICK

Burned fireclay refractories are composed largely of mullite and silica (quartz, cristobalite, and rarely tridymite). The crystals are largely submicroscopic in size, but are identifiable by means of X-ray diffraction patterns. Glass also is present, in amounts depending upon the composition of the material, the time and temperature of firing, and the rate of cooling. Intermediate duty brick usually contain more glass than brick of the high duty class. In high-fired brick, practically all of the impurities are contained in the glass.

In fireclay brick exposed to high temperatures, the mullite crystals increase in size. In photomicrographs of super-duty fireclay brick reheated to 2910° F. (1600° C.), the presence of mullite crystals is clearly indicated.

High-alumina brick contain mullite and usually corundum, free silica and glass in amounts varying with the alumina content of the brick, the raw materials from which they were made, the proportion of accessory oxides, and the firing treatment to which the brick were subjected. If complete equilibrium could be attained during the firing, any pure alumina-silica refractory with less than 71.8% alumina would contain no crystalline material other than mullite and free silica, and one with more than 71.8% alumina would contain only mullite and corundum. However, in brick made wholly or in part from diaspore clay, corundum may be present even in compositions with less than 71.8% alumina, and free silica may be present even in compositions with more than 71.8% alumina. Under favorable conditions the development of mullite during firing proceeds to an advanced degree, yet it does not proceed to completion. The mullite formed at the sur-

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faces of the grains of diaspore appears to act as a protective film, retarding or preventing further reaction between the corundum of the interior of the grains and the free silica formed from the fire clay between the grains.

A similar condition exists when fused alumina (artificial corundum) is added to or is bonded by fire clay in the manufacture of high-alumina brick. When the refractory is fired, a protective film of mullite forms at the surfaces of the grains of corundum by combining with free silica released by recrystallization of the fire clay. The interior of the corundum grains is unaltered by the firing treatment.

THE MINERALS IN SILICA REFRACTORIES

Stability Relations of the Silica Minerals: Prior to 1913 there was little general understanding of the mineral changes which occur in silica refractories during manufacture and use, nor of the consequences of these changes. In that year, however, great light was thrown upon the subject, with the publication by C. N. Fenner[13-1] of the paper entitled "Stability Relations of the Silica Minerals".

The three crystal modifications of silica are quartz, tridymite and cristobalite. Any one of these minerals may be converted into either of the others by appropriate heat treatment. The formation of tridymite appears always to require the presence of a liquid formed by reaction of silica with a suitable fluxing agent; cristobalite is formed in the absence of a liquid. Below 1598° F. (870° C.) quartz is the stable form of silica; from 1598° F. (870° C.) to 2678° F. (1470° C.), tridymite is the stable form; and above 2678° F. (1470° C.), cristobalite is the stable form. However, at atmospheric temperatures, there is no perceptible tendency for cristobalite and tridymite to change to quartz.

In the absence of a liquid phase, quartz does not change to tridymite, even within the temperature range at which tridymite is the stable form. At about 2280° F. (1250° C.) quartz begins to change slowly to cristobalite; the rate of transformation increases rapidly as the temperature rises. At 2900° F. (1595° C.) transformation is complete in approximately one hour.

In the presence of an appropriate liquid, cristobalite changes to tridymite at temperatures between 2300° F. (1260° C.) and 2678° F. (1470° C.). The change is very slow at 2300° F. and is not rapid even at 2630° F. (about 1445° C.).

The specific gravity at room temperatures of quartz is 2.65; that of cristobalite, 2.32; that of tridymite 2.26. Hence the transformation of quartz to cristobalite causes a volume increase of 14.3%; of quartz to tridymite, 17.2%.

Each of the three crystal forms of silica has a high-temperature and a low-temperature modification. These are known as high-quartz and low-quartz; high-cristobalite and low-cristobalite; and high-tridymite and low-tridymite. A change takes place rapidly from a low to a high form on heating, and from a high to a low form on cooling. The temperatures of inversion are given in Table XIII.

The change from low-quartz to high-quartz, or the reverse, is accompanied by an abrupt volume-change of approximately 0.9%. When heated or cooled rapidly through the inversion temperature at about 1067° F. (575° C.), quartz shows a strong tendency to crack.

Cristobalite, when heated or cooled through the inversion range, has a volume change of about 2.8%. Bodies consisting largely of cristobalite tend to crack or spall if heated or cooled rapidly through the inversion temperatures.

Table XIII.

LOW-HIGH INVERSION TEMPERATURES OF THE SILICA MINERALS

Mineral	Inversion Temperatures			
	On Heating		On Cooling	
	°F.	°C.	°F.	°C.
Quartz	1067	575	1067	575
Cristobalite	428–527	220–275	466–388	241–198
Tridymite	243 and 325	117 and 163	325 and 243	163 and 117

The total volume change through the two inversion points of tridymite is very small, being approximately 0.3%. So far as is known, no cracking occurs when tridymite is heated or cooled rapidly through these inversion points.

Equilibrium Diagrams and Silica Refractories: A second study which has had a profound effect upon the technology of silica refractories is the contribution of J. W. Greig[27-1] in 1927, on "Immiscibility in Silicate Melts".

Greig found that highly siliceous mixtures of silica with certain other oxides have a constant temperature of complete melting over a wide range of composition; and that within this range the mixtures form two liquids upon melting, instead of the usual single liquid. The two liquids do not blend, but preserve their separate identities, like mixtures of oil and water. Highly siliceous mixtures of silica with lime or with ferrous oxide exhibit this type of melting behavior. All mixtures of silica and lime containing 1% to 27.5% lime melt completely at 3108° F. (1709° C.); mixtures of silica and ferrous oxide, containing from 1% to 40% ferrous oxide, melt completely at 3092° F. (1700° C.). Partial equilibrium diagrams for the two systems are given in Figure 44.

The equilibrium diagrams of silica with alumina, with titania, and with the alkalies do not show the "Immiscibility Plateau" effect.[47-3] Instead, a single liquid results from melting, and the temperature of complete melting drops rapidly with even small additions of any one of these oxides. The effect of the "Immiscibility Plateau" upon the melting temperature can be seen by comparison of Figures 44 and 45. At 2920° F. (or 1605° C.), a mixture of 5.5% lime with 94.5% silica under equilibrium conditions will consist of 82% solid material with 18% liquid, while at the same temperature a mixture of 5.5% alumina, soda or potash with silica will be completely melted.

THE MINERAL CHANGES WHICH OCCUR UPON FIRING SILICA BRICK

The raw material used in the manufacture of silica refractories is a rock high in quartz. The sum of the alumina, titania and alkalies is usually about 1.0% to 1.3% and the ferric oxide content about 0.8%. A washed rock used in the manufacture of super-duty silica refractories contains about 99.0% silica, and a maximum of 0.5% alumina plus titania plus alkalies. In the manufacturing process, 1.8 to 3.5 per cent of lime is added for bonding.

During the firing, most of the quartz changes with accompanying expansion into other forms of silica. The lime combines with silica and the impurities of the rock to form a liquid; under some conditions, the mineral pseudo-wollastonite ($CaO \cdot SiO_2$) is formed also.

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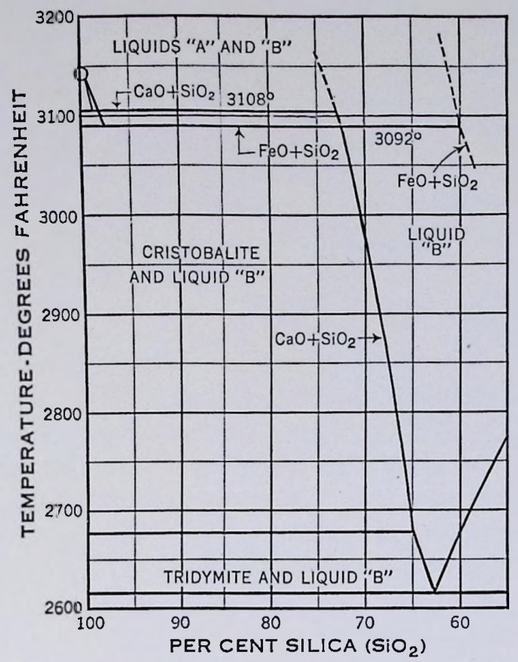


Fig. 44. Partial Equilibrium Diagram of the Systems Lime-Silica and Ferrous Oxide-Silica (CaO–SiO_2 and FeO–SiO_2) (Based on Data of J. W. Greig, Amer. Jour. Sci., 1927)

The lime which is added passes entirely into the fine-grained groundmass, comprising about 25% of the weight of the brick. Hence that portion of the ground material which is finer than 200 mesh contains about 8% lime. The relatively high concentration of lime in the groundmass is an important factor in the formation of a liquid phase, and influences both the rate at which the mineral transformations occur, and the bonding strength.

At temperatures which depend upon the relative proportions of lime, alumina, alkalies and silica in the groundmass of the brick, chemical reactions occur which cause the formation of the liquid phase. These reactions probably begin at a relatively low temperature, since one of the eutectics in the lime-alumina-silica system, containing 23% CaO, 15% Al_2O_3 and 62% SiO_2, has a melting point of 2129° F. (1165° C.). This temperature would be depressed somewhat by the small amounts of alkalies present.

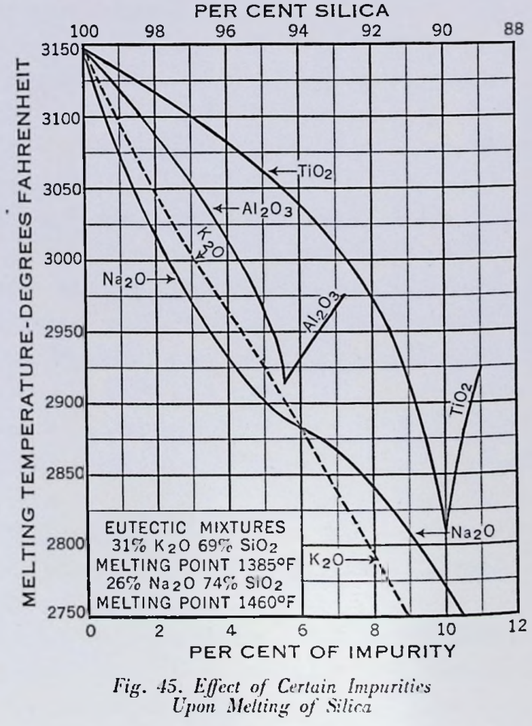


Fig. 45. Effect of Certain Impurities Upon Melting of Silica

In the firing of silica brick, conversion of quartz to cristobalite, which begins slowly at about 2280° F. (1250° C.), takes place more rapidly as the temperature rises. The quartz first to be converted is in the groundmass, and around the borders of the larger grains. Ultimately, the only quartz remaining is that in the interior of the largest grains.

During the firing, much of the cristobalite formed from the quartz is transformed into tridymite, which is the stable form of silica at the firing temperature of about 2625° F. (1440° C.). The formation of cristobalite from quartz in some parts of the brick proceeds simultaneously with the formation of tridymite from cristobalite in other parts.

The linear expansion of silica brick during firing, due to the transformation of quartz to cristobalite and tridymite, is about 3.5%.

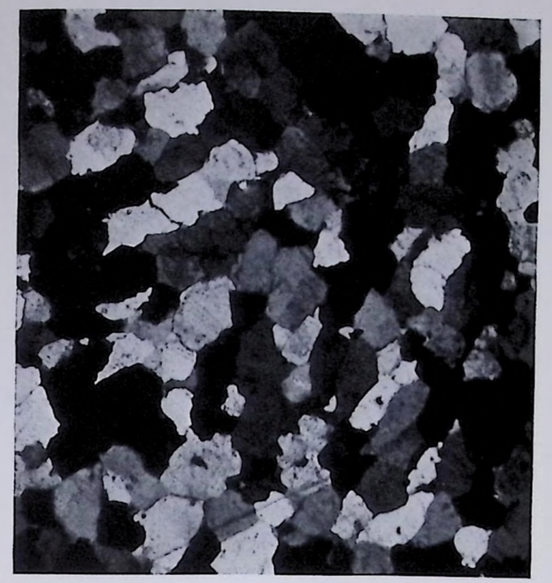


Fig. 46. Typical Section of Tuscarora Quartzite. Polarized Light. Linear Magnification, 35. The field shows a mass of closely packed quartz crystals.



Fig. 47. Typical Section of Tuscarora Quartzite. Polarized Light. Linear Magnification, 110. Secondary quartz has filled the voids between the original grains, and is in crystallographic continuity with them.



Fig. 48. Section of Star Silica Brick, Unused. Polarized Light. Linear Magnification, 110. The light-colored lath- and wedge-shaped areas represent tridymite crystals; the darker areas are mainly cristobalite.



Fig. 49. Section of Star Silica Brick After Use. Polarized Light. Linear Magnification, 110. From flue of by-product coke oven, after ten years' service. The large wedge-shaped light-colored area near the center of the field is a tridymite twin crystal, about 0.02 inch in length.

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THE MINERAL COMPOSITION OF SILICA BRICK

Silica brick, as now manufactured, usually contain 45 to 60 per cent tridymite, 30 to 40 per cent cristobalite, and up to 5 per cent residual quartz. The remainder consists of a highly siliceous glass, or of siliceous glass and finely crystalline material, which has been identified as pseudo-wollastonite ($CaO \cdot SiO_2$). The cristobalite occurs only in the grains and the residual quartz only in the centers of the larger grains. The groundmass of the brick contains the glass, the pseudo-wollastonite and much of the tridymite. It is believed that interlacing of the tridymite and cristobalite crystals contributes to the bond of the brick.

Silica refractories ordinarily are light in color with a yellowish cast, but often are mottled or splotched in irregular patterns. Such coloration is due to subtle changes in the groundmass, accompanying devitrification. These odd colorings, which are of no practical significance, are most likely to appear in brick made from rock of the highest purity, or in brick containing more than about three times as much lime as alumina.

THE MINERAL COMPOSITION OF MAGNESIA REFRACTORIES

Magnesite Materials: The raw materials used in the manufacture of magnesite refractories are (1) the mineral magnesite, which is naturally occurring magnesium carbonate, (2) chemically precipitated magnesium hydroxide, and (3) to a minor extent the mineral brucite, naturally occurring magnesium hydroxide. The mineral magnesite contains small amounts of accessory minerals, such as dolomite, serpentine, talc, chalcedony and quartz. Iron carbonate, in solid solution with the magnesium carbonate, is present in many magnesites. Chemically precipitated magnesium hydroxide, prepared by causing slaked lime or slaked calcined dolomite to react with magnesium-bearing brine, contains small amounts of accessory minerals derived from the limestone or dolomite, and from the brine. During the dead-burning of either magnesite or magnesium hydroxide, additions of iron oxide, lime or silica may be made to obtain desired compositions.

The temperature of dead-burning varies from about 2800° F. to 3350° F. (1540° C. to 1845° C.), depending upon the type and purity of the product. In the process of dead-burning, magnesium carbonate dissociates to form magnesia and carbon dioxide gas; magnesium hydroxide dissociates to form magnesia and water vapor. The carbon dioxide and the water vapor escape with the kiln gases. The dead-burned product consists mainly of particles of magnesia in the form of periclase crystals, with a fine-grained crystalline groundmass usually consisting of silicates of magnesium and calcium. Dead-burned magnesite which contains several per cent of iron oxide is generally chocolate-brown in color, and microscopic examination shows that the periclase crystals usually have dark moss-like inclusions. These have been identified as magnesioferrite. The color of dead-burned magnesite low in iron oxide varies from tan to buff.

The most desirable amounts of the accessory constituents, and their relative proportions, depend upon the purposes for which the product is to be used. Dead-burned grain magnesite used in furnace hearths in general has a higher content of accessory constituents than that used for making brick. The compositions of most of the commercial dead-burned magnesites used in the United States lie within the ranges shown in Table XIV.

Table XIV.

TYPICAL COMPOSITIONS OF DEAD-BURNED MAGNESITE

	For Furnace Bottoms	For Making Brick
Magnesia (MgO)	80–85%	85–97%
Lime (CaO)	3–6	1–5
Silica (SiO_2)	5–7	1–6
Alumina (Al_2O_3)	1–2	0.5–2.0
Ferric Oxide (Fe_2O_3)	3–5	0.5–4.0

The exact mineral composition of magnesite grains cannot be calculated accurately from the chemical composition, because adequate data regarding the five-component system MgO–CaO–Al_2O_3–Fe_2O_3–SiO_2 are not available, and because equilibrium conditions are not entirely reached in the brief period of exposure to high temperatures during dead-burning. However, the major components can be identified by painstaking research with the X-ray.

The CaO-MgO-SiO_2 System: Consideration of the three-component system CaO–MgO–SiO_2 serves as an excellent starting point in studying the mineral composition of magnesia refractories. The composition triangles in this system are shown in Figure 50, which is explained as follows: Any *point* within the large equilateral triangle of Figure 50 represents a definite composition, consisting solely of CaO, MgO, and SiO_2. For example, the point "A" represents a composition of 35.9% CaO, 25.6% MgO and 38.5% SiO_2, which corresponds to the composition of the mineral monticellite.

The large equilateral triangle is divided by heavy lines into triangles of unequal size. These are known as "composition triangles". Each of the three apexes of any composition triangle represents the chemical composition of a specific mineral. A *line* connecting any two apexes represents all compositions in which the two minerals indicated may coexist in equilibrium. The *area* within a triangle represents all compositions in which the three minerals indicated by the apexes may coexist in equilibrium.

The particular minerals to be found in any stable blend of lime, magnesia and silica may be predicted from the triangle within which the composition lies. Under equilibrium conditions, the body would consist of the three minerals represented by the apexes of the triangle, in relative amounts fixed by the distances from the point representing the composition, to the individual apexes.

That part of the CaO–MgO–SiO_2 system in which the magnesia is present in great excess, and in which therefore periclase (MgO) is invariably a component, is of particular interest in connection with magnesite refractories. In Figure 50 the composition triangles of this part of the system appear as full lines. The calcium and magnesium silicates which may coexist in equilibrium with periclase are indicated. For any given composition, the particular silicates which may be present, and their relative proportions, are fixed by the lime-silica ratio.

In that part of the three-component system CaO–MgO–SiO_2 in which magnesia is present in great excess, and in which the lime-silica ratio is less than 1.865 to 1, either one or two magnesium-bearing silicate minerals will invariably be present at room temperatures, as shown in Table XV. If the lime-silica ratio is 1.865 or higher, no magnesium-bearing silicates will be present.

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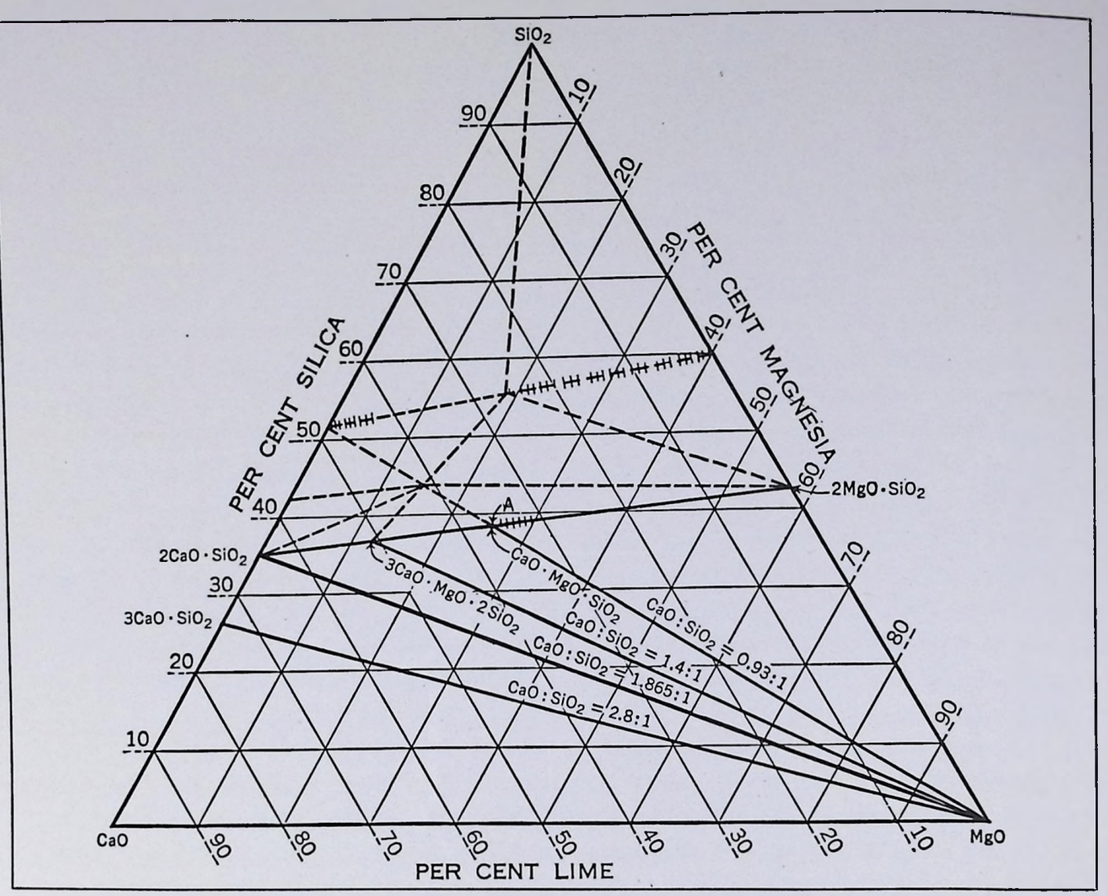


Fig. 50. Composition Triangles in the Lime-Magnesia-Silica ($CaO–MgO–SiO_2$) System. Compositions are given in weight per cent

The lime-silica ratio has an important bearing upon the melting behavior of lime-magnesia-silica compositions. Any combination of lime, magnesia, and silica alone, in which periclase is a component, and in which the amount of lime by weight is *less than 1.865 times* the amount of silica, will develop a liquid phase at 2871° F. (1577° C.), and may develop liquid at a temperature as low as 2730° F. (1499° C.). If completely homogeneous mixtures could be obtained, no combination of these oxides in which the amount of lime is *equal to or more than 1.865 times* the amount of silica, would form liquid below 3630° F. (2000° C.). However, lower lime-silica ratios, in areas of even microscopic size, would permit small quantities of liquid to form at temperatures lower than 3630° F. (2000° C.), and would cause some sintering together of particles, even though diffusion at higher burning temperatures should cause the liquid to disappear.

The Accessory Minerals in Magnesite Refractories: Only limited data are available concerning the complex five-component system $CaO–MgO–SiO_2–Al_2O_3–Fe_2O_3$, the system applicable to magnesite refractories. However, it has been found that when the amount of lime is less than 1.865 times the amount of silica,

Table XV.

MINERALS IN THE $CaO–MgO–SiO_2$ SYSTEM WHICH COEXIST IN EQUILIBRIUM WITH PERICLASE

Case	Molecules of CaO to 1 Molecule of SiO_2	Parts by Weight of CaO to 1 part of SiO_2	Compatible Components	
			Minerals	Compositions
1	Under 1 (Less CaO than SiO_2)	Less than 0.93 parts	Forsterite Monticellite	$2MgO·SiO_2$ $CaO·MgO·SiO_2$
2	1	0.93 parts	Monticellite	$CaO·MgO·SiO_2$
3	1–1½ (More CaO than SiO_2)	0.93–1.40 parts	Monticellite Merwinite	$CaO·MgO·SiO$ $3CaO·MgO·2SiO_2$
4	1½	1.40 parts	Merwinite	$3CaO·MgO·2SiO_2$
5	1½–2	1.40–1.865 parts	Merwinite Dicalcium Silicate	$3CaO·MgO·2SiO_2$ $2CaO·SiO_2$
6	2	1.865 parts	Dicalcium Silicate	$2CaO·SiO_2$
7	2–3	1.865–2.80 parts	Dicalcium Silicate Tricalcium Silicate	$2CaO·SiO_2$ $3CaO·SiO_2$
8	3	2.80 parts	Tricalcium Silicate	$3CaO·SiO_2$
9	Over 3	Over 2.80 parts	Tricalcium Silicate Lime	$3CaO·SiO_2$ CaO

the same silicate minerals occur as would be predicted from the $CaO–MgO–SiO_2$ equilibrium diagram; and the alumina and ferric oxide present are combined with magnesia, forming the spinel minerals $MgO·Al_2O_3$ and $MgO·Fe_2O_3$. When the amount of lime equals or exceeds 1.865 times the amount of silica, in the five-component system, the mineral relationships are much more complex. The lime reacts with silica to form dicalcium or tricalcium silicate, and with alumina and ferric oxide to form calcium aluminates and calcium ferrites. The lime-silica ratio does not suffice to determine what minerals are present. Many attempts have been made to formulate rules whereby the mineral compositions at room temperatures can be calculated from the chemical analyses, but often the calculated compositions are not in satisfactory agreement with the results of microscopic and X-ray determinations.

Forsterite is a common bonding constituent of magnesite refractories of low lime content. It is highly refractory and has no undesirable mineral inversions; it is little affected by the presence of moderate amounts of ferric oxide, but reacts with lime to form the minerals monticellite and merwinite.

Monticellite and merwinite melt at relatively low temperatures, and in minor amounts may have some value in the development of the ceramic bond of magnesite brick. Dead-burned magnesite compositions having a lime-silica

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Table XVI.

MELTING POINTS OF COMPOUNDS WHICH MAY BE PRESENT IN MAGNESITE REFRACTORIES

		°F.	°C.
Lime	CaO	4660	2570
Periclase	MgO	5070	2800
Spinel	$MgO \cdot Al_2O_3$	3875	2135
Dicalcium Silicate	$2CaO \cdot SiO_2$	3865	2130
Forsterite	$2MgO \cdot SiO_2$	3461	1905
Tricalcium Silicate	$3CaO \cdot SiO_2$	Stable only from 3452° F. (1900° C.) to about 2010° – 2280° F. (about 1100° – 1250° C.). At and above 3452° F. (1900° C.) it dissociates into 2CaO SiO_2 and CaO; below 2010° – 2280° F. (about 1100° – 1250° C.) it tends to dissociate into $2CaO \cdot SiO_2$ and CaO.	
Clino-enstatite	$MgO \cdot SiO_2$	Melts incongruently at 2838° F. (1559° C.) to form forsterite and liquid.	
Dicalcium Ferrite	$2CaO \cdot Fe_2O_3$	Dissociates at 2617° F. (1436° C.) into CaO and liquid.	
Magnesioferrite	$MgO \cdot Fe_2O_3$	Dissociates slightly; begins to melt at 3209° F. (1765° C.).	
Monticellite	$CaO \cdot MgO \cdot SiO_2$	Melts incongruently at 2730° F. (1499° C.); melting complete at approximately 2966° F. (1630° C.).	
Merwinite	$3CaO \cdot MgO \cdot 2SiO_2$	Melts incongruently at 2871° F. (1577° C.) to form $2CaO \cdot SiO_2$, MgO and liquid.	

Table XVII.

MELTING POINTS OF SOME CaO–MgO–SiO_2 EUTECTICS

Eutectics Between These Compounds	Melting Points of Eutectics	
	°F.	°C.
MgO and CaO	4172	2300
MgO and $2CaO \cdot SiO_2$	Above 3630	Above 2000
MgO and $2MgO \cdot SiO_2$	3389	1865
MgO, $2CaO \cdot SiO_2$ and CaO	Above 3630	Above 2000
MgO, $2CaO \cdot SiO_2$ and $3CaO \cdot MgO \cdot 2SiO_2$	2871	1577
MgO, $3CaO \cdot MgO \cdot 2SiO_2$ and $CaO \cdot MgO \cdot SiO_2$	2730	1499
MgO, $CaO \cdot MgO \cdot SiO_2$ and $2MgO \cdot SiO_2$	2737	1503

ratio favorable to the development of an undesirable amount of monticellite or merwinite can be corrected by the addition of sufficient lime so that there will be 1.865 times as much lime as silica, by weight. When this is done, magnesia is displaced from the silicates, and the lime and silica combine to form the compound dicalcium silicate ($2CaO \cdot SiO_2$).

Dicalcium silicate ($2CaO \cdot SiO_2$) is highly refractory. It does not react with magnesia (MgO), and it is stable in the presence of moderate amounts of ferric oxide (Fe_2O_3). At one time, it was regarded as an undesirable component of basic refractories, because of its tendency to turn completely into dust on cooling; this effect results from a mineral inversion at 1247° F. (675° C.) which is accompanied by an abrupt volume increase of 10 per cent. Within recent years, means have been found to prevent the dusting of dicalcium silicate, by the addition of small amounts of materials which act as stabilizers. Dicalcium silicate is not highly resistant to attack by siliceous slags.

The lime compounds tricalcium silicate ($3CaO \cdot SiO_2$) and dicalcium ferrite ($2CaO \cdot Fe_2O_3$), which may occur in magnesite refractories having a high lime-silica ratio, are compatible with dicalcium silicate but do not coexist in equilibrium with monticellite, merwinite or forsterite. Tricalcium silicate is unstable below about 2010° to 2280° F. (about 1100° to 1250° C.), and tends to dissociate into dicalcium silicate and free lime. Dicalcium ferrite is unstable above 2617° F. (1436° C.), and decomposes into free lime and a liquid high in iron oxide. It has been suggested that when this occurs the iron oxide may leave the liquid and combine with magnesia to form the mineral magnesioferrite ($MgO \cdot Fe_2O_3$); and that, if the material is cooled rapidly, the dicalcium ferrite might not re-form. Under these conditions, free lime would be present in the dead-burned magnesite after cooling.

At atmospheric temperatures, iron oxide in dead-burned magnesite or in magnesite brick may be present *within the periclase grains* as MgO–FeO solid solution, as MgO–$MgO \cdot Fe_2O_3$ solid solution, or as inclusions of magnesioferrite ($MgO \cdot Fe_2O_3$) granules. Iron oxide may be present also *in the groundmass* in combination with lime and alumina as brownmillerite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$), in combination with lime as dicalcium ferrite ($2CaO \cdot Fe_2O_3$), or in solid solution with silicates.

Magnesioferrite is completely soluble in periclase at high temperatures, but separates out upon cooling, unless cooled very rapidly. This accounts for the presence of the dark colored inclusions in the periclase crystals observed in microscopic examination. The characteristic color of periclase which contains iron oxide compounds in solid solution is aqua-green; that of periclase grains which contain disseminated particles of magnesioferrite, which have separated from solid solution by unmixing, is chocolate-brown. Grains of very dense dead-burned magnesite often are green in their interiors, which were cooled out of contact with air, and brown at their surfaces, which were exposed to air during cooling. In the green centers the periclase crystals probably contain ferrous oxide in solid solution; in the brown surface portions the periclase crystals contain inclusions of magnesioferrite particles. Porous grains are less likely to have green centers than dense grains.

Dead-burned magnesites frequently contain somewhat more free lime than would be anticipated from their chemical compositions. The free lime has no disadvantage from the standpoint of melting, but it is very active chemically and slakes upon exposure to the air.

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CHROME REFRACTORIES

Ores: Refractory chrome ores may be regarded as naturally occurring mixtures of two components: (1) the essential constituent, a highly refractory chrome spinel; (2) accessory constituents, consisting mainly of magnesian silicates in the form of interstitial material and veinlets. These silicates are often of complex and widely varying compositions.

Chrome Spinel: The spinel minerals all have the general formula $RO \cdot R_2O_3$ and all crystallize in the cubic system. In the spinels of chrome ores, the RO is FeO and MgO, and the R_2O_3 is Cr_2O_3, Al_2O_3 and Fe_2O_3. The proportion of Fe_2O_3 is relatively small.

An important property of the spinel minerals is their habit of forming solid solutions, or isomorphous mixtures, with each other. The various spinel minerals are soluble in each other over a very wide range of compositions. Their tendency to form mixed crystals is so great that some of the spinel minerals are not known to occur pure in nature. For example, chromite of the formula $FeO \cdot Cr_2O_3$ is known only in meteorites; all other natural chromites are believed to be isomorphous mixtures.

The composition of a chrome spinel (excluding all accessory minerals) may be stated in terms of molecular ratios of RO and R_2O_3. For example, the average molecular composition of the spinel in chromite of the larger deposits in the Camaguey district of Cuba is approximately the following:[46-1]

RO		R_2O_3	
MgO	75%	Cr_2O_3	40%
FeO	25%	Al_2O_3	55%
		Fe_2O_3	5%
	100%		100%

This composition may be expressed more simply by the formula $\mathbf{m}_{75}\mathbf{f}_{25} \cdot (\mathbf{c}_{40}\mathbf{a}_{55}\mathbf{f}_5)$, in which $\mathbf{m} = MgO$, $\mathbf{c} = Cr_2O_3$, $\mathbf{a} = Al_2O_3$, $\mathbf{f}$ outside the parentheses $= FeO$, $\mathbf{f}$ within the parentheses $= Fe_2O_3$. The subscripts represent molecular percentages.

The approximate molecular compositions of certain other chrome spinels, as reported by J. R. Rait,[46-2] may be represented by the following formulas:

Grecian (Volo)	$\mathbf{m}_{65}\,\mathbf{f}_{35}\,(\mathbf{c}_{51}\,\mathbf{a}_{46}\,\mathbf{f}_3)$
Rhodesian	$\mathbf{m}_{66}\,\mathbf{f}_{34}\,(\mathbf{c}_{73}\,\mathbf{a}_{21}\,\mathbf{f}_6)$
Transvaal, brown	$\mathbf{m}_{47}\,\mathbf{f}_{53}\,(\mathbf{c}_{62}\,\mathbf{a}_{28}\,\mathbf{f}_{10})$
Turkish	$\mathbf{m}_{75}\,\mathbf{f}_{25}\,(\mathbf{c}_{66}\,\mathbf{a}_{26}\,\mathbf{f}_8)$

There is evidence which indicates that the crystals of balanced spinel in a given specimen of chrome ore may not all be of identical composition. Therefore, the molecular formula of a chrome spinel, calculated from its chemical composition, is merely an average value, and does not necessarily apply strictly to each individual spinel crystal.[46-2]

Accessory Minerals: The accessory minerals which occur most abundantly in chrome ores are serpentine ($3\,MgO \cdot 2SiO_2 \cdot 2H_2O$) and chlorite, a complex hydrated silicate of magnesia, iron oxide and alumina. The composition of clinochlore, one of the members of this group, is given as $5(Mg, Fe)O \cdot Al_2O_3 \cdot 3SiO_2 \cdot 4H_2O$. Other accessory minerals include the following:

Olivine	$2(Mg, Fe)O \cdot SiO_2$
Talc	$3\,MgO \cdot 4SiO_2 \cdot 2H_2O$
Pyroxene	
Diopside	$CaO \cdot MgO \cdot 2SiO_2$
Enstatite	$MgO \cdot SiO_2$
Hypersthene	$(Mg, Fe)O \cdot SiO_2$
Feldspar	
Anorthite	$CaO \cdot Al_2O_3 \cdot 2SiO_2$

The amount of accessory minerals in commercial chrome ores varies from 5% to 25%. Most of the accessory minerals have relatively low melting points, well below 3000° F. or 1650° C. The heat resisting qualities of a chrome ore depend largely upon the character and the amount of the silicates present.

Table XVIII.

IMPORTANT SPINEL MINERALS AND THEIR MELTING POINTS

Mineral	Formula	Melting Point °F.	Melting Point °C.
Ferrochromite	$FeO \cdot Cr_2O_3$	†	†
Magnesiochromite	$MgO \cdot Cr_2O_3$	3990 (Approx.)	2200 (Approx.)
Hercynite*	$FeO \cdot Al_2O_3$	2624	1440
Spinel	$MgO \cdot Al_2O_3$	3875	2135
Magnetite	$FeO \cdot Fe_2O_3$	2903	1595
Magnesioferrite*	$MgO \cdot Fe_2O_3$	3209	1765

†Under most conditions, would decompose before melting, on account of oxidation or reduction.
*Melts incongruently.

Table XIX.

TYPICAL ANALYSES OF CHROME ORES

Ore	SiO_2	Al_2O_3	FeO*	Cr_2O_3	CaO	MgO	Ignition Loss
Cuban	5.6	27.9	12.6	32.4	0.8	18.7	1.7
Cuban	4.6	26.1	13.6	35.7	1.0	17.5	1.7
Grecian	4.0	22.0	13.0	41.5	0.9	16.7	1.7
Philippine	4.7	30.1	12.5	32.8	0.5	17.9	1.0
Rhodesian	9.1	12.6	13.5	46.7	0.1	14.1	2.6
Rhodesian	4.4	12.4	16.4	49.9	0.0	14.3	1.1
Transvaal	1.2	14.1	25.1	46.2	0.4	10.6	0.3
Turkish	3.9	16.2	11.9	44.5	0.2	19.9	1.3

* All iron oxide is reported as FeO; however, a small amount is present as Fe_2O_3.

MINERAL CHANGES DURING FIRING OF CHROME ORE

The investigations of Rigby, Lovell and Green[46-2] and others,[41-2] concerning the behavior of chrome ores and synthetic spinels on firing, appear to have established the following facts:

(1) Chrome spinels in general are balanced, containing equal molecular percentages of RO and R_2O_3 constituents.

(2) Raw chrome ores apparently are affected relatively little by firing in reducing atmospheres.

(3) Fe_2O_3 in the form of hematite, or in a simple spinel consisting solely of $FeO \cdot Fe_2O_3$ or of $MgO \cdot Fe_2O_3$ is easily reduced to metallic iron.

(4) The FeO in the spinel of most chrome ores is oxidized almost completely to Fe_2O_3, without increase in size of the spinel grains, when the ores are fired in an oxidizing atmosphere. Two solid phases result: (a) spinel crystals consisting mainly of $MgO \cdot R_2O_3$, and (b) a solid solution of the excess R_2O_3 constituents (Fe_2O_3, Cr_2O_3 and Al_2O_3). Most of the latter solid solution is believed to dissolve in the spinel crystals. However, a portion of the R_2O_3 probably migrates into the groundmass or matrix. Certain chrome spinels in which the ratio of alumina to ferrous

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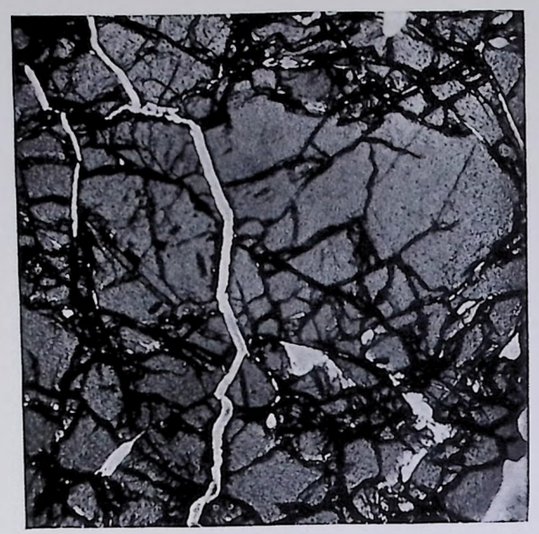


Fig. 51. Photomicrograph of Crude Chrome Ore Natural Light. Linear Magnification, 35.
The darker areas represent the chrome-bearing spinel minerals, while the white areas and veinlets are magnesium silicates.

oxide is relatively high appear to have a lesser tendency to oxidize in air at temperatures up to 2640° F. (1450° C.) than spinels in which this ratio is lower.

(5) In most cases, the Fe_2O_3 in the solid solution of R_2O_3 formed in a chrome spinel upon oxidation is readily reduced by heat treatment in a reducing atmosphere. It is inferred that the products of reduction re-enter the spinel crystal structure.

(6) In a chrome ore which has become oxidized on firing, reduction of the Fe_2O_3 in the solid solution of R_2O_3 is usually accompanied by expansion and increase in porosity, and sometimes by cracking. The expansion and cracking are observed only when the oxidized ore is exposed to the action of reducing gases. Repeated oxidation and reduction may cause an ore to become friable.

(7) Certain chrome ores, after having been oxidized and subsequently heated under reducing conditions, show little if any tendency to expand and become friable. It is believed that in these ores the accessory minerals melt upon the original heating to form a liquid, and that this liquid forms a protective film on the surfaces of the spinel grains.

(8) When a brick mix consisting of chrome ore with an excess of added magnesia is fired under reducing conditions, the FeO in the spinel is replaced, at least in part, by MgO. The FeO diffuses outward from the grains into the matrix, as the MgO diffuses inward. Outwardly the spinel crystals appear to be unchanged.

(9) When a brick mix consisting of chrome ore with added magnesia is fired under oxidizing conditions, most of the FeO in the spinel is oxidized to Fe_2O_3, and MgO enters the spinel not only to substitute for the FeO, but also to combine with the newly formed Fe_2O_3 as well, thus preserving the spinel structure.

(10) While Fe_2O_3 in the simple spinel $MgO \cdot Fe_2O_3$ is easily reduced, solid solutions of $MgO \cdot Fe_2O_3$ with $MgO \cdot Al_2O_3$ and $MgO \cdot Cr_2O_3$ are more stable. Hence, fixing of the spinel structure of a chrome ore, by subjecting it to an oxidizing heat treatment during which MgO is absorbed, diminishes the tendency of the ore to become friable when exposed alternately to oxidizing and to reducing conditions.

(11) Of the amount of magnesia which a chrome spinel is capable of absorbing when the FeO is oxidized, a portion may be available from accessory minerals in the ore, such as serpentine, which have an $MgO:SiO_2$ molecular ratio greater than 1:1. In such accessory minerals, the only magnesia available for absorption by the chrome spinel, is the excess above the $MgO:SiO_2$ ratio of 1:1. Since this amount is limited, addition of magnesia either as such or in the form of minerals high in magnesia may be necessary to satisfy the oxidized chrome spinel.

(12) Originally, in the manufacture of chrome-magnesite brick, the magnesia was added to the chrome ore primarily for the purpose of converting the magnesium silicates of low melting point in the groundmass into the refractory silicate forsterite. However, as shown in the preceding paragraphs, the added magnesia plays an additional role: that of entering the spinel crystal to maintain the $RO \cdot R_2O_3$ balance when the FeO of chrome ore is oxidized to Fe_2O_3. The amount of MgO absorbed by the spinel is probably much greater than that which enters into the formation of forsterite in the matrix.

(13) Oxidation of the FeO in a chrome spinel, with simultaneous absorption of MgO, may be accompanied by a volume increase of about 5 per cent to 10 per cent, depending upon the composition of the spinel. This effect, however, is sometimes masked by shrinkage of the silicates.

(14) The increase in volume of the chrome spinel grains, due to absorption of MgO, may cause the grains to shatter and may also be expected to weaken the natural bond between the grains. In addition, the increase in refractoriness of the silicate groundmass, resulting from the addition of MgO, may decrease its bonding strength. For these reasons, a fired chrome-magnesite brick normally will not be as strong at atmospheric temperatures as a brick made of chrome ore only. However, brick made of chrome-magnesite compositions usually are stronger at high temperatures than brick made of chrome ore alone.

(15) The refractoriness of the spinel grains is raised appreciably by the replacement of FeO by MgO in the isomorphous mixture, since the spinels formed by MgO with Cr_2O_3, Al_2O_3 and Fe_2O_3 have higher melting points than the corresponding spinels formed by FeO.

FORSTERITE REFRACTORIES

The work reported by Goldschmidt and by Birch and Harvey[38-1] in the development of forsterite refractories is an outstanding illustration of the application of phase-rule principles to the solution of a research problem. Forsterite is a magnesium silicate with the theoretical formula $2MgO \cdot SiO_2$, corresponding to 57.3% magnesia (MgO), 42.7% silica (SiO_2). Its melting point is 3461° F. (1905° C.). Forsterite rarely occurs alone, but is common in homogeneous combinations with fayalite ($2FeO \cdot SiO_2$), which has a melting point of only 2201° F. (1205° C.). The series of mixed crystals consisting of forsterite and fayalite is called "olivine" or "chrysolite", while the rock consisting of Mg–Fe olivine, with minor amounts of accessory minerals, is known as "dunite". Commonly there is about 15% of fayalite in the magnesian olivines used for the production of refractories.

The accessory minerals occurring in the dunite used for making forsterite brick are largely serpentine and talc. Serpentine has the composition $3MgO \cdot 2SiO_2 \cdot 2H_2O$, and contains equal amounts of magnesia and silica by weight. The composition of talc is $3MgO \cdot 4SiO_2 \cdot 2H_2O$,

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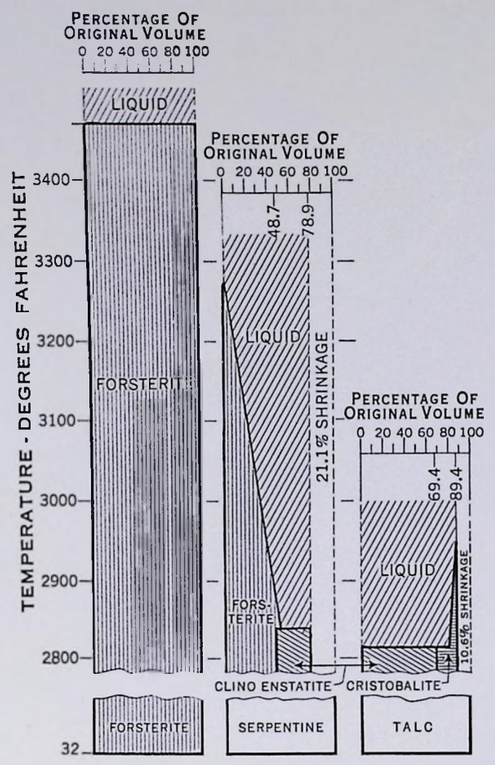


Fig. 52. Modified Equilibrium Diagram showing behavior of Forsterite, Serpentine and Talc when heated. (After Birch and Harvey.[35-2])

corresponding to only half as much magnesia as silica by weight. Upon heating, both these minerals develop large amounts of liquid at relatively low temperatures. At 2838° F. (1559° C.) pure serpentine would be converted into 60.5% forsterite and 39.5% of a siliceous liquid; at 2811° F. (1544° C.) pure talc would become 4.4% cristobalite and 95.6% liquid. In either case, the presence of these natural impurities in olivine would lower the temperature at which liquid would form. Diagrams showing the melting behavior of forsterite, serpentine and talc are given in Figure 52.

The development of a considerable amount of liquid in a refractory body is not of itself a serious matter. For example, as shown on pages 320 and 321, fireclay brick contain large proportions of liquid at temperatures within their working range. Yet the liquid is so very viscous that there can be no drainage from the pores. However, brick containing magnesium silicate melts behave quite differently. Birch and Harvey[35-2] found that a brick made of Mg–Fe olivine relatively high in accessory minerals, when heated to 2640° F. (1450° C.) developed a melt of such high fluidity that liquid drained freely from the pores. They also found that this drainage could be prevented by the addition of sufficient magnesia to convert the magnesium silicates serpentine and talc into forsterite upon firing, and to unite chemically with the iron oxide present to form magnesioferrite ($MgO \cdot Fe_2O_3$).

During the firing of forsterite brick under oxidizing conditions, important changes take place in the forsterite-fayalite solid solution of the olivine. The ferrous oxide (FeO) of the fayalite oxidizes to form ferric oxide (Fe_2O_3), the silica (SiO_2) of the fayalite is liberated, and forsterite is set free from the olivine solid solution by unmixing. The ferric oxide combines with a part of the added magnesia to form magnesioferrite ($MgO \cdot Fe_2O_3$). This enters into solid solution in the crystals of free magnesia (periclase). The silica liberated by the decomposition of the fayalite unites with part of the added magnesia to form secondary forsterite.

A comparable transformation occurs in the accessory magnesium silicate minerals in the olivine rock. Any serpentine present in fissures or in groundmass decomposes upon firing to form secondary forsterite and a liquid. The latter apparently drains out to the surfaces of the grains and forms additional amounts of secondary forsterite by reacting with a portion of the magnesia which was added.

Part II. CHEMICAL AND PHYSICAL PROPERTIES

PHYSICAL CHARACTERISTICS—COLD

Among the properties of refractories which can be determined readily are specific gravity, porosity, and strength at atmospheric temperatures. The specific gravity of a refractory is dependent upon the characteristics of the raw material used in its manufacture, and usually upon the time and temperature of firing. The strength and the porosity are influenced by various factors, among which are type and quality of the material, size and "fit" of the particles, water content at time of molding, pressure of molding, temperature and duration of firing, kiln atmosphere, and rate of cooling.

With some materials, the true specific gravity is a measure of the degree to which the crystalline changes brought about by firing have taken place. In the case of most silica brick, for example, a true specific gravity higher than 2.40 suggests that the brick were not burned hard enough to effect the desirable degree of transformation of quartz to cristobalite and tridymite.

The porosity of a refractory has an effect upon its ability to withstand load at high temperatures, its resistance to penetration by slags and fluxes, its permeability to gases and its thermal conductivity.

The strength of brick at atmospheric temperatures provides little or no indication of their strength at furnace operating temperatures. However, if the cold strength is too low, the brick will not withstand handling and shipping without scuffing and breakage.

In Table XX, data are given regarding some of the physical properties of refractory brick. The values shown in Table XX, and in the other tables of this chapter, are not intended to be applicable to specific brands. In most cases, the figures represent typical data obtained from tests on various brands of refractories made in the United States.

CHEMICAL COMPOSITION

The primary value of chemical analysis is in control of quality of both raw materials and finished products. It serves also as a basis for classification of refractories, and as a guide to their melting behavior. Examples of the application of chemical analysis to quality control are the determination of the iron oxide content of some clays, the alumina content of diaspore clays, the alumina and alkali contents of certain quartzites, and the percentages of silica and lime in chrome ores.

The chemical composition of a refractory is not usually the most important criterion of its commercial utility. It is well known that brick of almost identical compositions may differ widely in their behavior under the same furnace conditions. Chemical analysis alone does not permit evaluation of the stability of volume of a refractory at high temperatures, or of its ability to withstand pressure, slagging or spalling.

For making chemical analyses of refractory materials, the procedures recommended by the American Society for Testing Materials (Standard Methods C18) are in common use. As an aid in checking the accuracy of analytical technique, "standard" samples of certain refractory materials, of known compositions, may be purchased from the National Bureau of Standards.

In any given type of refractory brick the various brands commercially available differ somewhat among themselves in chemical composition. For that reason, the analyses shown in Tables XXI and XXII are given in the form of ranges rather than as definite values.

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Table XX.

PHYSICAL PROPERTIES OF REFRACTORIES

Typical Values for Standard 9-Inch Straights

Type of Brick	True Specific Gravity	Per Cent Apparent Porosity	Cold Crushing Strength Lb. per Sq. In. Set on End	Modulus of Rupture Lb. per Sq. In.
FIRECLAY				
Super-Duty	2.65–2.75	12–20	900–4000	600–1300
High Duty, Aluminous, Hand Made	2.60–2.70	20–30	700–2500	400–1300
High Duty, Aluminous, Machine Made	2.60–2.70	12–25	1000–6000	400–2000
High Duty, Siliceous	2.40–2.45	23–33	1000–2000	400–1000
Intermediate Duty	2.55–2.65	10–25	1200–6000	600–2200
Low Duty	2.55–2.65	12–25	2000–6000	1000–2000
HIGH-ALUMINA				
50% Alumina Class	2.75–2.85	18–25	2500–5000	1000–1500
60% Alumina Class	2.90–3.05	17–27	1800–6000	600–1600
70% Alumina Class	3.15–3.25	23–35	4000–6000	1200–1500
80% Alumina Class	3.35–3.45	20–30	5000–8000	1500–2000
90% Alumina Class	3.55–3.65	20–26	4000–7000	1200–2000
99% Alumina Class	3.70–3.90	20–26	5000–9000	1500–3000
SILICA	2.30–2.38	20–30	1000–3000	400–1200
BASIC				
Chrome, Fired	3.90–4.10	18–25	3000–6000	1200–2000
Chrome-Magnesite, Chemically Bonded	3.90–4.10	18–22*	2000–4000	750–1000
Chrome-Magnesite, Fired	3.90–4.10	18–23	2000–3500	900–1500
Forsterite	3.30–3.40	18–27	1500–4000	450– 800
Magnesite, Fired	3.40–3.60	20–26	5000–10000	1500–3000
Magnesite-Chrome, Chemically Bonded	3.60–3.80	18–22*	2000–4000	750–1000

* Porosities determined after heating the brick to remove non-permanent bonding ingredients from pores.

Table XXI.

TYPICAL COMPOSITIONS OF FIRECLAY AND HIGH-ALUMINA BRICK

Type of Brick	Per Cent			
	Silica (SiO_2)	Alumina (Al_2O_3)	Titania (TiO_2)	Other Oxides
FIRECLAY				
Super-duty	49–53	40–44	2.0–2.5	3–4
High Duty, Aluminous	51–60	35–40	1.7–3.3	3–6
High Duty, Siliceous	65–80	18–28	1.0–2.0	2–6
Intermediate Duty	57–70	25–36	1.3–2.1	4–7
Low Duty	60–70	22–33	1.0–2.0	5–8
HIGH ALUMINA				
50% Alumina Class	41–47	47.5–52.5	2.0–2.8	3–4
60% Alumina Class	31–37	57.5–62.5	2.0–3.3	3–4
70% Alumina Class	20–26	67.5–72.5	3.0–4.0	3–4
80% Alumina Class	11–15	77.5–82.5	3.0–4.0	3–4
90% Alumina Class	8–9	89–91	0.4–0.8	1–2
99% Alumina Class	0.5–1.0	98–99	Trace	0.6

Table XXII.

TYPICAL COMPOSITIONS OF SILICA AND BASIC BRICK

Type of Brick	Per Cent						
	Silica (SiO_2)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Iron Oxide (Fe_2O_3)	Chromic Oxide (Cr_2O_3)	Other Oxides
SILICA							
Conventional and Super-Duty	95–97	0.25–1.2	1.8–3.5	.....	0.3–0.9	.....	0.1–0.3
BASIC							
Chrome	3–6	15–33	.....	14–19	11–17	30–45	1–2
Forsterite	33–39	.....	.....	47–55	9–11	.....	3–4
Magnesite	3–6	0.4–2.0	1–5	85–95+	0.5–4.0	.....	0.5–1.0

BEHAVIOR OF REFRACTORIES AT HIGH TEMPERATURES

The one condition obviously common to all furnace operations is high temperature prevailing within a refractory structure. Stemming from the high temperature and from the rate of change in temperature, is a closely related combination of other thermal effects, simultaneously produced. Heat energy flows into the refractory materials, and a temperature difference develops between the inside and outside surfaces of walls and arches. Part of the heat energy is stored in the refractory structure and its foundation, and part flows through walls, arches and hearths, and is lost to the outside air through radiation and convection.

When refractories are heated, their linear dimensions and volume increase. With some refractories, additional volume change results from mineral inversions or transformations, and sometimes from other causes.

Within a single brick in a wall or arch, there is commonly a temperature drop of many hundreds of degrees from the hot face to the cold face. The difference in the amounts of thermal expansion in different sections of the brick will cause internal stresses to develop. In a refractory structure, pressures inherent in the furnace construction, such as arch stresses, generally will be increased by thermal expansion of the brickwork. Unequal volume changes resulting from rapid heating or sudden chilling of a furnace may also develop high stresses within the refractories.

The amount and viscosity of the glassy constituent of a refractory, which vary with the temperature, will affect the strength of the brick and its ability to withstand pressure. Crystal development and growth, solution of solids in any glass which may be present, or melting of some or all of the constituents of a brick, will all take place under conducive conditions. Migration of the liquid phase formed by partial melting may cause the development of zones in which constituents of relatively low melting temperature are concentrated.

Chemical reactions may occur between the refractories and the materials in the furnace, or in some cases, between different types of refractories in contact. Absorption by the refractories of material from a furnace charge, bath or slag, or the penetration of gases or fumes into the refractories, may cause the formation of new minerals, and bring about changes in the physical and chemical characteristics of the brick. Under certain conditions, carbon monoxide may decompose within the brick, deposit carbon in the pores, and weaken the structure.

Modern Refractory Practice: 3rd Edition (1950)
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SOFTENING TEMPERATURES OF REFRACTORIES

Most commercial refractories have no true melting points, but when heated soften gradually over a range of temperature. No definite temperature marks the transition from the distinctly solid to the distinctly liquid state. The ability of a refractory to remain rigid at high temperatures depends not only upon the melting points of its crystalline constituents or those of the eutectics which may form from them, but also upon the amount and viscosity of any glass which it may contain.

The different types of refractory materials vary widely in their softening behavior at high temperatures. Some refractories, such as most fireclay and high-alumina brick, soften progressively over a relatively wide range of temperature; others, such as silica brick, have a relatively narrow range of softening.

PYROMETRIC CONE EQUIVALENT

The time-honored method of evaluating the high-temperature softening behavior of alumina-silica refractories consists in the determination of their "Pyrometric Cone Equivalent", which is abbreviated to "P.C.E.". The standard method of determining the Pyrometric Cone Equivalent is described in detail in the Manual of A.S.T.M. Standards on Refractory Materials.[48-1]

A ground sample of the material to be tested is molded into the form of "test cones" and mounted on a plaque with a series of standard pyrometric cones having known time-temperature softening values. The plaque is heated at a definite rate until the test cones soften and bend. The number of the standard cone which shows approximately the same degree of softening as the test cones is reported as the P.C.E. The softening temperatures of the Standard Pyrometric Cones, when heated under standard conditions, are given in the table on page 350.

The P.C.E. does not indicate a definite "melting point" or "softening point", because the test is not a measurement of temperature, but "a comparison of thermal behavior in terms of standard cones".[44-1] Results should preferably be reported merely as P.C.E. values. However, it is common practice to report the indicated softening temperatures also.

The P.C.E. test is most reliable when used for refractories of compositions similar to those of the standard cones; it is least reliable when the materials tested are radically different in composition or in thermal behavior from the standard cones. The high-temperature series of cones, numbers 28 to 42, is based nominally upon mixtures of kaolinite, quartz and alumina.[44-1] They are useful in evaluating the refractoriness of fireclay and high-alumina refractories, but are not suitable for testing silica or basic refractories.

MELTING BEHAVIOR OF ALUMINA-SILICA REFRACTORIES

Fireclay Brick: Fireclay brick as placed in service contain appreciable quantities of a rigid glass developed during the firing procedure. At low temperatures, this glass helps to bond the entire mass strongly together. When a fireclay brick of the high duty class is progressively heated, the glass retains its rigidity up to a temperature of approximately 1800° to 2000° F. (about 980° to 1095° C.), and the brick as a whole remains mechanically strong. As the temperature rises, the glassy bond begins to lose its rigidity and becomes a viscous liquid.

Table XXIII.

TYPICAL PYROMETRIC CONE EQUIVALENTS OF REFRACTORY BRICK

Kind of Brick	Cone	Approximate Softening Temperatures Under Test Conditions	
		°F.	°C.
FIRECLAY			
Super-Duty	33 to 34	3173 to 3200	1745 to 1760
High Duty, Aluminous	31-32 to 33	3074 to 3173	1690 to 1745
High Duty, Siliceous	28 to 31	2939 to 3056	1615 to 1680
Intermediate Duty	29 to 31	2984 to 3056	1640 to 1680
Low Duty	19 to 26	2768 to 2903	1520 to 1595
HIGH-ALUMINA			
50% Alumina Class	34 to 35	3200 to 3245	1760 to 1785
60% Alumina Class	35 to 37	3245 to 3308	1785 to 1820
70% Alumina Class	36 to 38	3290 to 3335	1810 to 1835
80% Alumina Class	38 to 39	3335 to 3389	1835 to 1865
90% Alumina Class	39 to 40	3389 to 3425	1865 to 1885
99% Alumina Class	41 – 42	3620	1990

In reporting P.C.E. values the word "to" is used between two standard cone numbers to indicate that different lots of the given material have a range in softening from the lower to the higher value. A dash (–) between two standard cone numbers does not indicate a range, but shows that the material has a position as to softening, approximately midway between the two pyrometric cone values.

However, within a wide range of temperature above 2000° F. (1095° C.), the liquid remains so stiff and viscous that the brick as a whole behaves almost as it would if it were entirely solid. Within this range, deformation occurs only as a result of pressure. Under load, the stiff liquid will yield slowly, serving as a lubricant for the solid particles, and permitting them to slide past each other. Under these conditions, the brick will become deformed at a rate dependent upon the temperature and the amount of pressure.

With still further rise in temperature, the liquid will increase in amount at the expense of the solid, and will decrease in viscosity, until finally the brick, if heated uniformly throughout, will deform merely under its own weight. The rate of heating has an effect upon the temperature at which this deformation occurs.

Finally, at a sufficiently high temperature, all crystalline material suspended in the liquid will be dissolved and the brick will then be completely melted.

During the original firing procedure, partial solution of the solid portions of the brick will occur to an extent dependent upon the time and temperature of heating; consequently, in a subsequent reheating below the original firing temperature, the liquid portion will have a greater viscosity than during the original heat treatment. In a brick held at a constant high temperature, gradual solution of solid material up to the limit of its solubility in the liquid may cause some increase in the viscosity of the liquid. These facts may explain in part why a hard-burned fireclay brick generally is more resistant to pressure than one which is light-burned, and why a brick which has been thoroughly seasoned in service generally is more resistant to pressure than an unused brick.

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Additional factors contributing to this increased resistance to pressure are believed to be more thorough distribution of liquid throughout the brick, the growth of crystals through the influence of heat, and crystallization of a portion of the liquid during cooling, resulting from a diminishing capacity to retain dissolved material in solution.

The compressive strength of high duty fireclay brick changes little up to about 1800° to 2000° F. (980° to 1095° C.), and any failure under load below 2000° F. (or 1095° C.) would occur by crushing or shearing. As the temperature rises above 2000° F. (1095° C.), the compressive strength diminishes, until a condition is reached in which the brick will crush or shear under a relatively heavy load rapidly applied, but will also exhibit slow plastic deformation under a lighter load.

The temperature of initial plastic deformation under a pressure of 25 pounds per square inch (the load commonly applied in laboratory testing), varies considerably between the various classes of fireclay brick, between various brands of the same class, and also between hard and light burned brick of the same brand. Approximate mean values for the initial deformation temperature of aluminous fireclay brick under the 25-pound load, at the rate of heating used in the A.S.T.M. test, are the following: super-duty, 2325° F. (about 1275° C.); high duty, 2250° F. (about 1230° C.); intermediate duty, 2175° F. (about 1190° C.).

High-Alumina Brick: The melting behavior of high-alumina brick made from diaspore clays resembles that of fireclay brick of the aluminous type. When the brick are heated, liquid begins to develop at about 1800° F. (980° C.), and at progressively higher temperatures the amount of liquid increases. However, the rate of increase of the liquid phase, and its amount at any given temperature, is least for brick of the highest alumina content. The temperature at which complete melting occurs is highest for brick of highest alumina content.

Brick made of fused alumina or mullite bonded by fireclay will develop a small amount of liquid in the fireclay groundmass at about 1800° F. (980° C.). However, the amount of liquid in such brick will increase very slowly upon progressive heating, until a temperature of 3000° to 3200° F. (1650° to 1760° C.) is reached, above which liquid development may proceed rapidly. In brick of the 99% alumina class, very little liquid is present at any temperature below that of complete melting. In general, high-alumina brick will undergo slow plastic deformation when subjected to pressure at high temperatures.

The Load Test: The standard laboratory tests for refractories include one for the determination of the behavior of brick under load at high temperatures. In this test, 9-inch brick are set on end in a furnace of specified design, and a vertical load of 25 pounds per square inch is applied. In the standard procedure, A.S.T.M. Method C16 – 41, the temperature is gradually raised in accordance with a definitely prescribed schedule. In testing high duty fireclay brick, the maximum temperature is 2460° F. (1350° C.); for super-duty fireclay brick, and for most classes of high-alumina brick, it is 2640° F. (1450° C.). The maximum temperature is held for 1½ hours, after which the furnace is allowed to cool by radiation to 1830° F. (1000° C.), or lower, before the load is removed. The amount of subsidence is reported in terms of linear percentage.

Typical results in the standard load tests are given in Table XXIV.

Table XXIV.

TYPICAL RESULTS OF LOAD TEST AT 25 POUNDS PER SQUARE INCH

Type of Brick	Constant Temperature For 1½ Hours		Linear Subsidence Per Cent
	°F.	°C.	
FIRECLAY			
Super-Duty	2640	1450	3–9
Super-Duty, High Fired	2640	1450	1–4
High Duty, Aluminous	2460	1350	1–10
High Duty, Siliceous	2460	1350	0.5–3.0
Intermediate Duty	2460	1350	3–10
HIGH ALUMINA			
50% Alumina Class	2640	1450	2–7
60% Alumina Class	2640	1450	2–6
70% Alumina Class	2640	1450	2–5
80% Alumina Class	2640	1450	1–5
90% Alumina Class	2910	1600	1–3
99% Alumina Class	3000	1650	0–3

MELTING BEHAVIOR OF SILICA BRICK

Silica refractories differ greatly from fireclay refractories in their melting behavior. In the cold condition, a silica brick is almost wholly crystalline. The crystal phase generally consists largely of tridymite and cristobalite, with a small amount of quartz. When heated, very little liquid develops below the lime-alumina-silica eutectic temperature of 2129° F. (1165° C.).

R. E. Birch[41-1] has estimated the rate of liquid formation in a conventional silica brick containing 1.2% Al_2O_3 plus TiO_2 plus alkalies, and in a super-duty silica brick containing 0.4% Al_2O_3 plus TiO_2 plus alkalies. Because these liquid-forming oxides have similar effects, they were all treated as alumina for the purpose of the calculation. The percentages of liquid at different temperatures were estimated from the equilibrium diagram of the $CaO–Al_2O_3–SiO_2$ system. As shown in Figure 53, the amount of liquid increases very slowly until the temperature is well above 2900° F. (or 1595° C.).

Even at 2900° F. (1595° C.), silica brick retain their rigidity. The crystalline portion forms a rigid skeleton, with liquid merely between the solid particles. In the load test at 25 pounds per square inch, conventional silica brick do not fail until a temperature of about 2975° to 3025° F. (1635° to 1665° C.) is reached; failure, when it occurs, is abrupt. Super-duty silica brick withstand the 25-pound load up to about 3060° to 3080° F. (1680° to 1695° C.), at which temperature abrupt failure by shearing occurs. It is estimated that the brick are about one-third melted at the temperature of failure.

The ultimate melting temperatures of conventional and super-duty silica brick differ less than their temperatures of failure in the standard load test. In the absence of fluxing agents, a silica brick of the conventional type in a furnace roof may begin to show evidence of surface melting at about 3085° F. (1696° C.); super-duty silica, at about 3105° F. (1707° C.).

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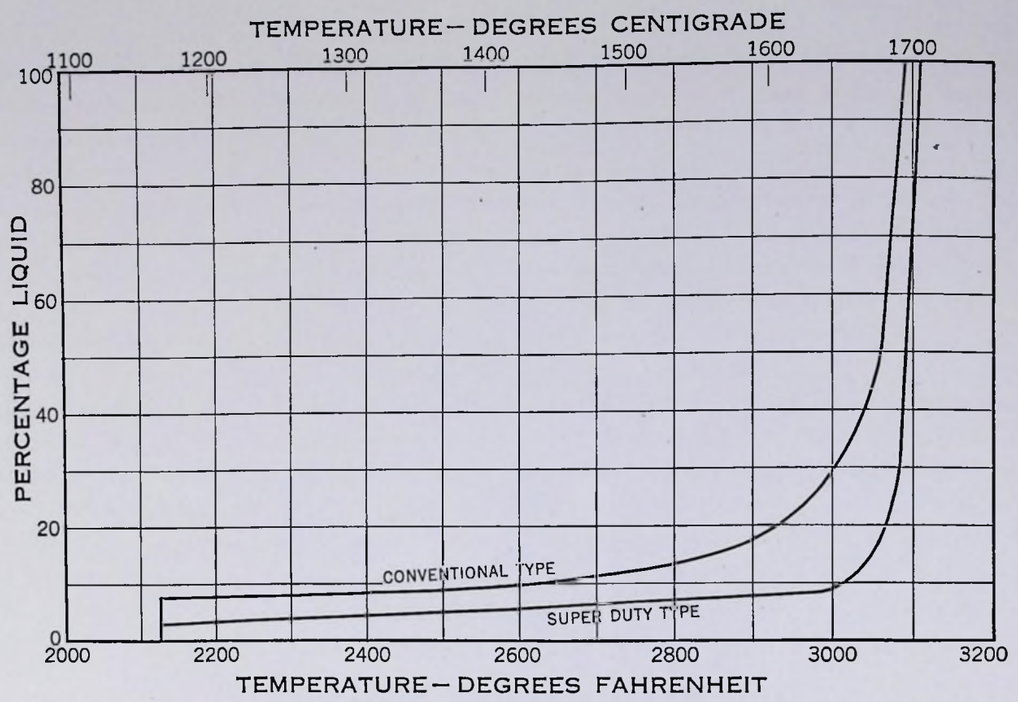


Fig. 53. Estimated Progress of Melting in Two Silica Brick Compositions

MELTING BEHAVIOR OF BASIC REFRACTORIES

Most basic brick are composed of highly refractory granules bonded by a groundmass of finely crystalline silicate minerals. In some of the raw materials used in manufacture, the groundmass minerals occurring naturally are of inadequate refractoriness. However, in many cases the composition of the groundmass can be "corrected" by appropriate additions, and its temperature of melting thereby raised several hundred degrees.

In brick made of uncorrected raw materials containing significant percentages of groundmass minerals of low refractoriness, appreciable amounts of a very fluid liquid might develop at temperatures considerably below those of normal furnace operation. For example, it is shown on page 316 that a test brick made of uncorrected olivine, when heated to 2640° F. (1450° C.), developed a small amount of liquid which was so fluid that it drained from the pores of the brick. Correction of the composition by the addition of magnesia transformed the groundmass into a highly refractory material.

Magnesite brick are composed mainly of periclase grains in a silicate matrix or groundmass of minor amount. Most of the iron oxide present is distributed uniformly throughout the periclase grains. The silicate groundmass is composed of lime, silica, alumina, alkalies, a minor portion of the iron oxide and a small amount of magnesia.

Chrome brick consist of chrome spinel grains with a groundmass which is largely magnesium silicate, and which contains iron oxide and small amounts of lime and other oxides. Forsterite brick are composed of granules which

are mainly primary forsterite, and of groundmass material containing secondary forsterite, periclase, magnesioferrite and a small quantity of other minerals.

Periclase, chrome spinel and forsterite all have extremely high melting temperatures. However, the groundmass material may vary widely in refractoriness. In some magnesite compositions, for example, liquid begins to develop in the groundmass at temperatures little if any above 2300° F. (1260° C.); in others, at temperatures probably approaching 2700° F. (1480° C.). Hence, the softening behavior under heat and the ultimate refractoriness of basic brick are fixed largely by the amount and composition of the groundmass minerals. A basic brick as a whole will be highly refractory either if the groundmass material has a high melting temperature, or if it is small in amount.

In the load test at 25 pounds per square inch, basic brick in general do not deform at high temperatures, but fail abruptly by shearing at temperatures high enough to weaken the bond. The temperature of failure will range from about 2400° to 3100° F. (1315° to 1705° C.), depending upon the kind of brick, the amount and composition of the groundmass material, and the method of manufacture. Both high-fired chrome-magnesite brick and forsterite brick have a high temperature of failure in the load test — ranging from about 2960° to 3060° F. (1630° to 1680° C.).

CHANGES IN DIMENSIONS

Permanent Changes at High Temperatures: In the firing of refractory ware, permanent changes in dimensions occur, altering the individual brick from the mold size to the fired size. It is desirable that these changes be completed in the firing, as far as is industrially possible, in order to prevent excessive expansion or shrinkage later in service. However, the changes in dimensions and in volume require time as well as a suitable temperature for their completion. As firing proceeds, the rate of change in dimensions gradually diminishes to such an extent that it is rarely feasible to attain complete expansion or contraction during the firing process. In service therefore, if the furnace temperature is high enough, and if it is maintained for a sufficient length of time, there will be an additional change in dimensions, generally slight, of a permanent character. Excessive changes of dimensions in service are objectionable, on account of their harmful effects upon the stability of the furnace structure.

Determination of the amount of change in the dimensions of refractory brick which may occur at high temperatures is made by subjecting them to a reheat test. In the Standard A.S.T.M. Method C113 – 46, the brick are placed in a furnace and gradually heated to a predetermined temperature, which is held for five hours. After cooling, measurements are made to determine the change in linear dimensions and volume. In most cases, the test is used for brick made of materials which shrink in firing. Excessive after-shrinkage, in the test, may indicate that during manufacture the brick had not been fired to a high enough temperature, or that the final firing temperature had not been held long enough.

In A.S.T.M. specifications, high duty fireclay brick may show not more than 1.5% linear contraction in the reheat test at 2550° F. (1400° C.), while super-duty fireclay brick may show not more than 1% linear contraction at 2910° F. (1600° C.). No limit is specified as to the amount of permanent expansion.

Some high-alumina brick of the 50% to 80%

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alumina classes may shrink 2.0% to 2.5% in length in the test at 2910° F. (1600° C.); brick of the 90% and 99% alumina classes will shrink 0.5% to 1.5% when tested at 3140° F. (1725° C.).

In the reheat test at 2910° F. (1600° C.), most basic brick show a slight linear shrinkage, varying from a few tenths of a per cent or less for some types of brick, up to 2.5 per cent for others. Chemically bonded chrome-magnesite brick have a slight linear expansion in the test, amounting to less than one per cent. High fired chrome-magnesite brick usually have no shrinkage in the reheat test at 2910° F. (1600° C.) and a shrinkage of only a few tenths of a per cent at 3000° F. (1650° C.).

Most silica brick show a slight permanent expansion when reheated at high temperatures. However, it is not necessary to subject silica brick to the reheat test, as determination of their specific gravity provides an adequate measure of the amount of residual expansion.

Permanent expansion at high temperatures is more difficult to interpret than permanent shrinkage. It may result from any one of the following conditions:

(a) *Incomplete mineral transformations* — Under-burned silica brick, for example, may expand considerably in a high temperature reheat test, as a result of further transformation of quartz to cristobalite and tridymite. Certain high-alumina brick made of calcined diaspore and fireclay show a permanent expansion which is attributed to additional formation of mullite, by reaction of particles of calcined diaspore with silica from the clay.

(b) *Secondary expansion* — Secondary expansion, with increase in porosity, is exhibited by various highly refractory clays. It may be caused by separation of the clay particles along original bedding planes. The amount of secondary expansion may be fairly high when single brick, not confined in any way, are tested; but it is small in amount if the brick when heated are subjected to even light pressure, as in a furnace wall. In many cases this slight expansion is advantageous, for it tightens the joints. It has been shown that secondary expansion can be induced artificially in various fireclay and high-alumina brick mixes by the addition of definite quantities of soluble compounds containing sulphur. Such secondary expansion is believed to be caused by increase in size of bubbles of gas entrapped in glassy material of the brick.[46-3]

(c) *Overfiring* — When certain clays, such as those used for making ladle brick, are heated beyond a critical temperature, they tend to swell and become vesicular. This phenomenon is known as "overfiring".

Thermal Expansion: When refractory brick are heated they expand, and when cooled they contract. If no changes of a permanent nature have occurred during the heating, the brick will return to their original dimensions when cooled. This effect, therefore, is known as the "reversible thermal expansion".

The linear thermal expansions of several types of refractory brick are given in Figures 54 and 55. The expansions of different brands in each type of refractory differ somewhat among themselves, and the curves therefore represent mean values. Magnesite and forsterite brick have relatively high rates of thermal expansion; fireclay brick of the aluminous type and most insulating fire brick have relatively low rates. The thermal expansions of other refractories have intermediate values.

The thermal expansion of most refractories proceeds at a fairly uniform rate over their entire working range of temperature. However, the greater part of the expansion of silica brick takes place below 575° F. (about 300° C.).

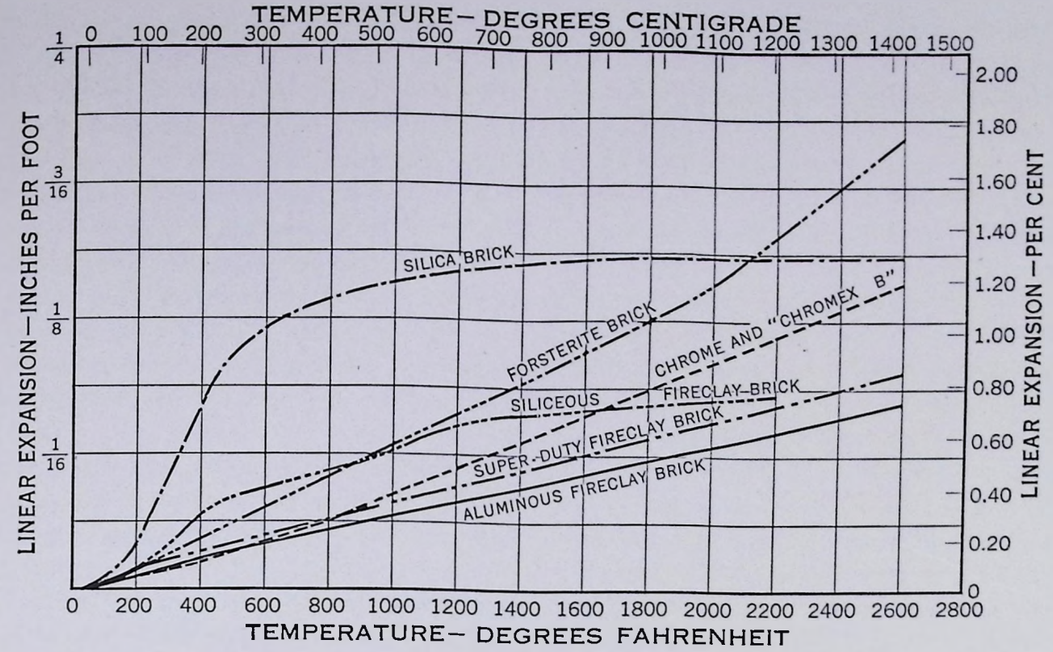


Fig. 54. Approximate Reversible Thermal Expansion of Refractory Brick

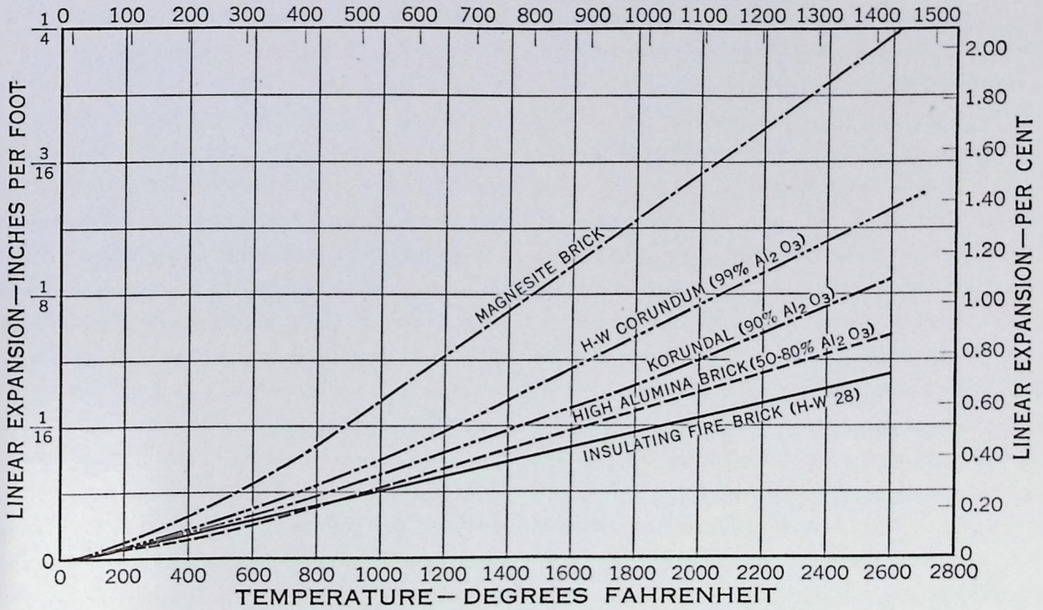


Fig. 55. Approximate Reversible Thermal Expansion of Refractory Brick

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SPALLING

Spalling may be defined as the loss of fragments or spalls from the face of a refractory brick or structure through cracking and rupture, with exposure of inner portions of the original refractory mass. In various types of furnace operation, the service conditions are necessarily such as to expose the brickwork to spalling influences. The resistance of refractory brick to spalling is enhanced by proper design of the shapes, by optimum sizing of the grains, and by close control of each step in manufacture. For a given refractory the amount of spalling which occurs in service can be reduced to a minimum by proper design, construction and operation of the furnaces.

Spalling of refractory brick is of three general types: thermal, mechanical and structural.

Thermal Spalling: This type of spalling is caused by stresses resulting from unequal rates of expansion or contraction in different parts of the brick, and usually is associated with rapid changes in temperature. The brick of greatest resistance to thermal spalling are those having the lowest thermal expansion, the most uniform rate of thermal expansion, and a texture conducive to flexibility and relief of strain.

The spalling characteristics of fireclay brick are largely dependent upon the proportion of free silica in the constituent clays, upon the size and "fit" of the particles, and upon the amount and composition of the glassy bond. The amount and character of the glass is fixed by the quantity and kind of accessory minerals in the clays, and by the hardness of burn. Within the temperature range at which the glass is rigid (from room temperature up to 1800° to 2000° F., or 980° to 1095° C.), a high content of glass is conducive to spalling. However, at temperatures high enough to cause the glassy bond to become somewhat viscous, fireclay brick are not subject to thermal spalling.

Relatively porous high duty fireclay brick of the aluminous type, when light-burned, are usually more resistant initially to thermal spalling than are denser hard-burned brick, and they retain this property in service if subjected to temperatures which are low or merely moderate. However, in service at high temperatures, the hot ends of the light-burned brick change in texture, develop a larger content of glass, and become hard-burned and less resistant to spalling.

Super-duty fireclay brick, while dense and hard-burned, have the greatest resistance to thermal spalling of all the various types of commonly used brick, and they retain this resistance upon exposure to high temperatures.

Some brands of high-alumina brick have excellent resistance to spalling. However, brands customarily used in service where other properties are more important sometimes have these other properties enhanced in manufacture at the expense of spalling resistance.

Silica brick are sensitive to rapid temperature change below a dull red heat, on account of the abrupt volume change accompanying the crystalline inversion of the mineral cristobalite. However, silica brick may be heated very rapidly without thermal spalling after they have reached a temperature of about 1200° F. (650° C.) throughout. They may safely be cooled rapidly from furnace operating temperatures to about 1200° F. (650° C.).

Neither magnesite nor chrome brick have as high resistance to thermal spalling as fireclay and high-alumina brick. Both fired and chemically-bonded chrome-magnesite brick, magnesite brick high in periclase, and metal-encased magnesite brick have higher resistance to spalling than most other basic brick.

Mechanical Spalling: Shattering and spalling of brickwork may result from such influences as the following:

1. Rapid drying of wet brickwork, with development of steam in the pores of the brick.
2. "Pinching" of hot ends of brick.
3. Inadequate provision for thermal expansion.

The brick which are strongest and toughest at operating temperatures have the greatest resistance to mechanical spalling.

"Pinch spalling" is frequently observed in sprung arches. It results from the fact that the hot ends of the brick in arches expand more than the cold ends. This greater expansion may cause a concentration of arch stresses upon relatively small bearing surfaces at the inner ends of the brick. Insulation decreases the temperature drop through a roof arch, and tends to reduce pinch spalling.

Structural Spalling: Changes in the texture or in the mineral composition of the hot end of a brick, through the action of heat, or absorption of slags or fluxes, may result in the formation of zones between the inner and outer ends of the brick which differ in their physical properties. The hot end of the brick may tend to spall or fall off for various reasons, such as the development of shrinkage cracks, differences in thermal expansion between adjacent zones, or increased sensitiveness to thermal shock, due to vitrification or slag absorption.

Panel Spalling Test: This test, which is applicable to fireclay and high-alumina brick, is intended to measure the comparative resistance of the brick to thermal and structural spalling. In the A.S.T.M. Standard Method C38 – 47, the brick to be tested, 14 in number, are laid flat as headers, in such manner as to form a section about 18 inches square, in a movable panel. One side of the panel is backed with insulation, while the other side is exposed, and is subjected to the desired heat treatments. The test consists of the following procedure:

(a) A 24-hour preheat at 2910° F. (1600° C.) for high duty brick, or 3000° F. (1650° C.) for super-duty brick.

(b) A thermal shock treatment, consisting of 12 cycles in which the face of the panel is alternately heated to 2550° F. (1400° C.) and cooled in a specified manner.

Results are reported in terms of the average percentage loss in weight for all the test brick in the panel.

According to the A.S.T.M. Standard Classification for fireclay refractories C27 – 41, super-duty fireclay brick may have a maximum of 4 per cent loss in the panel spalling test.

Experience has shown that certain modifications of super-duty fireclay brick give superior service life under specific operating conditions where high resistance to spalling is not an essential requirement. These modifications may vary from the usual super-duty fireclay brick in grind, in process of manufacture, and in temperature of firing. Frequently, such special-service brick show a higher spalling loss in the panel spalling test than is prescribed by the A.S.T.M. specification.

In A.S.T.M. specifications for heavy duty stationary boilers, the spalling loss of high duty fireclay brick, preheated to 2910° F. (1600° C.), may not be more than 15 per cent for average conditions nor more than 10 per cent for moderately severe spalling conditions.

Data on the comparative spalling resistance of various refractories are given in Table XXV. Since basic refractories are less resistant to thermal shock than fireclay and high-alumina refractories, the terms used in Table XXV to express the relative spalling resistance of the basic group denote a comparison merely within the group, and not with other refractories.

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Table XXV.

COMPARATIVE RESISTANCE OF REFRACTORIES TO SPALLING

Type of Brick	Resistance to Spalling
FIRECLAY	
Super-Duty	Excellent
High Duty, Aluminous	
(a) Spall-resistant	Good
(b) General purpose	Fair
High Duty, Siliceous	Good
SILICA	Excellent above 1200° F. (650° C.) Poor below 1200° F. (650° C.)
HIGH-ALUMINA	Excellent to fair
BASIC (See last paragraph on page 329)	
Chrome, fired	Fair
Chrome-Magnesite, Chemically Bonded	Excellent
Chrome-Magnesite, Fired	Good
Magnesite, Fired	Fair to excellent
Magnesite-Chrome, Chemically Bonded	Excellent
Forsterite	Good

CHEMICAL REACTIONS AFFECTING REFRACTORIES

In many types of furnaces, chemical action is one of the greatest factors contributing to the ultimate destruction of the refractory linings. In service, a refractory material may react with material charged into the furnace, with slags or other products of furnace operation, with fuel ash, with furnace gases, with fumes or dust in the gases, or in some cases with other refractory materials.

In the selection of refractories for service where they will be in contact with molten slags or other fluxing agents, the resistance of the brick to chemical attack is an important consideration. Fireclay, high-alumina or silica brick generally will be used where the corrosive agent is a siliceous slag. Fireclay or high-alumina brick may be preferred if the flux is a slightly basic slag, or is ash from coal or fuel oil. Silica brick are resistant to dusts and fum es containing iron oxide or lime but are not resistant to molten slags which are high in lime or in other basic oxides.

Silica, forsterite, and high-alumina brick containing 50% or more alumina are used in contact with strongly alkaline dusts and fumes at high temperatures. For use in contact with highly basic slags, the brick which give best service generally consist of magnesite, chrome, or a blend of these two materials.

In each case, the selection of the refractories will be governed by the characteristics of the fluxing agent and by the conditions of operation, especially the temperature.

Fluxing Action: The term "slag attack" is used to designate (a) chemical reactions and solutions which corrode the *face* of a refractory lining in service, and (b) reactions which take place *within the brick* between the refractory material and molten slag or other fluxing agents which have been absorbed.

Coal ash of low fusion point and high in basic oxide content is very corrosive, as are the various kinds of ash resulting from the burning of some fuel oils, wood, lumber mill refuse, bagasse and other organic materials. Metallurgical slags, lime added as a flux, glass, the oxides of metals, alkaline earths and portland cement clinker have destructive chemical action upon refractory materials. The intensity of the corrosive action will depend upon such factors as the following:

Temperature of the furnace.
Furnace atmosphere.
Chemical composition of the refractory.
Porosity and pore structure of the refractory.
Temperature gradient through the brick, which governs the depth to which a molten flux will penetrate.
Chemical composition and melting temperature of the fluxing agent.
Fluidity of the fluxing agent.
Rate at which the fluxing agent is supplied.
Surface tension between the flux and the refractory; that is, the tendency of the flux to "wet" the refractory.
Fluidity of the reaction product.
Rate at which the reaction product flows away from the face of the refractory, or is removed in other ways.
Agitation or turbulence of molten fluxing agent flowing down the face of the furnace wall. (The turbulence is usually caused by gases moving at high velocity.)
Turbulence of a slag floating upon a molten bath, as in a copper converter.
Convection currents, as in a molten bath such as glass.

The temperature at which brick and slagging agents react is often the principal factor governing the maximum allowable furnace temperature. In some cases, a temperature rise of a relatively few degrees above the point of safe operation will cause destruction of a lining in a short time. Therefore, a change in furnace practice which raises the operating temperature even slightly may necessitate a change in the type of refractory required.

A furnace slag or product of high viscosity may freeze and adhere to the lining, forming a coating. Under some conditions of operation, as in rotary cement kilns, this coating acts as a protective layer, shielding the brickwork from chemical attack and from abrasion. Another example of such protection is afforded by the magnetite coating on copper converter linings. It is important that the operating conditions be so regulated as to retain the coating, while avoiding excessive build-up which would restrict the areas of furnace openings. Coatings which gradually increase in thickness usually must be removed periodically. When this is done the brick are subjected to mechanical damage by the tools used, and not infrequently portions of the brickwork are broken away with the coating.

A slag or fuel ash of low viscosity will tend to flow down the wall, leaving only a thin coating. The extent to which it will attack the brick chemically will depend upon the compositions of both slag and brick. The lining may gradually become thinner as brick material is dissolved by the slag and washed away, and as undissolved particles become loosened and are likewise washed away. The depth of slag penetration depends upon various factors, of which the permeability of the brick and the temperature drop through the refractory wall are among the most important. As a slag penetrates into successively cooler portions of the wall, it becomes increasingly viscous until a temperature is reached at which it is too viscous to penetrate farther. Absorption of slags and fluxes may result in the formation of zones of different composition and texture within the same brick. When this occurs, the end of the brick which

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has become impregnated with slag may develop a glassy texture and become very sensitive to the spalling effects of thermal shock.

Dust and fume in furnace gases may have a strongly corrosive action upon refractories. This is illustrated by the effect of the alkaline dust and volatilized alkalies upon the ports, downtakes and checkers of glass tanks. In some cases, alkaline vapors cause a surface glazing of fireclay brick linings.

Because of the many variables involved in the corrosion of refractories, it has not been found possible to adopt as standard a single slag test of general utility.

Effect of Gases: Furnace gases probably have more effect upon the properties of refractory materials than is generally realized. Refractories containing ferrous compounds may be affected by oxidizing furnace atmospheres, while those containing ferric compounds are affected by reducing conditions. Exposure of a brick to alternate oxidizing and reducing conditions in many cases will affect the ceramic bond and cause the brick to become weak and friable.

It has been known for many years that furnace linings built of some types of refractories are damaged by carbon monoxide gas. Within a critical temperature range, and in the presence of certain catalysts, such as iron oxide particles occurring within the refractory, the carbon monoxide will decompose into carbon dioxide and carbon. This reaction takes place most rapidly at 700° to 1000° F., or 370° to 540° C. When the reaction occurs within the body of a brick, the continued deposition of carbon may weaken the bond, and cause the brick to disintegrate. Partially cracked natural gas has an effect similar to that of carbon monoxide. Fireclay and high-alumina brick which have been fired to Cone 18 or higher are practically immune to disintegration by carbon monoxide.

The bond in many kinds of brick is weakened by exposure at furnace temperatures to chlorine, hydrochloric acid gas, sulphur dioxide, sulphur trioxide, volatile oxides of metals, and by carbon monoxide even above the temperature at which it causes a carbon deposit. The strength of hard-burned high-alumina brick appears to be affected relatively little by most of these gases below 1740° F. (or 950° C.).

Chemical Reactions Between Refractories: Refractory materials of dissimilar chemical compositions, if in contact at high temperatures, may react chemically with each other. It is good practice to separate two such dissimilar refractories by a course of brick of such composition that it will not react to a damaging extent with either.

The results of laboratory investigations to determine the temperatures of reaction between refractories are given in Table XXVI. Tests were made at 2550°, 2730°, 2910°, 3000° and 3100° F. (1400°, 1500°, 1600°, 1650° and 1705° C.) in a gas-fired furnace. In each case the maximum temperature was held for five hours.

The figures given cannot be expected to apply precisely under service conditions because with longer periods of heating, or in the presence of slags, fumes or reducing gases, the temperatures of reaction are probably somewhat lower. Moreover, two refractories which reacted slightly or not at all at a given temperature in the short-time laboratory tests might react to a damaging extent at the same temperature after longer periods of time in service.

The reaction between magnesite brick and high duty fireclay brick, in the tests made at approximately 2730° F. (1500° C.), was accompanied by the formation of a thin, liquid slag. The reaction between magnesite and silica brick was much less severe, but became damaging at about 2910° F. (1600° C.).

Table XXVI.

REACTION TEMPERATURES BETWEEN DIFFERENT REFRACTORIES

Types of Refractory Brick in Contact With Each Other		Reaction First Observed °F.	Reaction Became Damaging °F.	Reaction at 3000° F.	Reaction at 3100° F.
Chrome, Fired	Fireclay, High Duty Aluminous	2910	—	Slight	—
Chrome, Fired	Forsterite	2910	3000	Damaging	—
Chrome, Fired	High-Alumina				
	70% Alumina Class	2910	2910	Damaging	—
	90% Alumina Class	3000	—	Slight	Slight
Chrome, Fired	Magnesite, Fired	3100	—	None	Slight
Chrome, Fired	Silica	3000	—	Slight	—
Chrome-Magnesite					
Chemically Bonded	Fireclay, High Duty Aluminous	2910	—	Slight	—
Chemically Bonded	Forsterite	3100	—	None	Slight
Chemically Bonded	High-Alumina				
	70% Alumina Class	2910	3100	Slight	Damaging
	90% Alumina Class	3000	—	Slight	Slight
Chemically Bonded	Silica	2910	—	Slight	—
Chrome-Magnesite					
Fired	Fireclay, High Duty Aluminous	2910	—	Slight	—
Fired	Forsterite	—	—	None	None
Fired	High-Alumina				
	70% Alumina Class	2910	3100	Slight	Damaging
	90% Alumina Class	3000	—	Slight	Slight
Fired	Silica	2910	—	Slight	—
Fireclay, High Duty					
Aluminous	Chrome, Fired	2910	—	Slight	—
Aluminous	Chrome-Magnesite	2910	—	Slight	—
Aluminous	Forsterite	2730	2910	Damaging	—
Aluminous	High-Alumina				
	70% Alumina Class	—	—	None	—
Aluminous	Magnesite, Fired	2550	2730	Damaging	—
Aluminous	Silica	2730	2910	Damaging	—
Forsterite	Chrome, Fired	2910	3000	Damaging	—
Forsterite	Chrome-Magnesite				
	Chemically Bonded	3100	—	None	Slight
	Fired	—	—	None	None
Forsterite	Fireclay				
	High Duty, Aluminous	2730	2910	Damaging	—
Forsterite	High-Alumina				
	70% Alumina Class	3000	3100	Slight	Damaging
	90% Alumina Class	3000	3100	Slight	Damaging
Forsterite	Magnesite, Fired	3100	3100	None	Damaging
Forsterite	Magnesite-Chrome				
	Chemically Bonded	3100	—	None	Slight
Forsterite	Silica	3000	—	Slight	—

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Table XXVI. — Continued

REACTION TEMPERATURES BETWEEN DIFFERENT REFRACTORIES

Types of Refractory Brick in Contact With Each Other		Reaction First Observed °F.	Reaction Became Damaging °F.	Reaction at 3000° F.	Reaction at 3100° F.
High-Alumina					
70% Alumina Class	Chrome, Fired	2910	2910	Damaging	—
70% Alumina Class	Chrome-Magnesite	2910	3100	Slight	Damaging
70% Alumina Class	Fireclay				
	High Duty, Aluminous	—	—	None	—
70% Alumina Class	Forsterite	3000	3100	Slight	Damaging
70% Alumina Class	Magnesite, Fired	2730	3100	Slight	Damaging
70% Alumina Class	Magnesite-Chrome				
	Chemically Bonded	2910	3100	Slight	Damaging
70% Alumina Class	Silica	2910	—	Slight	—
90% Alumina Class	Chrome, Fired	3000	—	Slight	Slight
90% Alumina Class	Chrome-Magnesite	3000	—	Slight	Slight
90% Alumina Class	Forsterite	3000	3100	Slight	Damaging
90% Alumina Class	Magnesite, Fired	2910	3000	Damaging	Damaging
90% Alumina Class	Magnesite-Chrome	2910	—	Slight	Slight
90% Alumina Class	Silica	3000	—	Slight	—
Magnesite, Fired	Chrome, Fired	3100	—	None	Slight
Magnesite, Fired	Fireclay, High Duty,				
	Aluminous	2550	2730	Damaging	—
Magnesite, Fired	Forsterite	3100	3100	None	Damaging
Magnesite, Fired	High-Alumina				
	70% Alumina Class	2730	3100	Slight	Damaging
	90% Alumina Class	2910	3000	Damaging	Slight
Magnesite, Fired	Silica	2730	2910	Damaging	—
Magnesite-Chrome					
Chemically Bonded	Forsterite	3100	—	None	Slight
Chemically Bonded	High-Alumina				
	70% Alumina Class	2910	3100	Slight	Damaging
	90% Alumina Class	2910	—	Slight	Slight
Chemically Bonded	Silica	2910	3000	Damaging	—
Silica	Chrome, Fired	3000	—	Slight	—
Silica	Chrome-Magnesite	2910	—	Slight	—
Silica	Fireclay, High Duty				
	Aluminous	2730	2910	Damaging	—
Silica	Forsterite	3000	—	Slight	—
Silica	High-Alumina				
	70% Alumina Class	2910	—	Slight	—
	90% Alumina Class	3000	—	Slight	—
Silica	Magnesite, Fired	2730	2910	Damaging	—
Silica	Magnesite-Chrome	2910	3000	Damaging	—

PERMEABILITY

For various service conditions, the extent to which refractory brick can be penetrated by fluids has an important bearing upon their utility. An impermeable brick could be attacked by liquid fluxes only at exposed faces; however, when a flux can penetrate into the pores of a brick, the area exposed to chemical attack is multiplied many times. Such an effect as the deposition of carbon through decomposition of carbon monoxide gas within the pores depends upon the ability of the gas to penetrate the brick.

While permeability of a refractory is related to its porosity, the relationship is not direct. The rate of flow of a fluid into or through a refractory body is influenced by the number and size of the open pores, the extent to which they are interconnected, and the orientation and diameters of the connecting channels. The temperature also is important, because of its effect upon the viscosity of the penetrating fluids. The viscosity of liquid slags and fluxes decreases with rising temperatures, and their ability to penetrate a refractory therefore increases. However, as shown by Clews and Green,[32-1,33-1] the rate of flow of air through refractory brick decreases as the temperature rises, being about 0.4 times as great at 1560° F. (850° C.) as at 50° F. (10° C.). It was shown that the decrease in permeability is caused by increase in the viscosity of the air with rising temperature.

D. O. McCreight[47-1] has reported the results of an investigation made to determine the relative permeabilities of full-sized 9-inch straight brick to air at room temperature under a definite applied pressure. The results showed that there are wide differences in permeability between different types of refractories, and even between different brands of the same type. Insulating fire brick had the greatest permeability, as well as the widest range of permeability. The permeability of standard iron blast furnace brick was found to be extremely low.

ELECTRICAL RESISTIVITY

Relatively few publications have reported the results of studies of the electrical resistivity of refractories. The results reported by various observers for any particular type of refractory material show wide variations, due probably in part to differences in the materials which were studied, and in part to differences in test methods used.

In Figure 56, page 337, the approximate electrical resistivities of several refractory materials are given. The figures from which the chart was prepared were taken from papers which have appeared in the technical press of the United States and Europe over a period of years. In the chart, the resistivities are shown as bands rather than as lines, in order to include the results obtained by various investigators.

For all the refractories included in the chart, the electrical resistivities are very high at low temperatures, but drop rapidly as the temperature rises. At 800° C., pure magnesia has a resistivity of more than 100 million ohms per centimeter cube; at 1500° C. its resistivity is only a little above 10,000 ohms. The resistivity of most commercial magnesite brick is considerably lower than these figures. At 1500° C., the electrical resistivity of commercial silica brick, as determined by most investigators, lies between 2000 and 8000 ohms per centimeter cube; that of fireclay brick, between 300 and 1050 ohms; and that of chrome brick, between 18 and 250 ohms.

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Table XXVII.

SPECIFIC HEATS OF REFRACTORY BRICK AND MINERALS

Mean Specific Heats between 32° F. and t° F.

t° F.	Fireclay Brick	Silica Brick	Magnesite Brick	Chrome Brick	t° F.	Mullite $3Al_2O_3 2SiO_2$	Cristobalite SiO_2	Periclase MgO	Corundum Al_2O_3
32	0.193	0.169	0.208	0.170	32	0.184	0.165	0.208	0.171
200	0.199	0.188	0.219	0.176	200	0.192	0.183	0.227	0.196
400	0.206	0.211	0.232	0.182	400	0.214	0.204	0.240	0.214
600	0.212	0.229	0.242	0.188	600	0.223	0.239	0.251	0.226
800	0.220	0.238	0.251	0.194	800	0.229	0.251	0.257	0.235
1000	0.227	0.246	0.258	0.199	1000	0.233	0.258	0.262	0.242
1200	0.234	0.252	0.263	0.204	1200	0.237	0.264	0.267	0.248
1400	0.241	0.256	0.268	0.208	1400	0.240	0.268	0.270	0.252
1600	0.248	0.260	0.273	0.212	1600	0.242	0.271	0.274	0.257
1800	0.253	0.264	0.278	0.216	1800	0.245	0.273	0.277	0.260
2000	0.258	0.268	0.283	0.220	2000	0.247	0.275	0.280	0.264
2200	0.262	0.272	0.288	0.222	2200	0.249	0.277	0.282	0.267
2400	0.266	0.276	0.293	0.224	2400	0.251	0.278	0.285	0.270
2600	0.269	0.279	0.297	0.226	2600	0.253	0.279	0.288	0.273
					2800	0.255	0.280	0.290	0.276
					3000	0.256	0.281	0.292	0.279
					3200	0.258		0.294	0.282

The data on the specific heats of refractory brick are based upon the work of various observers, whose results do not agree with exactness.

The specific heats of minerals were calculated from data given in Paper 1058 of the Geophysical Laboratory, Carnegie Institution of Washington, "Heat Capacity; Heat of Fusion", by Roy W. Goronson, 1942.

SPECIFIC HEAT AND HEAT CAPACITY

Table XXVII gives the specific heats of certain refractory brick and refractory minerals. The heat content of a brick at any temperature is a function of its specific heat and of its weight. It may be calculated from the following formula:

$$H = SW (T - 32)$$

H = The heat content of brick above 32° F.
S = The mean specific heat of a brick between 32° F. and its mean temperature.
W = Weight of brick in pounds.
T = Mean temperature of brick in degrees F.

HEAT TRANSFER

Thermal Conductivity: The amount of heat flowing through a wall can be calculated only approximately, for the following reasons:

(1) The conductivity values upon which the computations are based, have not yet been determined with a high degree of precision.

(2) The temperatures of the inner and outer wall surfaces are rarely known with exactness.

(3) The conductivity of a refractory is altered by absorption of slag or other materials, by glazing or vitrification of the hot surface, and by shrinkage or expansion.

(4) The thickness of a furnace lining may not remain constant during operation, as the lining may become thinner because of wear, or thicker because of the formation of a coating.

(5) The rate of heat flow is influenced by the pressure of the furnace gases, and by the

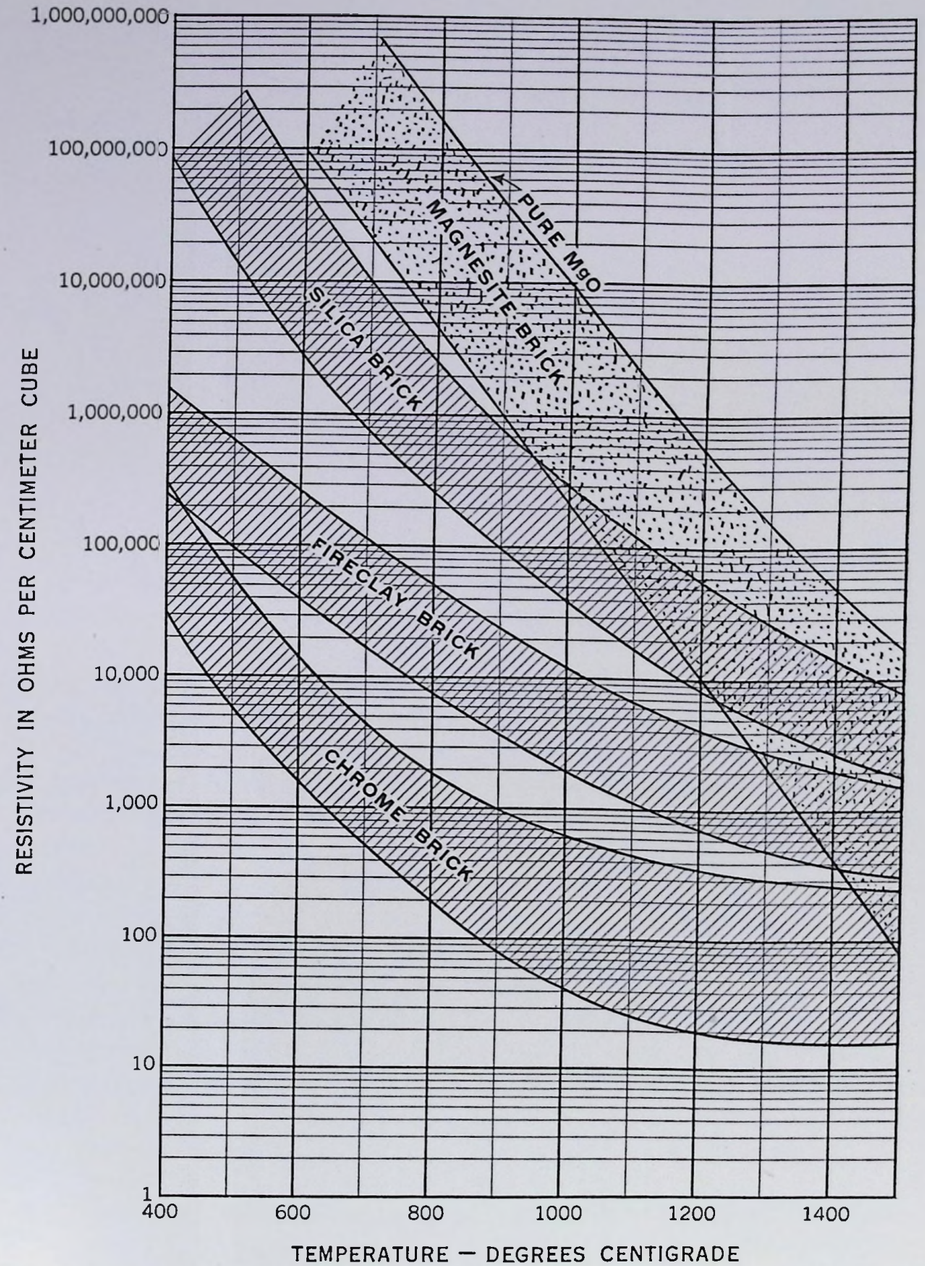


Fig. 56. Approximate Electrical Resistivity of Refractory Brick

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Table XXVIII.

APPROXIMATE THERMAL DATA FOR WALLS 13½ INCHES THICK WITH HOT-FACE TEMPERATURE OF 2600° F.

Kind of Brick	Cold-Face Temperature	Heat Flow per Square Foot of Wall per Hour
Fireclay	460° F.	1500 B.t.u.
70% Alumina	480° F.	1640 B.t.u.
Forsterite	500° F.	1700 B.t.u.
Silica	515° F.	1830 B.t.u.
Chrome	535° F.	1980 B.t.u.
90% Alumina	550° F.	2150 B.t.u.
Magnesite	665° F.	3280 B.t.u.

permeability of the brick. A positive pressure tends to force hot gases out through the walls, and a negative pressure to draw cold outside air into the furnace.

(6) The rate of heat flow is influenced by the thickness of the joints and by the character of the bonding mortar.

High thermal conductivity is desirable for refractories used in constructions involving the transfer of heat through brickwork, as in retorts, muffles, by-product coke oven walls, and recuperators. In most types of furnaces, however, low thermal conductivity is desirable for heat conservation, but is usually less important than other properties of the refractories.

J. B. Austin[39-1] has made a thorough study of the factors which affect the thermal conductivity of refractory materials. The main factors are the temperature, the porosity of the refractory, its chemical and mineral composition, and the amount of amorphous material (glass or liquid) which it contains.

For any particular type of refractory, the proportion of pore-space and the size of the pores of a brick are unquestionably the most important factors affecting the amount of heat which will flow through it at a given temperature, since the conductivity of the air in the pores is much lower than that of the solid material forming the body of the brick.

The conductivity of most refractory materials increases with rising temperatures; that of magnesite, forsterite and some high-alumina refractories decreases as the temperature rises.

At atmospheric temperatures, the thermal conductivity of a glass is lower than that of crystalline material of the same composition. With rising temperatures, the conductivity of glasses tends to increase, while that of crystalline material tends to decrease. However, in refractory bodies consisting of crystal aggregates with a limited amount of glass, this effect is usually obscured by other factors. In service at high temperatures, increase in the amount of glass or liquid in a refractory may possibly cause some decrease in its conductivity, while devitrification of the glass would theoretically cause an increase.

Hard-burned brick usually have somewhat higher thermal conductivity than light-burned brick of the same type. Burned chrome-magnesite brick initially have higher conductivity than chemically bonded brick of approximately the same chemical compositions. However, in service at high temperatures, the conductivity of the chemically bonded brick increases gradually, and at the hot end ultimately becomes about the same as that of burned brick.

Other factors which affect the amount of heat flowing through refractory constructions include the texture of the surface of the refractory, the position of the refractory construction (whether horizontal or vertical), and the effects of external air currents.

Table XXIX.

APPROXIMATE THERMAL CONDUCTIVITY OF REFRACTORY BRICK

Conductivity at t° F.

B.t.u. per Hour, / Square Foot, / Degree F. Temperature Difference, for One Inch Thickness.

Temperature t° F.	0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
Chrome	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
Fireclay *	6.4	6.8	7.2	7.6	8.0	8.4	8.8	9.2	9.6	10.0	10.4	10.8	11.2	11.6	12.0
Forsterite	14.2	13.5	12.8	12.3	11.8	11.4	11.0	10.7	10.5	10.4	10.3	10.3	10.4	10.6	10.8
70% Alumina (Alusite)	12.8	12.3	11.9	11.6	11.2	10.9	10.7	10.4	10.3	10.1	10.0	9.9	9.9	9.9	10.0
90% Alumina (H-W Korundal)	22.4	20.4	18.7	17.3	16.1	15.2	14.3	13.9	13.5	13.3	13.2	13.2	13.3	13.5	13.8
Magnesite (Fired)	39.6	36.4	33.5	30.7	28.4	26.3	24.5	23.1	21.9	21.0	20.4	20.1	20.0	20.2	20.5
Silica (Star)	6.0	6.8	7.5	8.3	9.0	9.8	10.5	11.3	12.0	12.8	13.5	14.3	15.0	15.8	16.5

** The conductivities given for fireclay brick are mean values for brick weighing 130 pounds per cubic foot. The conductivities of fireclay brick of other densities will differ from the values given, approximately in proportion to their weights per cubic foot.*

Table XXX.

APPROXIMATE MEAN THERMAL CONDUCTIVITY OF FORSTERITE, ALUSITE, H-W KORUNDAL, AND MAGNESITE BRICK

Mean Thermal Conductivity between 0° F. and t° F.

B.t.u. per Hour, / Square Foot, / Degree F. Temperature Difference, for One Inch Thickness.

Temperature t° F.	0	200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
Forsterite	14.2	13.8	13.5	13.2	12.9	12.6	12.4	12.2	12.0	11.8	11.7	11.5	11.4	11.4	11.3
70% Alumina (Alusite)	12.8	12.6	12.4	12.1	12.0	11.8	11.6	11.5	11.3	11.2	11.1	11.0	10.9	10.8	10.7
90% Alumina (H-W Korundal)	22.4	21.4	20.5	19.7	18.9	18.3	17.6	17.2	16.7	16.4	16.1	15.8	15.6	15.4	15.3
Magnesite (Fired)	39.6	38.0	36.4	34.9	33.6	32.3	31.2	30.1	29.1	28.3	27.5	26.8	26.3	25.8	25.4

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HEAT FLOW CALCULATIONS

Subject to the limitations mentioned on pages 336 and 338, the amount of heat flowing through a wall can be calculated with sufficient accuracy for most engineering purposes.

SYMBOLS

Q = The quantity of heat flowing through a wall.
T_1 = Temperature of cold face of wall, degrees F.
T_2 = Temperature of hot face of wall, degrees F.
K = Thermal conductivity in B.t.u. per hour, / square foot of area, / degree F. temperature difference, for 1 inch thickness.
K_1 = Thermal conductivity at the cold-face temperature T_1.
K_2 = Thermal conductivity at the hot-face temperature T_2.
$K_{0\text{-}1}$ = Mean thermal conductivity between 0° F. and T_1.
$K_{0\text{-}2}$ = Mean thermal conductivity between 0° F. and T_2.
$K_{1\text{-}2}$ = Mean thermal conductivity between T_1 and T_2.
A = Area in square feet.
t = Time in hours.
d = Thickness of wall in inches.

FORMULAS

Determination of $K_{1\text{-}2}$, the mean thermal conductivity between T_1 and T_2:

Case 1. The conductivity is represented by a straight line. (See Figure 57.)

(Formula 1): $K_{1\text{-}2} = \frac{K_1 + K_2}{2} = K \text{ at mean temperature } \frac{T_1 + T_2}{2}$

Case 2. The conductivity is represented by a curved line. (See Figure 57.)

(Formula 2): $K_{1\text{-}2} = (K_{0\text{-}2}\, T_2 - K_{0\text{-}1}\, T_1)\left(\frac{1}{T_2 - T_1}\right)$

For Formula 1, use values shown in Table XXIX; for Formula 2, use those in Table XXX.

Determination of Q, the amount of heat flowing through a wall:

(Formula 3): $Q = K_{1\text{-}2}\,(T_2 - T_1)\frac{At}{d}$

EXAMPLES

In the following examples, it is assumed that the brick are placed in the walls of furnaces surrounded by still air at 70° F., that the furnace temperature is constant, and that there is no difference between the pressure of the gas within the furnaces and that of the air outside.

Example A: *How much heat per square foot per hour will flow through a fireclay brick wall 13½ inches thick, with a hot-face temperature of 2600° F. and a cold-face temperature of 460° F.?*

Mean temperature between the hot and cold face $= \frac{T_1 + T_2}{2} = \frac{460 + 2600}{2} = 1530°$ F.

From Formula 1, the mean conductivity ($K_{1\text{-}2}$) between T_1 (460° F.) and T_2 (2000° F.) is the conductivity K at the mean temperature of 1530° F.

K of fireclay brick at 1400° F. = 9.2 (From Table XXIX.)
K of fireclay brick at 1600° F. = 9.6 (From Table XXIX.)
By interpolation, $K_{1\text{-}2}$ at 1530° F. is 9.46.

From Formula 3, $Q = K_{1\text{-}2}\,(T_2 - T_1)\frac{At}{d} = 9.46\ (2600 - 460)\left(\frac{1 \times 1}{13\frac{1}{2}}\right) = 1500$ B.t.u. per square foot per hour. (See Footnote to Table XXIX.)

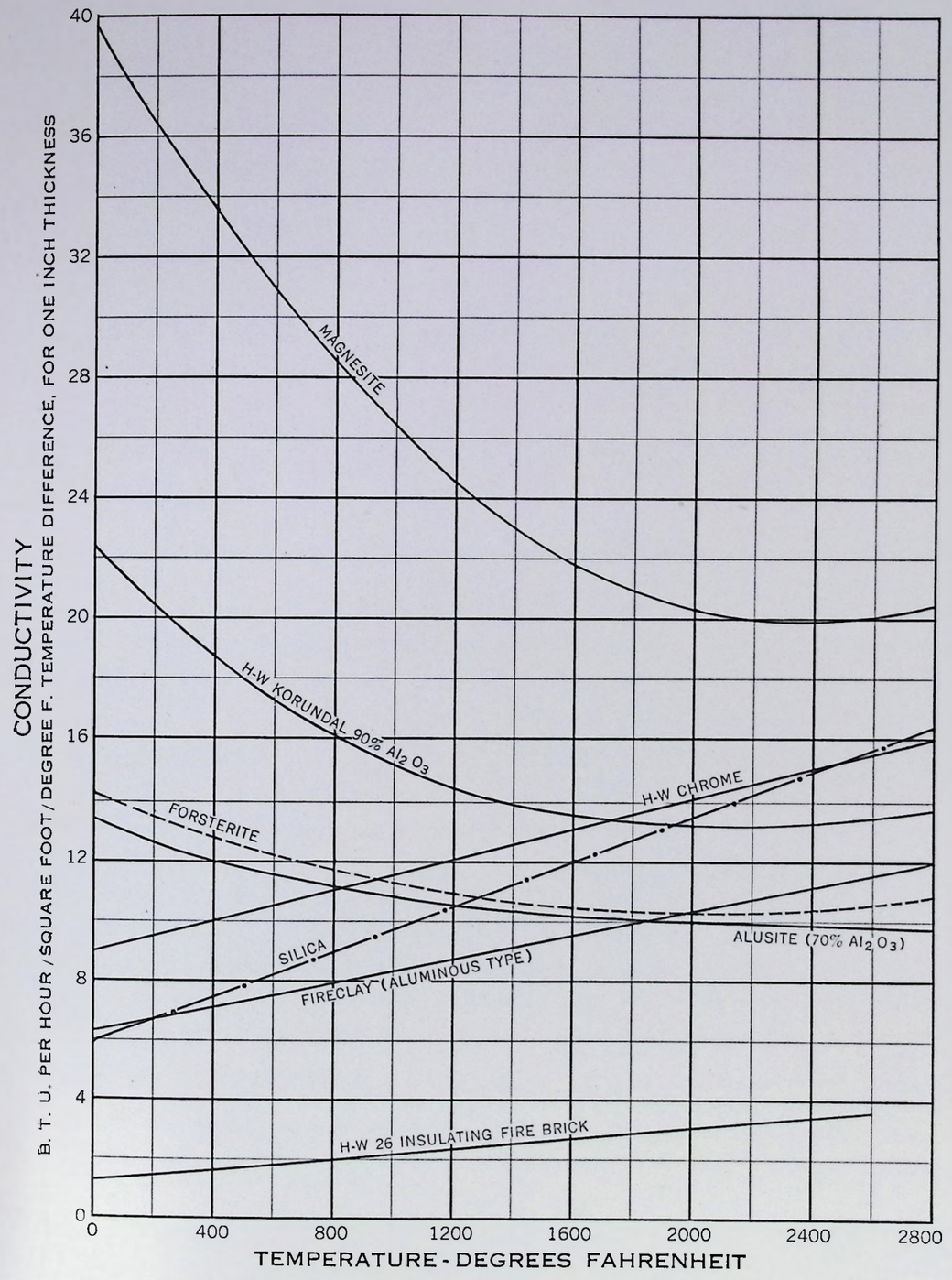


Fig. 57. Approximate Thermal Conductivity of Refractory Brick at Temperatures Shown

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Example B: *How much heat per square foot per hour will flow through a forsterite brick wall 13½ inches thick, with a hot-face temperature of 2600° F. and a cold-face temperature of 500° F.?*

Reference to Figure 57 will show that the conductivity of forsterite brick is represented by a curved line. Consequently Formula 2 must be used in estimating the heat flow, and the mean conductivities will be obtained from Table XXX.

$K_{0\text{-}1}$, the mean thermal conductivity between 0° F. and 500° F. = 13.35 (From Table XXX.)

$K_{0\text{-}2}$, the mean thermal conductivity between 0° F. and 2600° F. = 11.4 (From Table XXX.)

From Formula 2,

$K_{1\text{-}2}$, the mean thermal conductivity between 500° F. and 2600° F. $= (K_{0\text{-}2}\,T_2 - K_{0\text{-}1}\,T_1)\left(\frac{1}{T_2 - T_1}\right)$

$= (11.4 \times 2600) - (13.35 \times 500) \times \left(\frac{1}{2600 - 500}\right) = \frac{29640 - 6675}{2100} = 10.94$

From Formula 3, $Q = K_{1\text{-}2}\,(T_2 - T_1)\,\frac{At}{d} = 10.94 \times 2100 \times \left(\frac{1 \times 1}{13.5}\right) = 1700$ B.t.u.

In many heat transfer problems, the hot-face temperature is known approximately, but both the cold-face temperature and the amount of heat transmitted must be estimated. Such problems usually are solved by a trial-and-error method based upon the assumption that the furnaces are surrounded by still air, and that consequently all of the heat which flows through a wall is lost from the outside surface by radiation and convection. The method may be illustrated by the following example:

Example C: *Estimate the cold-face temperature (T_1) and the rate of heat flow (Q) for a silica brick wall 13½ inches thick, having a hot-face temperature (T_2) of 2600° F.*

First Trial: Assume the cold-face temperature (T_1) = 400° F.

Mean temperature of wall $= \frac{400 + 2600}{2} = 1500°$ F.

From Table XXIX, the conductivity of silica brick at 1500° F. is 11.65

$T_2 - T_1 = 2600 - 400 = 2200$

From Formula 3, page 340, the amount of heat flowing through the wall (Q) $= \frac{11.65 \times 2200}{13.5} =$ 1900 B.t.u. per square foot per hour. This is assumed to be also the amount of heat lost from the wall by radiation and convection.

From the heat transmission chart, page 343, it is seen that for a loss of 1900 B.t.u. per square foot per hour, the cold-face temperature of the wall is 522° F. This temperature may be rounded off to the nearest 5°; that is, to 520° F.

Obviously, the assumed temperature of 400° F. cannot be correct, and another assumption must be made.

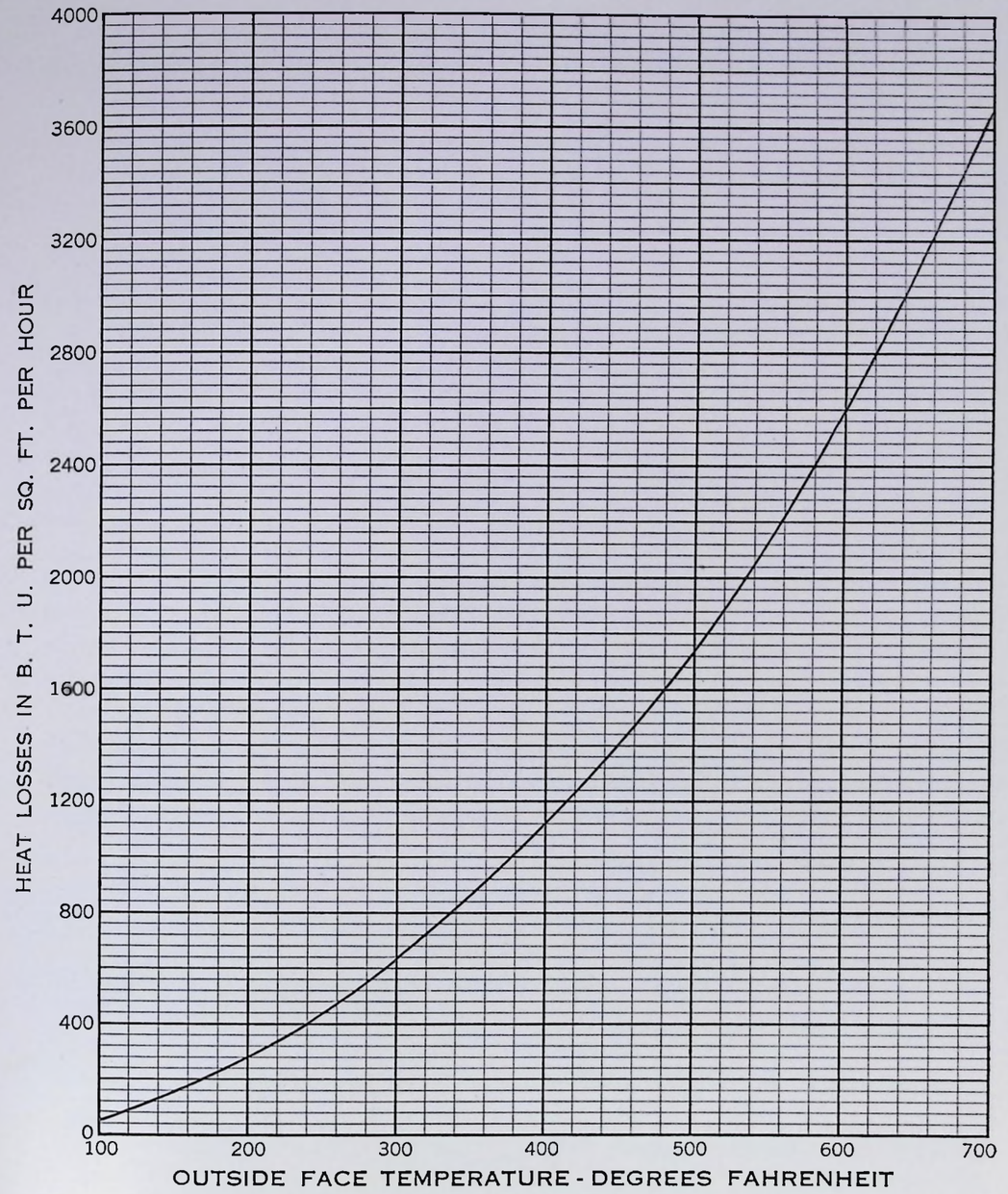


Fig. 58. Heat Transmission from Vertical Walls. Atmosphere = 70 Degrees Fahrenheit

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Second Trial: Assume T_1 = 520° F. (from First Trial).

(In this method, the cold-face temperature (T_1) as determined by the calculations of one trial, is always the assumed cold-face temperature for the next trial.)

Mean temperature of wall = $\frac{520 + 2600}{2}$ = 1560° F.

From Table XXIX, the conductivity of silica brick at 1560° F. = 11.86

$T_2 - T_1 = 2600 - 520 = 2080°$

$Q = \frac{11.86 \times 2080}{13.5}$ = 1825 B.t.u. per square foot per hour

From the heat transmission chart, a heat loss of 1825 B.t.u. per square foot per hour corresponds to a cold-face temperature of 510° F.

Since 510° F. is within 10° of the assumed temperature, no further trials need be made.

Conclusion:

Heat loss (Q) = 1825 B.t.u. per square foot per hour.
Cold-face temperature (T_1) = 510° F.

Walls built of two or more kinds of brick are common in furnace construction. The standard procedure for estimating heat flow, interface temperatures and cold-face temperature of a composite wall, when the hot-face temperature is known, is described in the Manual of A.S.T.M. Standards for Refractory Materials.[48-1] The method illustrated in the following example represents a departure in detail but not in principle from the standard procedure. It consists in (1) estimating the "equivalent thickness" of the wall in terms of one of the components and (2) estimating the heat flow for this thickness by the trial-and-error method of Example C.

Example D: *A furnace wall consists of 9" fireclay brick and 4½" of H-W 23 insulating brick, and the hot-face temperature is 2500° F. Estimate the rate of heat flow per square foot per hour (Q), the interface temperature, and the cold-face temperature (T_1).*

First Trial: Assume the cold-face temperature (T_1) = 500° F.

Assume also that the temperature drop from the hot face to the interface between refractory brick and insulating brick is one-fourth of the total temperature drop from hot face to cold face. Therefore,

Interface temperature = $T_2 - \frac{T_2 - T_1}{4} = 2500° - \frac{2500° - 500°}{4} = 2500° - 500° = 2000°$ F.

Mean temperature of fireclay brick component of wall = $\frac{2500° + 2000°}{2}$ = 2250° F.

Mean temperature of H-W 23 component of wall = $\frac{2000° + 500°}{2}$ = 1250° F.

Conductivity of fireclay brick at 2250° F. = 10.9 (Table XXX, page 339)

Conductivity of H-W 23 at 1250° F. = 2.26 (page 135)

Since H-W 23 has lower thermal conductivity than fireclay brick, its insulating value is greater. Its "relative insulating value", as compared with the fireclay brick, is found by dividing the thermal conductivity of fireclay brick by the thermal conductivity of H-W 23. Therefore, the relative insulating value of the H-W 23 = $\frac{10.9}{2.26}$ = 4.82, on a basis of 1 for fireclay brick.

The "equivalent thickness" of the entire wall, in terms of fireclay brick = (9" × 1) + (4.5" × 4.82) = 30.69":

$Q = \frac{K (T_2 - T_1)}{d}$ in B.t.u. per square foot per hour

K = 10.9, the conductivity of fireclay brick at 2000° F., since this is the figure used to obtain the equivalent insulating value of the H-W 23.

$T_2 - T_1 = 2500 - 500 = 2000$

d = "equivalent thickness" of wall = 30.69" as calculated above.

$Q = \frac{10.9 \times 2000}{30.69}$ = 710 B.t.u. per square foot per hour.

From heat transmission chart, page 343, the cold-face temperature corresponding to a heat loss of 710 B.t.u. per hour is 315°.

The cold-face temperature assumed (500° F.) is obviously incorrect, and another assumption must be made.

Second Trial: Assume T (cold-face temperature) = 315° F. (from First Trial).

(In this method, the cold-face temperature (T_1) determined by the calculations of one trial is always the assumed cold-face temperature for the next trial.)

Estimated temperature drop through fireclay brick component of wall = $\frac{9"}{30.69"}$ (2500 − 315) = 640° F.

Revised interface temperature = 2500 − 640 = 1860° F.

Revised mean temperature of fireclay brick component of wall = $\frac{2500 + 1860}{2}$ = 2180° F.

Revised mean temperature of H-W 23 component of wall = $\frac{1860 + 315}{2}$ = 1088° F.

K of fireclay brick at 2180° F = 10.76 (Table XXX, page 339.)

K of H-W 23 at 1088° F. = 2.13 (page 135)

Revised "relative insulating value" of H-W 23 = $\frac{10.76}{2.13}$ = 5.05, as compared with fireclay brick = 1.

Revised equivalent thickness of wall = (9" × 1) − (4.5" × 5.05) = 31.72"

$Q = \frac{10.76 (2500 - 315)}{31.72}$ = 740 B.t.u. per square foot per hour

From heat transmission chart, page 343, cold-face temperature corresponding to heat loss of 740 B.t.u. per hour = 325° F.

Since this is within 10° of the assumed temperature a third trial is unnecessary.

Final estimate of temperature drop through fireclay brick in wall = $\frac{9"}{31.72"}$ (2500° − 325°) = 617° F.

Final estimate of interface temperature = 2500° − 617° F. = 1883° F. (1885° F. to nearest 5°).

Conclusion:

Q = 740 B.t.u. per square foot per hour
T_1 (cold-face temperature) = 325° F.
Interface temperature = 1885° F.

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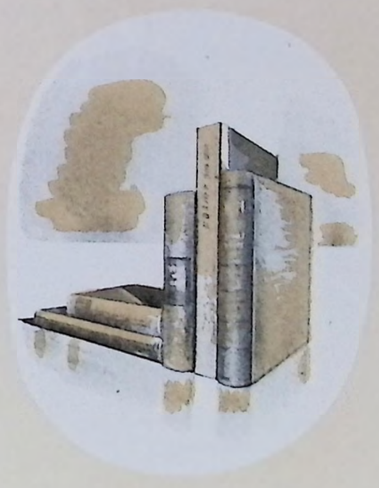
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GENERAL INFORMATION

OF INTEREST IN CONNECTION WITH REFRACTORIES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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TEMPERATURE CONVERSION TABLE

By Albert Sauveur

0 to 100						100 to 1000						1000 to 2000					
C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.
−17.8	**0**	32.0	10.0	**50**	122.0	37.8	**100**	212	260	**500**	932	538	**1000**	1832	816	**1500**	2732
−17.2	**1**	33.8	10.6	**51**	123.8	38	**101**	214	266	**510**	950	543	**1010**	1850	821	**1510**	2750
−16.7	**2**	35.6	11.1	**52**	125.6	39	**102**	216	271	**520**	968	549	**1020**	1868	827	**1520**	2768
−16.1	**3**	37.4	11.7	**53**	127.4	39	**103**	217	277	**530**	986	554	**1030**	1886	832	**1530**	2786
−15.6	**4**	39.2	12.2	**54**	129.2	40	**104**	219	282	**540**	1004	560	**1040**	1904	838	**1540**	2804
−15.0	**5**	41.0	12.8	**55**	131.0	41	**105**	221	288	**550**	1022	566	**1050**	1922	843	**1550**	2822
−14.4	**6**	42.8	13.3	**56**	132.8	41	**106**	223	293	**560**	1040	571	**1060**	1940	849	**1560**	2840
−13.9	**7**	44.6	13.9	**57**	134.6	42	**107**	225	299	**570**	1058	577	**1070**	1958	854	**1570**	2858
−13.3	**8**	46.4	14.4	**58**	136.4	42	**108**	226	304	**580**	1076	582	**1080**	1976	860	**1580**	2876
−12.8	**9**	48.2	15.0	**59**	138.2	43	**109**	228	310	**590**	1094	588	**1090**	1994	866	**1590**	2894
−12.2	**10**	50.0	15.6	**60**	140.0	43	**110**	230	316	**600**	1112	593	**1100**	2012	871	**1600**	2912
−11.7	**11**	51.8	16.1	**61**	141.8	49	**120**	248	321	**610**	1130	599	**1110**	2030	877	**1610**	2930
−11.1	**12**	53.6	16.7	**62**	143.6	54	**130**	266	327	**620**	1148	604	**1120**	2048	882	**1620**	2948
−10.6	**13**	55.4	17.2	**63**	145.4	60	**140**	284	332	**630**	1166	610	**1130**	2066	888	**1630**	2966
−10.0	**14**	57.2	17.8	**64**	147.2	66	**150**	302	338	**640**	1184	616	**1140**	2084	893	**1640**	2984
− 9.44	**15**	59.0	18.3	**65**	149.0	71	**160**	320	343	**650**	1202	621	**1150**	2102	899	**1650**	3002
− 8.89	**16**	60.8	18.9	**66**	150.8	77	**170**	338	349	**660**	1220	627	**1160**	2120	904	**1660**	3020
− 8.33	**17**	62.6	19.4	**67**	152.6	82	**180**	356	354	**670**	1238	632	**1170**	2138	910	**1670**	3038
− 7.78	**18**	64.4	20.0	**68**	154.4	88	**190**	374	360	**680**	1256	638	**1180**	2156	916	**1680**	3056
− 7.22	**19**	66.2	20.6	**69**	156.2	93	**200**	392	366	**690**	1274	643	**1190**	2174	921	**1690**	3074
− 6.67	**20**	68.0	21.1	**70**	158.0	99	**210**	410	371	**700**	1292	649	**1200**	2192	927	**1700**	3092
− 6.11	**21**	69.8	21.7	**71**	159.8	100	**212**	413.6	377	**710**	1310	654	**1210**	2210	932	**1710**	3110
− 5.56	**22**	71.6	22.2	**72**	161.6	104	**220**	428	382	**720**	1328	660	**1220**	2228	938	**1720**	3128
− 5.00	**23**	73.4	22.8	**73**	163.4	110	**230**	446	388	**730**	1346	666	**1230**	2246	943	**1730**	3146
− 4.44	**24**	75.2	23.3	**74**	165.2	116	**240**	464	393	**740**	1364	671	**1240**	2264	949	**1740**	3164
− 3.89	**25**	77.0	23.9	**75**	167.0	121	**250**	482	399	**750**	1382	677	**1250**	2282	954	**1750**	3182
− 3.33	**26**	78.8	24.4	**76**	168.8	127	**260**	500	404	**760**	1400	682	**1260**	2300	960	**1760**	3200
− 2.78	**27**	80.6	25.0	**77**	170.6	132	**270**	518	410	**770**	1418	688	**1270**	2318	966	**1770**	3218
− 2.22	**28**	82.4	25.6	**78**	172.4	138	**280**	536	416	**780**	1436	693	**1280**	2336	971	**1780**	3236
− 1.67	**29**	84.2	26.1	**79**	174.2	143	**290**	554	421	**790**	1454	699	**1290**	2354	977	**1790**	3254
− 1.11	**30**	86.0	26.7	**80**	176.0	149	**300**	572	427	**800**	1472	704	**1300**	2372	982	**1800**	3272
− 0.56	**31**	87.8	27.2	**81**	177.8	154	**310**	590	432	**810**	1490	710	**1310**	2390	988	**1810**	3290
0	**32**	89.6	27.8	**82**	179.6	160	**320**	608	438	**820**	1508	716	**1320**	2408	993	**1820**	3308
0.56	**33**	91.4	28.3	**83**	181.4	166	**330**	626	443	**830**	1526	721	**1330**	2426	999	**1830**	3326
1.11	**34**	93.2	28.9	**84**	183.2	171	**340**	644	449	**840**	1544	727	**1340**	2444	1004	**1840**	3344
1.67	**35**	95.0	29.4	**85**	185.0	177	**350**	662	454	**850**	1562	732	**1350**	2462	1010	**1850**	3362
2.22	**36**	96.8	30.0	**86**	186.8	182	**360**	680	460	**860**	1580	738	**1360**	2480	1016	**1860**	3380
2.78	**37**	98.6	30.6	**87**	188.6	188	**370**	698	466	**870**	1598	743	**1370**	2498	1021	**1870**	3398
3.33	**38**	100.4	31.1	**88**	190.4	193	**380**	716	471	**880**	1616	749	**1380**	2516	1027	**1880**	3416
3.89	**39**	102.2	31.7	**89**	192.2	199	**390**	734	477	**890**	1634	754	**1390**	2534	1032	**1890**	3434
4.44	**40**	104.0	32.2	**90**	194.0	204	**400**	752	482	**900**	1652	760	**1400**	2552	1038	**1900**	3452
5.00	**41**	105.8	32.8	**91**	195.8	210	**410**	770	488	**910**	1670	766	**1410**	2570	1043	**1910**	3470
5.56	**42**	107.6	33.3	**92**	197.6	216	**420**	788	493	**920**	1688	771	**1420**	2588	1049	**1920**	3488
6.11	**43**	109.4	33.9	**93**	199.4	221	**430**	806	499	**930**	1706	777	**1430**	2606	1054	**1930**	3506
6.67	**44**	111.2	34.4	**94**	201.2	227	**440**	824	504	**940**	1724	782	**1440**	2624	1060	**1940**	3524
7.22	**45**	113.0	35.0	**95**	203.0	232	**450**	842	510	**950**	1742	788	**1450**	2642	1066	**1950**	3542
7.78	**46**	114.8	35.6	**96**	204.8	238	**460**	860	516	**960**	1760	793	**1460**	2660	1071	**1960**	3560
8.33	**47**	116.6	36.1	**97**	206.6	243	**470**	878	521	**970**	1778	799	**1470**	2678	1077	**1970**	3578
8.89	**48**	118.4	36.7	**98**	208.4	249	**480**	896	527	**980**	1796	804	**1480**	2696	1082	**1980**	3596
9.44	**49**	120.2	37.2	**99**	210.2	254	**490**	914	532	**990**	1814	810	**1490**	2714	1088	**1990**	3614

NOTE: The numbers in bold face type refer to the temperature in degrees, either Fahrenheit or Centigrade, which it is desired to convert into the other scale.

EXAMPLE

To convert 410° F., read to left — Equivalent is 210° C.
To convert 410° C., read to right — Equivalent is 770° F.

INTERPOLATION FACTORS

C.	Degrees	F.	C.	Degrees	F.
0.56	**1**	1.8	3.33	**6**	10.8
1.11	**2**	3.6	3.89	**7**	12.6
1.67	**3**	5.4	4.44	**8**	14.4
2.22	**4**	7.2	5.00	**9**	16.2
2.78	**5**	9.0	5.56	**10**	18.0

TEMPERATURE CONVERSION TABLE

By Albert Sauveur

2000 to 2250			2250 to 2500			2500 to 2750			2750 to 3000		
C.		F.	C.		F.	C.		F.	C.		F.
1093	**2000**	3632	1232	**2250**	4082	1371	**2500**	4532	1510	**2750**	4982
1099	**2010**	3650	1238	**2260**	4100	1377	**2510**	4550	1516	**2760**	5000
1104	**2020**	3668	1243	**2270**	4118	1382	**2520**	4568	1521	**2770**	5018
1110	**2030**	3686	1249	**2280**	4136	1388	**2530**	4586	1527	**2780**	5036
1116	**2040**	3704	1254	**2290**	4154	1393	**2540**	4604	1532	**2790**	5054
1121	**2050**	3722	1260	**2300**	4172	1399	**2550**	4622	1538	**2800**	5072
1127	**2060**	3740	1266	**2310**	4190	1404	**2560**	4640	1543	**2810**	5090
1132	**2070**	3758	1271	**2320**	4208	1410	**2570**	4658	1549	**2820**	5108
1138	**2080**	3776	1277	**2330**	4226	1416	**2580**	4676	1554	**2830**	5126
1143	**2090**	3794	1282	**2340**	4244	1421	**2590**	4694	1560	**2840**	5144
1149	**2100**	3812	1288	**2350**	4262	1427	**2600**	4712	1566	**2850**	5162
1154	**2110**	3830	1293	**2360**	4280	1432	**2610**	4730	1571	**2860**	5180
1160	**2120**	3848	1299	**2370**	4298	1438	**2620**	4748	1577	**2870**	5198
1166	**2130**	3866	1304	**2380**	4316	1443	**2630**	4766	1582	**2880**	5216
1171	**2140**	3884	1310	**2390**	4334	1449	**2640**	4784	1588	**2890**	5234
1177	**2150**	3902	1316	**2400**	4352	1454	**2650**	4802	1593	**2900**	5252
1182	**2160**	3920	1321	**2410**	4370	1460	**2660**	4820	1599	**2910**	5270
1188	**2170**	3938	1327	**2420**	4388	1466	**2670**	4838	1604	**2920**	5288
1193	**2180**	3956	1332	**2430**	4406	1471	**2680**	4856	1610	**2930**	5306
1199	**2190**	3974	1338	**2440**	4424	1477	**2690**	4874	1616	**2940**	5324
1204	**2200**	3992	1343	**2450**	4442	1482	**2700**	4892	1621	**2950**	5342
1210	**2210**	4010	1349	**2460**	4460	1488	**2710**	4910	1627	**2960**	5360
1216	**2220**	4028	1354	**2470**	4478	1493	**2720**	4928	1632	**2970**	5378
1221	**2230**	4046	1360	**2480**	4496	1499	**2730**	4946	1638	**2980**	5396
1227	**2240**	4064	1366	**2490**	4514	1504	**2740**	4964	1643	**2990**	5414

TEMPERATURE CONVERSION TABLE

FAHRENHEIT TO CENTIGRADE SCALE

F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.
3000	1649	3200	1760	3400	1871	3600	1982	3800	2093	4000	2204
3010	1654	3210	1766	3410	1877	3610	1988	3810	2099	4050	2232
3020	1660	3220	1771	3420	1882	3620	1993	3820	2104	4100	2260
3030	1666	3230	1777	3430	1888	3630	1999	3830	2110	4150	2288
3040	1671	3240	1782	3440	1893	3640	2004	3840	2116	4200	2316
3050	1677	3250	1788	3450	1899	3650	2010	3850	2121	4250	2343
3060	1682	3260	1793	3460	1904	3660	2016	3860	2127	4300	2371
3070	1688	3270	1799	3470	1910	3670	2021	3870	2132	4350	2399
3080	1693	3280	1804	3480	1916	3680	2027	3880	2138	4400	2427
3090	1699	3290	1810	3490	1921	3690	2032	3890	2143	4450	2454
3100	1704	3300	1816	3500	1927	3700	2038	3900	2149	4500	2482
3110	1710	3310	1821	3510	1932	3710	2043	3910	2154	4550	2510
3120	1716	3320	1827	3520	1938	3720	2049	3920	2160	4600	2538
3130	1721	3330	1832	3530	1943	3730	2054	3930	2166	4650	2566
3140	1727	3340	1838	3540	1949	3740	2060	3940	2171	4700	2593
3150	1732	3350	1843	3550	1954	3750	2066	3950	2177	4750	2621
3160	1738	3360	1849	3560	1960	3760	2071	3960	2182	4800	2649
3170	1743	3370	1854	3570	1966	3770	2077	3970	2188	4850	2677
3180	1749	3380	1860	3580	1971	3780	2082	3980	2193	4900	2704
3190	1754	3390	1866	3590	1977	3790	2088	3990	2199	4950	2732

Degrees Fahrenheit $= 9/5\ C + 32$ *Degrees Centigrade* $= 5/9\ (F - 32)$

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PYROMETRIC CONE EQUIVALENT

Pyrometric Cone Equivalent is defined as "the number of that standard cone whose tip would touch the supporting plaque simultaneously with that of a cone of the material being investigated, when tested in accordance with the Standard Method of Test for Pyrometric Cone Equivalent (P.C.E.) of refractory materials (A.S.T.M. Designation C24) of the American Society for Testing Materials".

When it is desired to interpret P.C.E. values approximately in terms of temperature, the following table may be used. It is based on the work of Fairchild and Peters as published in the Journal of the American Ceramic Society, Volume 9, page 700 (1926). The heating rates were 150° C. per hour for cones 022 to 20 inclusive, and 100° C. per hour for cones 23 to 38 inclusive.

The temperatures associated with the particular cones apply only under standard conditions of heating. At the slower rates of heating common in the firing of refractories and other ceramic ware, the temperature end points are considerably lower than the figures given in the table.

TEMPERATURE END POINTS OF AMERICAN PYROMETRIC CONES

No. of Cone	End point		No. of Cone	End Point	
	Degrees Fahr.	Degrees Cent.		Degrees Fahr.	Degrees Cent.
022	1121	605	10	2381	1305
021	1139	615	11	2417	1325
020	1202	650	12	2435	1335
019	1220	660	13	2462	1350
018	1328	720	14	2552	1400
017	1418	770	15	2615	1435
016	1463	795	16	2669	1465
015	1481	805	17	2687	1475
014	1526	830	18	2714	1490
013	1580	860	19	2768	1520
012	1607	875	20	2786	1530
011	1661	905	23	2876	1580
010	1643	895	26	2903	1595
09	1706	930	27	2921	1605
08	1742	950	28	2939	1615
07	1814	990	29	2984	1640
06	1859	1015	30	3002	1650
05	1904	1040	31	3056	1680
04	1940	1060	32	3092	1700
03	2039	1115	†32½	3137	1725
02	2057	1125	33	3173	1745
01	2093	1145	34	3200	1760
1	2120	1160	35	3245	1785
2	2129	1165	36	3290	1810
3	2138	1170	37	3308	1820
4	2174	1190	38	3335	1835
5	2201	1205	†39	3389	1865
6	2246	1230	†40	3425	1885
7	2282	1250	†41	3578	1970
8	2300	1260	†42	3659	2015
9	2345	1285			

† NOTE: Not included in the tests of Fairchild and Peters. The temperatures given are approximate.

MELTING POINTS OF SELECTED METALS AND ALLOYS*

	Degrees Fahrenheit		Degrees Centigrade
Aluminum	1220.2		660.1
Antimony	1166.9		630.5
Bronze	approx. 1920.	approx.	1050.
Brass	approx. 1725.	approx.	940.
Cobalt	2718.		1492.
Copper (reducing atmosphere)	1981.		1083.
Gold	1945.4		1063.
Iron, pure	2797.		1536.
Cast iron, white	approx. 2100.	approx.	1150.
Cast iron, gray	approx. 2245.	approx.	1230.
Steel, plain carbon (1% carbon and less)	approx. 2680.	approx.	1470.
Iridium	4430.		2443.
Lead	621.1		327.3
Magnesium	1202.		650.
Nickel	2647.		1453.
Palladium	2826.		1552.
Platinum	3216.		1769.
Rhodium	3560.		1960.
Silver	1761.4		960.8
Tin	449.4		231.9
Titanium	3150.		1732.
Tungsten	6115.		3380.
Zinc	787.1		419.5

MELTING POINTS OF SELECTED MINERAL OXIDES*

Corundum	(Al_2O_3)	3720.	2050.
Cristobalite	(SiO_2)	3135.	1724.
Lime	(CaO)	4660.	2570.
Magnetite	(Fe_3O_4)	2903.	1595.
Periclase	(MgO)	5070.	2800.
Rutile	(TiO_2)	3310.	1820.
Zirconia	(ZrO_2)	4890.	2700.

MELTING POINTS OF SELECTED MINERAL COMPOUNDS*

Forsterite	($2MgO \cdot SiO_2$)	3460.	1905.
Spinel	($MgO \cdot Al_2O_3$)	3875.	2135.
Wollastonite	($CaO \cdot SiO_2$)	2806.	1541.
Dicalcium Silicate	($2CaO \cdot SiO_2$)	3865.	2130.
Fayalite	($2FeO \cdot SiO_2$)	2201.	1205.
Diopside	($CaO \cdot MgO \cdot 2SiO_2$)	2536.	1391.
Anorthite	($CaO \cdot Al_2O_3 \cdot 2SiO_2$)	2824.	1551.
Zircon	($ZrO_2 \cdot SiO_2$)	4405.	2430.

Kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$)
Kaolinite has a P.C.E. of Cone 35, corresponding to a softening temperature of 3245° F. (1785° C.)

* NOTE: Temperatures up to 3470° F. (1910° C.) are based on the International Temperature Scale of 1948. In converting temperatures from Centigrade to Fahrenheit, the temperatures above 3300° F. are given to the nearest five degrees.

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APPROXIMATE FURNACE TEMPERATURES

KIND OF FURNACE	Degrees Fahrenheit	Degrees Centigrade
Boiler Settings — Stationary	2200 – 2900	1205 – 1595
By-Product Coke Oven		
Checkers	2000 – 2300	1090 – 1260
Coking chamber	1800 – 2200	980 – 1215
Combustion flues	2500 – 2750	1370 – 1510
Copper Furnaces		
Converter	2200 – 2450	1205 – 1340
Reverberatory Smelting Furnace, Smelting end	2500 – 3000	1370 – 1650
Reverberatory Smelting Furnace, Skimming end	2300	1260
Refined copper, tapping temperature	about 2160	about 1180
Copper ladles	about 1990	about 1090
Gas Producer		
Combustion zone	2300 – 2400	1260 – 1315
Gas leaving producer	1100 – 1600	590 – 870
Glass, Bottle		
Melting end of furnace	2650 – 2850	1455 – 1565
Refining end of furnace	2200 – 2450	1200 – 1345
Feeders	2000 – 2400	1090 – 1315
Annealing lehrs	1000 – 1150	540 – 620
Glass, Plate		
Between second and third ports	2750 – 2860	1510 – 1570
Refining end	2150 – 2250	1180 – 1230
Glass entering rolls	2000 – 2100	1095 – 1150
Annealing lehrs, start at	1120 – 1200	605 – 650
Iron and Steel Furnaces		
Blast Furnace		
Casting temperature	2700 – 2800	1480 – 1540
Bessemer Converter		
Iron into vessel	2350 – 2500	1290 – 1370
Steel running into ladles	2900	1590
Steel running into molds	2850	1570
Electric Steel Furnaces	2750 – 3100	1510 – 1705
Malleable Iron		
Air Furnace — Melting zone	2950 – 3050	1620 – 1675
Annealing Furnace	1400 – 1600	760 – 870
Open-Hearth Furnace		
Refining Steel, wall and roof temperature	2910 – 3050	1600 – 1675
Steel running into ladles	2875 – 2950	1580 – 1620
Steel running into molds	2825 – 2875	1550 – 1580
Reheating Furnaces for Slabs and Billets		
Holding zone	2300 – 2500	1260 – 1370
Discharge end	2150 – 2250	1175 – 1230
Soaking Pits		
Ingots in pits	2250 – 2350	1230 – 1290
Linings	2200 – 2600	1205 – 1425
Portland Cement Kilns		
Clinkering zone	2400 – 3000	1315 – 1650

NOTE: In converting temperatures from Fahrenheit to Centigrade, the figures are given to nearest five degrees.

WEIGHTS OF VARIOUS MATERIALS

Material	Average Weight per Cubic Foot
Brick	
Building	100 – 135
Refractory (See page 247)	
Cement	
Portland, loose	90
Portland, set	180
Coal and Coke	
Anthracite, solid	97
Anthracite, loose lumps	50 – 55
Bituminous, solid	84
Bituminous, loose lumps	45 – 50
Coke, loose lumps	25 – 29
Earth	
Loam, dry, loose	76
Loam, dry, packed	95
Loam, soft, loose mud	108
Loam, dense mud	115
Gravel	
Dry, packed	100 – 120
Wet, packed	120
Lime	
Mortar	100
Quick, loose lumps	53
Quick, fine	75
Stone, solid	166
Stone, crushed	90 – 100
Masonry	
Dry	110 – 130
Mortar rubble	130 – 155
Ashler	140 – 165
Metals	
Aluminum	166
Brass, cast	534
Copper, cast	537
Copper, rolled or wire	555
Iron, gray cast	445
Iron, white cast	475
Iron, wrought	490
Lead	710
Nickel	537
Steel, cast or rolled	490
Tin, cast	455
Zinc, cast	443
Oils	
Crude	48
Fuel Oil	
No. 1	51
No. 2	53
No. 3	54
Bunker C	62
Gasoline	45
Kerosene	50
Lubricating Oil	55
Refractory Materials	
(See pages 247 and 248)	
Rocks in Solid	
Chalk	147
Dolomite	178
Granite	175
Gypsum	145
Limestone and Marble	166
Magnesite	190
Pumice	50
Quartz	165
Sandstone	162
Shale	170
Slate, American	175
Soapstone, talc	170
Sand	
Dry, loose	100
Dry, packed	110
Wet, packed	120
Water	
As ice	58.7
At 39.2° F.	62.425
At 60° F.	62.37
At 212° F.	59.76
Wood, Dry	
Hemlock	25 – 29
Hickory	45 – 50
Mahogany	45 – 50
Maple, hard	43 – 48
Oak, live	55 – 59
Oak, red, black	40 – 41
Oak, white	46 – 50
Pine, white	25 – 26
Pine, yellow short leaf	34 – 38
Pine, yellow long leaf	44 – 45
Spruce	25 – 27

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DECIMALS OF AN INCH FOR EACH 1-64TH

		1/4	.25	**1/2**	.5	**3/4**	.75
1/64	.015625	17/64	.265625	33/64	.515625	49/64	.765625
1/32	.03125	9/32	.28125	17/32	.53125	25/32	.78125
3/64	.046875	19/64	.296875	35/64	.546875	51/64	.796875
1/16	.0625	5/16	.3125	9/16	.5625	13/16	.8125
5/64	.078125	21/64	.328125	37/64	.578125	53/64	.828125
3/32	.09375	11/32	.34375	19/32	.59375	27/32	.84375
7/64	.109375	23/64	.359375	39/64	.609375	55/64	.859375
1/8	.125	**3/8**	.375	**5/8**	.625	**7/8**	.875
9/64	.140625	25/64	.390625	41/64	.640625	57/64	.890625
5/32	.15625	13/32	.40625	21/32	.65625	29/32	.90625
11/64	.171875	27/64	.421875	43/64	.671875	59/64	.921875
3/16	.1875	7/16	.4375	11/16	.6875	15/16	.9375
13/64	.203125	29/64	.453125	45/64	.703125	61/64	.953125
7/32	.21875	15/32	.46875	23/32	.71875	31/32	.96875
15/64	.234375	31/64	.484375	47/64	.734375	63/64	.984375

SCREEN SCALE SERIES

U. S. STANDARD				TYLER STANDARD			
Sieve Number	Sieve Opening Inches	Sieve Opening Millimeters	Diameter Wire Decimals of an Inch	Mesh	Opening in Inches	Opening in Millimeters	Diameter Wire Decimals of an Inch
...	.....	.....	.....	...	1.050	26.67	0.148
...	.....	.....	.....	...	0.742	18.85	0.135
...	.....	.....	.....	...	0.525	13.33	0.105
...	.....	.....	.....	...	0.371	9.423	0.092
2½	0.315	8.00	0.073	...	.....	.....	.....
3	0.265	6.73	0.065	3	0.263	6.680	0.070
3½	0.223	5.66	0.057	...	.....	.....	.....
4	0.187	4.76	0.050	4	0.185	4.699	0.065
5	0.157	4.00	0.044	...	.....	.....	.....
6	0.132	3.36	0.040	6	0.131	3.327	0.036
7	0.111	2.83	0.036	...	.....	.....	.....
8	0.0937	2.38	0.0331	8	0.093	2.362	0.032
10	0.0787	2.00	0.0299	...	.....	.....	.....
12	0.0661	1.68	0.0272	10	0.065	1.651	0.035
14	0.0555	1.41	0.0240	...	.....	.....	.....
16	0.0469	1.19	0.0213	14	0.046	1.168	0.025
18	0.0394	1.00	0.0189	...	.....	.....	.....
20	0.0331	0.84	0.0165	20	0.0328	0.833	0.0172
25	0.0280	0.71	0.0146	...	.....	.....	.....
30	0.0232	0.59	0.0130	28	0.0232	0.589	0.0125
35	0.0197	0.50	0.0114	...	.....	.....	.....
40	0.0165	0.42	0.0098	35	0.0164	0.417	0.0122
45	0.0138	0.35	0.0087	...	.....	.....	.....
50	0.0117	0.297	0.0074	48	0.0116	0.295	0.0092
60	0.0098	0.250	0.0064	...	.....	.....	.....
70	0.0083	0.210	0.0055	65	0.0082	0.208	0.0072
80	0.0070	0.177	0.0047	...	.....	.....	.....
100	0.0059	0.149	0.0040	100	0.0058	0.147	0.0042
120	0.0049	0.125	0.0034	...	.....	.....	.....
140	0.0041	0.105	0.0029	150	0.0041	0.104	0.0026
170	0.0035	0.088	0.0025	...	.....	.....	.....
200	0.0029	0.074	0.0021	200	0.0029	0.074	0.0021
230	0.0024	0.062	0.0018	250	0.0024	0.061	0.0016
270	0.0021	0.053	0.0016	270	0.0021	0.053	0.0016
325	0.0017	0.044	0.0014	325	0.0017	0.043	0.0014

CONVERSION TABLES

LENGTH

Multiply		By	To Obtain
Microns	(μ)	0.0001	Centimeters
Millimeters	(mm.)	0.001	Meters
Millimeters	(mm.)	0.039370	Inches
Centimeters	(cm.)	0.01	Meters
Centimeters	(cm.)	0.39370	Inches
Meters	(m.)	39.370	Inches
Meters	(m.)	3.2808	Feet
Inches	(in.)	25.400	Millimeters
Inches	(in.)	2.5400	Centimeters
Feet	(ft.)	30.480	Centimeters
Feet	(ft.)	0.30480	Meters

AREA

Multiply		By	To Obtain
Square Millimeters	(mm.² or sq. mm.)	0.0015500	Square Inches
Square Centimeters	(cm.² or sq. cm.)	0.15500	Square Inches
Square Meters	(m.² or sq. m.)	10,000.	Square Centimeters
Square Meters	(m.² or sq. m.)	10.764	Square Feet
Square Inch	(in.² or sq. in.)	645.16	Square Millimeters
Square Inch	(in.² or sq. in.)	6.4516	Square Centimeters
Square Feet	(ft.² or sq. ft.)	144.	Square Inches
Square Feet	(ft.² or sq. ft.)	929.03	Square Centimeters
Square Feet	(ft.² or sq. ft.)	0.092903	Square Meters

VOLUME

Multiply		By	To Obtain
Cubic Centimeters	(cm.³ or cu. cm.)	0.061023	Cubic Inches
Cubic Centimeters	(c.c.)	.001000	Liters
Cubic Meters	(m.³ or cu. m.)	35.315	Cubic Feet
Cubic Inches	(in.³ or cu. in.)	16.387	Cubic Centimeters
Cubic Feet	(ft.³ or cu. ft.)	1,728.	Cubic Inches
Cubic Feet	(ft.³ or cu. ft.)	28,317.	Cubic Centimeters
Cubic Feet	(ft.³ or cu. ft.)	28.32	Liters
Cubic Feet	(ft.³ or cu. ft.)	7.4805	Gallons, U. S. Liquid
Cubic Yards	(yd.³ or cu. yd.)	27.	Cubic Feet
Cubic Yards	(yd.³ or cu. yd.)	0.76456	Cubic Meters
Liters		1,000.027	Cubic Centimeters
Liters		61.02	Cubic Inches
Liters		0.03531	Cubic Feet
Liters		1.0567	Quarts, U. S. Liquid
Gallons, Imperial	(gal.)	1.20094	Gallons, U. S. Liquid
Gallons, U. S. Liquid	(gal.)	3.785	Liters
Gallons, U. S. Liquid	(gal.)	3,785.	Cubic Centimeters
Gallons, U. S. Liquid	(gal.)	231.	Cubic Inches
Gallons, U. S. Liquid	(gal.)	0.13368	Cubic Feet
Gallons, U. S. Liquid	(gal.)	0.8327	Imperial Gallons

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CONVERSION TABLES — Continued

MASS AND WEIGHT

Multiply		By	To Obtain
Grams	(g.)	0.035274	Ounces Avoirdupois
Grams per Cubic Centimeter		62.43	Pounds per Cubic Foot
Kilograms	(kg.)	2.2046	Pounds Avoirdupois
Ounces Avoirdupois	(oz. av.)	28.350	Grams
Pounds Avoirdupois	(lb. av.)	453.59	Grams
Pounds Avoirdupois	(lb. av.)	0.45359	Kilograms
Pounds per Cubic Foot		0.01602	Grams per Cubic Centimeter
Metric Tons	(t.)	1,000.	Kilograms
Metric Tons	(t.)	2,204.6	Pounds Avoirdupois
Gross Tons	(G.T.)	2,240.	Pounds Avoirdupois
Net Tons	(N.T.)	2,000.	Pounds Avoirdupois
Net Tons	(N.T.)	907.18	Kilograms
Cubic Feet of Water at 39.2° F.		62.43	Pounds Avoirdupois
Pounds of Water at 39.2° F.		0.016019	Cubic Feet
Pounds of Water at 39.2° F.		0.4536	Liters
U. S. Gallons of Water at 39.2° F.		8.345	Pounds Avoirdupois
U. S. Gallons of Water at 62° F.		8.336	Pounds Avoirdupois

HEAT, ENERGY, WORK

Multiply		By	To Obtain
Gram-Calories	(g.-cal.)	0.003968	British Thermal Units
Gram-Calories	(g.-cal.)	3.087	Foot-Pounds
Kilogram-Calories	(kg.-cal.)	3.968	British Thermal Units
Kilogram-Calories	(kg.-cal.)	3,087.	Foot-Pounds
Kilowatts	(kw.)	1.341	Horse Power
Kilowatts	(kw.)	56.88	B.t.u. per Minute
Kilowatts	(kw.)	44,253.	Foot-Pounds per Minute
Kilowatt-Hours	(kw.-hr.)	1.341	Horse Power-Hours
Kilowatt-Hours	(kw.-hr.)	3,413.	British Thermal Units
Kilowatt-Hours	(kw.-hr.)	2,655,000.	Foot-Pounds
British Thermal Units	(B.t.u.)	778.0	Foot-Pounds
British Thermal Units	(B.t.u.)	252.0	Gram-Calories
British Thermal Units	(B.t.u.)	0.0002930	Kilowatt-Hours
British Thermal Units per Minute	(B.t.u./min.)	0.01758	Kilowatts
Foot-Pounds	(ft.-lb.)	0.3239	Gram-Calories
Foot-Pounds	(ft.-lb.)	0.001285	British Thermal Units
Foot-Pounds	(ft.-lb.)	0.0000003766	Kilowatt-Hours
Horse Power	(h.p.)	0.7457	Kilowatts
Horse Power	(h.p.)	42.42	B.t.u. per Minute
Horse Power	(h.p.)	33,000.	Foot-Pounds per Minute

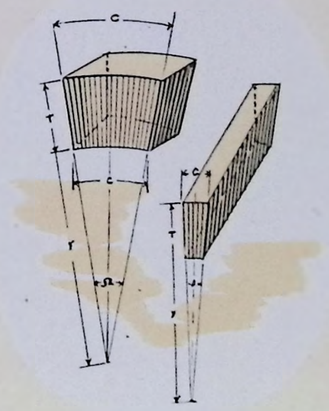
THERMAL CONDUCTIVITY

1 Gram-Calorie per Square Centimeter	3.687	B.t.u. per Sq. Ft.
1 Gram-Calorie per Sq. Cm. for 1 Cm. Thickness	1.451	B.t.u. per Sq. Ft. for 1 Inch Thickness
1 Gram-Calorie per Second per Sq. Cm. for 1 Cm. Thickness for 1° C. Temperature-Difference	2,903.	B.t.u. per Hr. per Sq. Ft. for 1 Inch Thickness for 1° F. Temperature-Difference
1 British Thermal Unit per Square Foot	0.2712	Gram-Calories per Sq. Cm.
1 British Thermal Unit per Square Foot for 1 Inch Thickness	0.6889	Gram-Calories per Sq. Cm. for 1 Centimeter Thickness
1 British Thermal Unit per Hour per Square Foot for 1 Inch Thickness for 1° Fahrenheit Temperature-Difference	0.0003445	Gram-Calories per Second per Sq. Cm. for 1 Cm. Thickness for 1° C. Temperature-Difference

FORMULAS AND TABLES

USEFUL IN

CALCULATING BRICKWORK

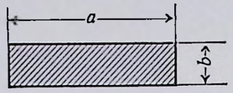


HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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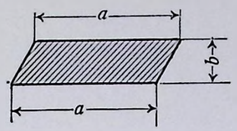
FORMULAS FOR CALCULATING AREAS AND VOLUMES

RECTANGLE



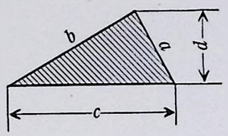
Area = ab

PARALLELOGRAM



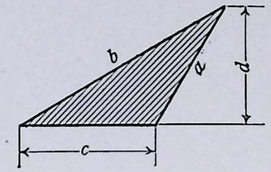
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TRIANGLE

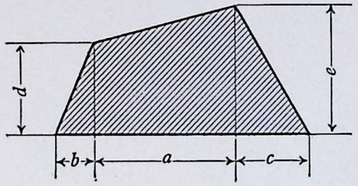


Area = ½ cd

Area =
$\sqrt{s\,(s-a)\,(s-b)\,(s-c)}$
when s = ½ (a + b + c)



TRAPEZIUM

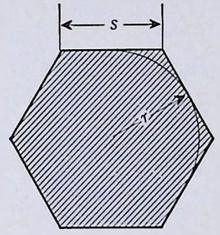


Area = ½ [a (e + d) + bd + ce]

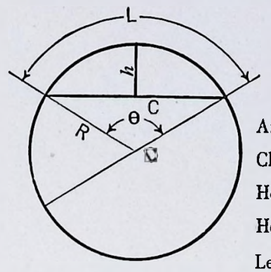
REGULAR POLYGON

Area = ½ nsr
when n = Number of sides.

Number of Sides	Area
6	2.5981 s^2 = 3.4641 r^2
8	4.8284 s^2 = 3.3137 r^2
9	6.1818 s^2 = 3.2757 r^2
10	7.6942 s^2 = 3.2492 r^2
12	11.1962 s^2 = 3.2154 r^2



CIRCLE

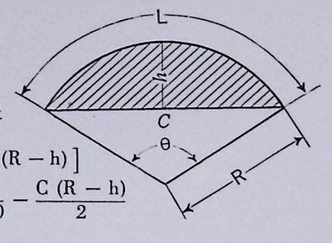


Θ (Theta) = included angle in degrees.
π (pi) = 3.1416
Circumference =
$\pi D = 2\pi R = 2\sqrt{\pi \times \text{Area}}$
Diameter, $D = 2R = 2\sqrt{\text{Area} \div \pi}$
Radius, $R = \frac{1}{2} D = \sqrt{\text{Area} \div \pi}$
Radius, R = Circumference ÷ 2 π
Radius, $R = \frac{(C \div 2)^2 + h^2}{2\,h}$

Area = 0.7854 D^2 = π R^2
Chord, $C = 2\sqrt{h\,(D-h)} = 2\,R \times \text{sine } \frac{1}{2}\,\Theta$
Height of Arc, $h = R - \sqrt{R^2 - (C \div 2)^2}$
Height of Arc, $h = R - \frac{1}{2}\sqrt{(2R + C)\,(2R - C)}$
Length of Arc, $L = \frac{\Theta}{360} \times 2\pi R = 0.017453\ R\Theta$
½ Θ = 28.648 L ÷ R
Sine ½ Θ = C ÷ 2R
1° = 0.017453 Radians, 1 radian = 57.296°

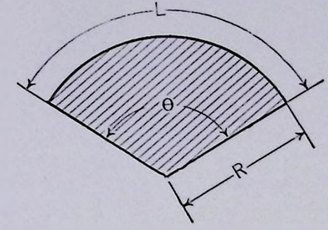
FORMULAS FOR CALCULATING AREAS AND VOLUMES — Continued

SEGMENT OF A CIRCLE



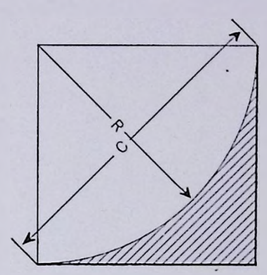
Tangent ¼ Θ = $\frac{2h}{C}$
Area = ½ [LR − C (R − h)]
Area = $\pi\ R^2 \times \frac{\Theta}{360} - \frac{C\,(R-h)}{2}$

SECTOR OF A CIRCLE



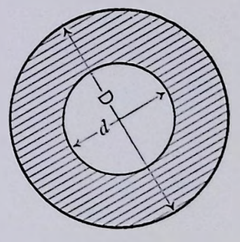
Area = ½ LR
Area = $\pi\ R^2 \times \frac{\Theta}{360}$
Area = 0.0087266 R^2 Θ

SPANDREL



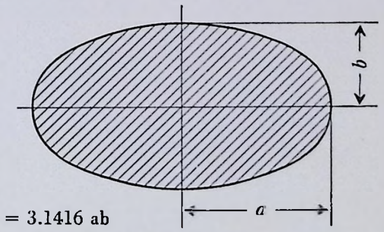
Area = 0.2146 R^2
Area = 0.1073 C^2

CIRCULAR RING



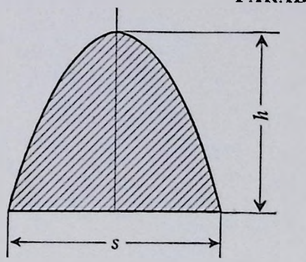
Area =
0.7854 (D^2 − d^2)
Area =
0.7854 (D + d) (D − d)

ELLIPSE



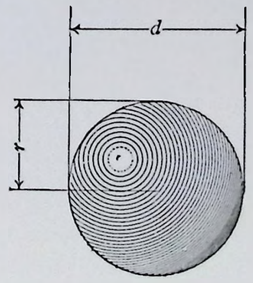
Area = πab = 3.1416 ab

PARABOLIC SEGMENT



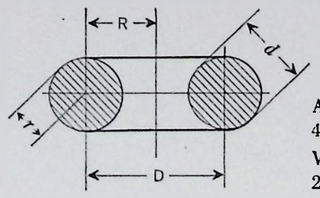
Area = ⅔ sh

SPHERE



Surface =
4 πr^2 = 12.566 r^2 = πd^2
Volume =
$\frac{4}{3}\ \pi r^3$ = 4.1888 r^3
Volume =
$\frac{1}{6}\ \pi d^3$ = 0.5236 d^3

RING OF CIRCULAR CROSS SECTION (Torus)

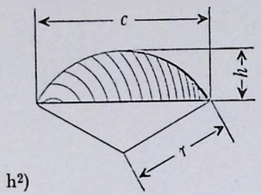


Area of Surface =
4π^2 Rr = 39.478 Rr
Volume =
2 π^2 Rr^2 = 19.739 Rr^2

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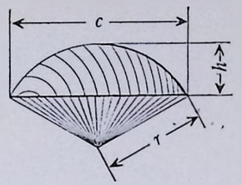
FORMULAS FOR CALCULATING AREAS AND VOLUMES — Continued

SEGMENT OF A SPHERE



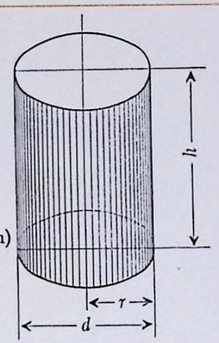
Spherical Surface =
$2\pi rh = 0.7854\ (c^2 + 4\ h^2)$
Total Surface $= 0.7854\ (c^2 + 8\ rh)$
Volume $= \frac{1}{3}\pi h^2\ (3\ r - h) = 1.0472\ h^2\ (3\ r - h)$
Volume $= \frac{1}{24}\pi h\ (3\ c^2 + 4\ h^2) = 0.1309\ h\ (3\ c^2 + 4\ h^2)$

SECTOR OF A SPHERE



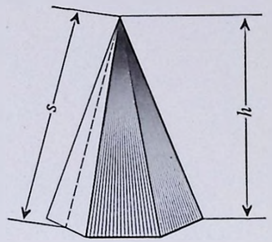
Total Surface $= 1.5708\ r\ (4\ h + c)$
Volume $= \frac{2}{3}\pi r^2 h = 2.0944\ r^2 h$

CYLINDER



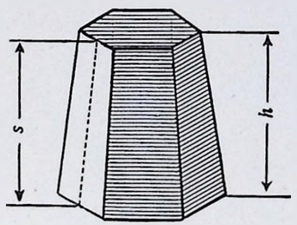
Cylindrical Surface =
$\pi dh = 2\pi rh = 6.2832\ rh$
Total Surface =
$2\pi r\ (r + h) = 6.2832\ r\ (r + h)$
Volume =
$\pi r^2 h = \frac{1}{4}\pi d^2 h = 0.7854\ d^2 h$

PYRAMID



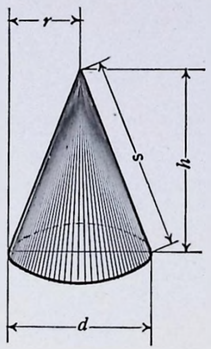
A = area of base
P = perimeter of base
Lateral Area $= \frac{1}{2}$ Ps
Volume $= \frac{1}{3}$ Ah

FRUSTUM OF A PYRAMID



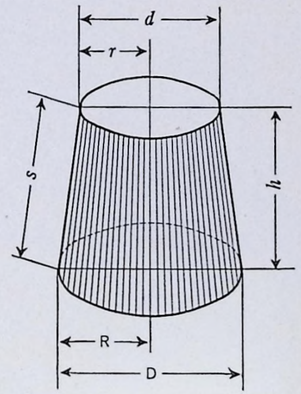
A = area of base
a = area of top
m = area of midsection
P = perimeter of base
p = perimeter of top
Lateral Area $= \frac{1}{2}$ s (P + p)
Volume $= \frac{1}{3}$ h $(a + A + \sqrt{aA})$
Volume $= \frac{1}{6}$ h (a + A + 4 m)

CONE



Conical Area =
$\pi rs = \pi r \sqrt{r^2 + h^2}$
Volume $= \frac{1}{3}\pi r^2 h =$
$1.0472\ r^2 h = 0.2618\ d^2 h$

FRUSTUM OF A CONE



A = area of base a = area of top
m = area of midsection
Area of Conical Surface $= \frac{1}{2}\pi s\ (D + d)$
Volume $= \frac{1}{3}\pi h\ (R^2 + Rr + r^2)$
Volume $= \frac{1}{3}$ h $(a + A + \sqrt{aA}) =$
$\frac{1}{6}$ h (a + A + 4 m)

CIRCUMFERENCES AND AREAS OF CIRCLES FOR GIVEN DIAMETERS

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
1/64	0.04909	0.00019	4	12.566	12.566	9 1/2	29.845	70.882	15	47.124	176.71
1/32	0.09818	0.00077	4 1/8	12.959	13.364	9 5/8	30.238	72.760	15 1/8	47.517	179.67
1/16	0.19635	0.00307	4 1/4	13.352	14.186	9 3/4	30.631	74.662	15 1/4	47.909	182.65
3/32	0.29452	0.00690	4 3/8	13.745	15.033	9 7/8	31.023	76.589	15 3/8	48.302	185.66
1/8	0.39270	0.01227	4 1/2	14.137	15.904	10	31.416	78.540	15 1/2	48.695	188.69
5/32	0.49087	0.01917	4 5/8	14.530	16.800	10 1/8	31.809	80.516	15 5/8	49.087	191.75
3/16	0.58905	0.02761	4 3/4	14.923	17.721	10 1/4	32.201	82.516	15 3/4	49.480	194.83
7/32	0.68722	0.03758	4 7/8	15.315	18.665	10 3/8	32.594	84.541	15 7/8	49.873	197.93
1/4	0.78540	0.04909	5	15.708	19.635	10 1/2	32.987	86.590	16	50.266	201.06
5/16	0.98175	0.07670	5 1/8	16.101	20.629	10 5/8	33.379	88.664	16 1/8	50.658	204.22
3/8	1.1781	0.11045	5 1/4	16.493	21.648	10 3/4	33.772	90.763	16 1/4	51.051	207.39
7/16	1.3745	0.15033	5 3/8	16.886	22.691	10 7/8	34.165	92.886	16 3/8	51.444	210.60
1/2	1.5708	0.19635	5 1/2	17.279	23.758	11	34.558	95.033	16 1/2	51.836	213.82
9/16	1.7672	0.24850	5 5/8	17.672	24.850	11 1/8	34.950	97.205	16 5/8	52.229	217.08
5/8	1.9635	0.30680	5 3/4	18.064	25.967	11 1/4	35.343	99.402	16 3/4	52.622	220.35
11/16	2.1598	0.37122	5 7/8	18.457	27.109	11 3/8	35.736	101.62	16 7/8	53.014	223.65
3/4	2.3562	0.44179	6	18.850	28.274	11 1/2	36.128	103.87	17	53.407	226.98
13/16	2.5525	0.51849	6 1/8	19.242	29.465	11 5/8	36.521	106.14	17 1/8	53.800	230.33
7/8	2.7489	0.60132	6 1/4	19.635	30.680	11 3/4	36.914	108.43	17 1/4	54.193	233.71
15/16	2.9452	0.69029	6 3/8	20.028	31.919	11 7/8	37.306	110.75	17 3/8	54.585	237.10
1	3.1416	0.78540	6 1/2	20.420	33.183	12	37.699	113.10	17 1/2	54.978	240.53
1 1/8	3.5343	0.99402	6 5/8	20.813	34.472	12 1/8	38.092	115.47	17 5/8	55.371	243.98
1 1/4	3.9270	1.2272	6 3/4	21.206	35.785	12 1/4	38.485	117.86	17 3/4	55.763	247.45
1 3/8	4.3197	1.4849	6 7/8	21.598	37.122	12 3/8	38.877	120.28	17 7/8	56.156	250.95
1 1/2	4.7124	1.7671	7	21.991	38.485	12 1/2	39.270	122.72	18	56.549	254.47
1 5/8	5.1051	2.0739	7 1/8	22.384	39.871	12 5/8	39.663	125.19	18 1/8	56.941	258.02
1 3/4	5.4978	2.4053	7 1/4	22.777	41.282	12 3/4	40.055	127.68	18 1/4	57.334	261.59
1 7/8	5.8905	2.7612	7 3/8	23.169	42.718	12 7/8	40.448	130.19	18 3/8	57.727	265.18
2	6.2832	3.1416	7 1/2	23.562	44.179	13	40.841	132.73	18 1/2	58.120	268.80
2 1/8	6.6759	3.5466	7 5/8	23.955	45.664	13 1/8	41.233	135.30	18 5/8	58.512	272.45
2 1/4	7.0686	3.9761	7 3/4	24.347	47.173	13 1/4	41.626	137.89	18 3/4	58.905	276.12
2 3/8	7.4613	4.4301	7 7/8	24.740	48.707	13 3/8	42.019	140.50	18 7/8	59.298	279.81
2 1/2	7.8540	4.9087	8	25.133	50.265	13 1/2	42.412	143.14	19	59.690	283.53
2 5/8	8.2467	5.4119	8 1/8	25.525	51.849	13 5/8	42.804	145.80	19 1/8	60.083	287.27
2 3/4	8.6394	5.9396	8 1/4	25.918	53.456	13 3/4	43.197	148.49	19 1/4	60.476	291.04
2 7/8	9.0321	6.4918	8 3/8	26.311	55.088	13 7/8	43.590	151.20	19 3/8	60.868	294.83
3	9.4248	7.0686	8 1/2	26.704	56.745	14	43.982	153.94	19 1/2	61.261	298.65
3 1/8	9.8175	7.6699	8 5/8	27.096	58.426	14 1/8	44.375	156.70	19 5/8	61.654	302.49
3 1/4	10.210	8.2958	8 3/4	27.489	60.132	14 1/4	44.768	159.48	19 3/4	62.047	306.35
3 3/8	10.603	8.9462	8 7/8	27.882	61.862	14 3/8	45.160	162.30	19 7/8	62.439	310.24
3 1/2	10.996	9.6211	9	28.274	63.617	14 1/2	45.553	165.13	20	62.832	314.16
3 5/8	11.388	10.321	9 1/8	28.667	65.397	14 5/8	45.946	167.99	20 1/8	63.225	318.10
3 3/4	11.781	11.045	9 1/4	29.060	67.201	14 3/4	46.339	170.87	20 1/4	63.617	322.06
3 7/8	12.174	11.793	9 3/8	29.452	69.029	14 7/8	46.731	173.78	20 3/8	64.010	326.05

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CIRCUMFERENCES AND AREAS OF CIRCLES FOR GIVEN DIAMETERS — Continued

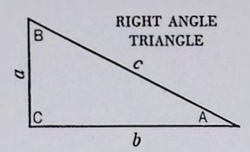
Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
20½	64.403	330.06	26	81.681	530.93	31½	98.960	779.31	37	116.24	1075.2
20⅝	64.795	334.10	26⅛	82.074	536.05	31⅝	99.353	785.51	37⅛	116.63	1082.5
20¾	65.188	338.16	26¼	82.467	541.19	31¾	99.746	791.73	37¼	117.02	1089.8
20⅞	65.581	342.25	26⅜	82.860	546.35	31⅞	100.14	797.98	37⅜	117.42	1097.1
21	65.973	346.36	26½	83.252	551.55	32	100.53	804.25	37½	117.81	1104.5
21⅛	66.366	350.50	26⅝	83.645	556.76	32⅛	100.92	810.54	37⅝	118.20	1111.8
21¼	66.759	354.66	26¾	84.038	562.00	32¼	101.32	816.86	37¾	118.60	1119.2
21⅜	67.152	358.84	26⅞	84.430	567.27	32⅜	101.71	823.21	37⅞	118.99	1126.7
21½	67.544	363.05	27	84.823	572.56	32½	102.10	829.58	38	119.38	1134.1
21⅝	67.937	367.28	27⅛	85.216	577.87	32⅝	102.49	835.97	38⅛	119.77	1141.6
21¾	68.330	371.54	27¼	85.608	583.21	32¾	102.89	842.39	38¼	120.17	1149.1
21⅞	68.722	375.83	27⅜	86.001	588.57	32⅞	103.28	848.83	38⅜	120.56	1156.6
22	69.115	380.13	27½	86.394	593.96	33	103.67	855.30	38½	120.95	1164.2
22⅛	69.508	384.46	27⅝	86.787	599.37	33⅛	104.07	861.79	38⅝	121.34	1171.7
22¼	69.900	388.82	27¾	87.179	604.81	33¼	104.46	868.31	38¾	121.74	1179.3
22⅜	70.293	393.20	27⅞	87.572	610.27	33⅜	104.85	874.85	38⅞	122.13	1186.9
22½	70.686	397.61	28	87.965	615.75	33½	105.24	881.41	39	122.52	1194.6
22⅝	71.079	402.04	28⅛	88.357	621.26	33⅝	105.64	888.00	39⅛	122.92	1202.3
22¾	71.471	406.49	28¼	88.750	626.80	33¾	106.03	894.62	39¼	123.31	1210.0
22⅞	71.864	410.97	28⅜	89.143	632.36	33⅞	106.42	901.26	39⅜	123.70	1217.7
23	72.257	415.48	28½	89.535	637.94	34	106.81	907.92	39½	124.09	1225.4
23⅛	72.649	420.00	28⅝	89.928	643.55	34⅛	107.21	914.61	39⅝	124.49	1233.2
23¼	73.042	424.56	28¾	90.321	649.18	34¼	107.60	921.32	39¾	124.88	1241.0
23⅜	73.435	429.13	28⅞	90.714	654.84	34⅜	107.99	928.06	39⅞	125.27	1248.8
23½	73.827	433.74	29	91.106	660.52	34½	108.39	934.82	40	125.66	1256.6
23⅝	74.220	438.36	29⅛	91.499	666.23	34⅝	108.78	941.61	40⅛	126.06	1264.5
23¾	74.613	443.01	29¼	91.892	671.96	34¾	109.17	948.42	40¼	126.45	1272.4
23⅞	75.006	447.69	29⅜	92.284	677.71	34⅞	109.56	955.25	40⅜	126.84	1280.3
24	75.398	452.39	29½	92.677	683.49	35	109.96	962.11	40½	127.24	1288.2
24⅛	75.791	457.11	29⅝	93.070	689.30	35⅛	110.35	969.00	40⅝	127.63	1296.2
24¼	76.184	461.86	29¾	93.462	695.13	35¼	110.74	975.91	40¾	128.02	1304.2
24⅜	76.578	466.64	29⅞	93.855	700.98	35⅜	111.13	982.84	40⅞	128.41	1312.2
24½	76.969	471.44	30	94.248	706.86	35½	111.53	989.80	41	128.81	1320.3
24⅝	77.362	476.26	30⅛	94.641	712.76	35⅝	111.92	996.78	41⅛	129.20	1328.3
24¾	77.754	481.11	30¼	95.033	718.69	35¾	112.31	1003.8	41¼	129.59	1336.4
24⅞	78.147	485.98	30⅜	95.426	724.64	35⅞	112.71	1010.8	41⅜	129.98	1344.5
25	78.540	490.87	30½	95.819	730.62	36	113.10	1017.9	41½	130.38	1352.7
25⅛	78.933	495.79	30⅝	96.211	736.62	36⅛	113.49	1025.0	41⅝	130.77	1360.8
25¼	79.325	500.74	30¾	96.604	742.64	36¼	113.88	1032.1	41¾	131.16	1369.0
25⅜	79.718	505.71	30⅞	96.997	748.69	36⅜	114.28	1039.2	41⅞	131.55	1377.2
25½	80.111	510.71	31	97.389	754.77	36½	114.67	1046.3	42	131.95	1385.4
25⅝	80.503	515.72	31⅛	97.782	760.87	36⅝	115.06	1053.5	42⅛	132.34	1393.7
25¾	80.896	520.77	31¼	98.175	766.99	36¾	115.45	1060.7	42¼	132.73	1402.0
25⅞	81.289	525.84	31⅜	98.568	773.14	36⅞	115.85	1068.0	42⅜	133.13	1410.3

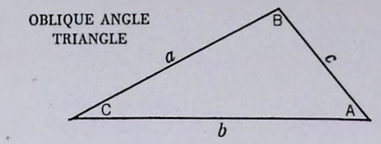
CIRCUMFERENCES AND AREAS OF CIRCLES FOR GIVEN DIAMETERS — Continued

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
42½	133.52	1418.6	47½	149.23	1772.1	60	188.50	2827.4	80	251.33	5026.5
42⅝	133.91	1427.0	47⅝	149.62	1781.4	60½	190.07	2874.8	80½	252.90	5089.6
42¾	134.30	1435.4	47¾	150.01	1790.8	61	191.64	2922.5	81	254.47	5153.0
42⅞	134.70	1443.8	47⅞	150.40	1800.1	61½	193.21	2970.6	81½	256.04	5216.8
43	135.09	1452.2	48	150.80	1809.6	62	194.78	3019.1	82	257.61	5281.0
43⅛	135.48	1460.7	48⅛	151.19	1819.0	62½	196.35	3068.0	82½	259.18	5345.6
43¼	135.87	1469.1	48¼	151.58	1828.5	63	197.92	3117.2	83	260.75	5410.6
43⅜	136.27	1477.6	48⅜	151.97	1837.9	63½	199.49	3166.9	83½	262.32	5476.0
43½	136.66	1486.2	48½	152.37	1847.5	64	201.06	3217.0	84	263.89	5541.8
43⅝	137.05	1494.7	48⅝	152.76	1857.0	64½	202.63	3267.5	84½	265.47	5607.9
43¾	137.45	1503.3	48¾	153.15	1866.5	65	204.20	3318.3	85	267.04	5674.5
43⅞	137.84	1511.9	48⅞	153.55	1876.1	65½	205.77	3369.6	85½	268.61	5741.5
44	138.23	1520.5	49	153.94	1885.7	66	207.35	3421.2	86	270.18	5808.8
44⅛	138.62	1529.2	49⅛	154.33	1895.4	66½	208.92	3473.2	86½	271.75	5876.5
44¼	139.02	1537.9	49¼	154.72	1905.0	67	210.49	3525.7	87	273.32	5944.7
44⅜	139.41	1546.6	49⅜	155.12	1914.7	67½	212.06	3578.5	87½	274.89	6013.2
44½	139.80	1555.3	49½	155.51	1924.4	68	213.63	3631.7	88	276.46	6082.1
44⅝	140.19	1564.0	49⅝	155.90	1934.2	68½	215.20	3685.3	88½	278.03	6151.4
44¾	140.59	1572.8	49¾	156.29	1943.9	69	216.77	3739.3	89	279.60	6221.1
44⅞	140.98	1581.6	49⅞	156.69	1953.7	69½	218.34	3793.7	89½	281.17	6291.2
45	141.37	1590.4	50	157.08	1963.5	70	219.91	3848.5	90	282.74	6361.7
45⅛	141.76	1599.3	50½	158.65	2003.0	70½	221.48	3903.6	90½	284.31	6432.6
45¼	142.16	1608.2	51	160.22	2042.8	71	223.05	3959.2	91	285.89	6503.9
45⅜	142.55	1617.0	51½	161.79	2083.1	71½	224.62	4015.2	91½	287.46	6575.5
45½	142.94	1626.0	52	163.36	2123.7	72	226.20	4071.5	92	289.03	6647.6
45⅝	143.34	1634.9	52½	164.93	2164.8	72½	227.77	4128.2	92½	290.60	6720.1
45¾	143.73	1643.9	53	166.50	2206.2	73	229.34	4185.4	93	292.17	6792.9
45⅞	144.12	1652.9	53½	168.08	2248.0	73½	230.91	4242.9	93½	293.74	6866.1
46	144.51	1661.9	54	169.65	2290.2	74	232.48	4300.8	94	295.31	6939.8
46⅛	144.91	1670.9	54½	171.22	2332.8	74½	234.05	4359.2	94½	296.88	7013.8
46¼	145.30	1680.0	55	172.79	2375.8	75	235.62	4417.9	95	298.45	7088.2
46⅜	145.69	1689.1	55½	174.36	2419.2	75½	237.19	4477.0	95½	300.02	7163.0
46½	146.08	1698.2	56	175.93	2463.0	76	238.76	4536.5	96	301.59	7238.2
46⅝	146.48	1707.4	56½	177.50	2507.2	76½	240.33	4596.3	96½	303.16	7313.8
46¾	146.87	1716.5	57	179.07	2551.8	77	241.90	4656.6	97	304.73	7389.8
46⅞	147.26	1725.7	57½	180.64	2596.7	77½	243.47	4717.3	97½	306.31	7466.2
47	147.66	1734.9	58	182.21	2642.1	78	245.04	4778.4	98	307.88	7543.0
47⅛	148.05	1744.2	58½	183.78	2687.8	78½	246.62	4839.8	98½	309.45	7620.1
47¼	148.44	1753.5	59	185.35	2734.0	79	248.19	4901.7	99	311.02	7697.7
47⅜	148.83	1762.7	59½	186.93	2780.5	79½	249.76	4963.9	99½	312.59	7775.6

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TRIGONOMETRIC SOLUTION OF TRIANGLES





RIGHT ANGLE TRIANGLES

Sine (sin) of angle A = opposite side divided by hypotenuse = a divided by c
Cosine (cos) of angle A = adjacent side divided by hypotenuse = b divided by c
Tangent (tan) of angle A = opposite side divided by adjacent side = a divided by b
Cotangent (cot) of angle A = adjacent side divided by opposite side = b divided by a
Sin B = cos A; cos B = sin A; tan B = cot A; cot B = tan A

Given	To Find	Formulas		
a, c	A, B, b	$\sin A = \frac{a}{c}$,	$\cos B = \frac{a}{c}$,	$b = \sqrt{c^2 - a^2}$
a, b	A, B, c	$\tan A = \frac{a}{b}$,	$\tan B = \frac{b}{a}$,	$c = \sqrt{a^2 + b^2}$
A, a	B, b, c	$B = 90° - A$,	$b = a \cot A$,	$c = \frac{a}{\sin A}$
A, b	B, a, c	$B = 90° - A$,	$a = b \tan A$,	$c = \frac{b}{\cos A}$
A, c	B, a, b	$B = 90° - A$,	$a = c \sin A$,	$b = c \cos A$

OBLIQUE ANGLE TRIANGLES

$s = \frac{1}{2}(a + b + c)$

Given	To Find	Formulas
a, b, c	A	$\sin \frac{1}{2}A = \sqrt{\frac{(s-b)(s-c)}{bc}}$, $\cos \frac{1}{2}A = \sqrt{\frac{s(s-a)}{bc}}$, $\tan \frac{1}{2}A = \sqrt{\frac{(s-b)(s-c)}{s(s-a)}}$
	B	$\sin \frac{1}{2}B = \sqrt{\frac{(s-a)(s-c)}{ac}}$, $\cos \frac{1}{2}B = \sqrt{\frac{s(s-b)}{ac}}$, $\tan \frac{1}{2}B = \sqrt{\frac{(s-a)(s-c)}{s(s-b)}}$
	C	$\sin \frac{1}{2}C = \sqrt{\frac{(s-a)(s-b)}{ab}}$, $\cos \frac{1}{2}C = \sqrt{\frac{s(s-c)}{ab}}$, $\tan \frac{1}{2}C = \sqrt{\frac{(s-a)(s-b)}{s(s-c)}}$
a, A, B	b, c	$b = \frac{a \sin B}{\sin A}$, $c = \frac{a \sin C}{\sin A} = \frac{a \sin (A + B)}{\sin A}$
a, b, A	B	$\sin B = \frac{b \sin A}{a}$
	c	$c = \frac{a \sin C}{\sin A} = \frac{b \sin C}{\sin B} = \sqrt{a^2 + b^2 - 2ab \cos C}$
a, b, C	A	$\tan A = \frac{a \sin C}{b - a \cos C}$, $\tan \frac{1}{2}(A - B) = \frac{a - b}{a + b} \cot \frac{1}{2}C$
	c	$c = \sqrt{a^2 + b^2 - 2ab \cos C} = \frac{a \sin C}{\sin A}$

TABLE OF NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	Sines .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Cosines .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	
0	0.00000	0.00436	0.00873	0.01309	0.01745	1.00000	0.99999	0.99996	0.99991	0.99985	89
1	0.01745	0.02181	0.02618	0.03054	0.03490	0.99985	0.99976	0.99966	0.99953	0.99939	88
2	0.03490	0.03926	0.04362	0.04798	0.05234	0.99939	0.99923	0.99905	0.99885	0.99853	87
3	0.05234	0.05669	0.06105	0.06540	0.06976	0.99863	0.99839	0.99813	0.99785	0.99756	86
4	0.06976	0.07411	0.07846	0.08281	0.08716	0.99756	0.99725	0.99692	0.99657	0.99619	85
5	0.08716	0.09150	0.09585	0.10019	0.10453	0.99619	0.99580	0.99540	0.99497	0.99452	84
6	0.10453	0.10887	0.11320	0.11754	0.12187	0.99452	0.99406	0.99357	0.99307	0.99255	83
7	0.12187	0.12620	0.13053	0.13485	0.13917	0.99255	0.99200	0.99144	0.99087	0.99027	82
8	0.13917	0.14349	0.14781	0.15212	0.15643	0.99027	0.98965	0.98902	0.98836	0.98769	81
9	0.15643	0.16074	0.16505	0.16935	0.17365	0.98769	0.98700	0.98629	0.98556	0.98481	80
10	0.17365	0.17794	0.18224	0.18652	0.19081	0.98481	0.98404	0.98325	0.98245	0.98163	79
11	0.19081	0.19509	0.19937	0.20364	0.20791	0.98163	0.98079	0.97992	0.97905	0.97815	78
12	0.20791	0.21218	0.21644	0.22070	0.22495	0.97815	0.97723	0.97630	0.97534	0.97437	77
13	0.22495	0.22920	0.23345	0.23769	0.24192	0.97437	0.97338	0.97237	0.97134	0.97030	76
14	0.24192	0.24615	0.25038	0.25460	0.25882	0.97030	0.96923	0.96815	0.96705	0.96593	75
15	0.25882	0.26303	0.26724	0.27144	0.27564	0.96593	0.96479	0.96363	0.96246	0.96126	74
16	0.27564	0.27983	0.28402	0.28820	0.29237	0.96126	0.96005	0.95882	0.95757	0.95630	73
17	0.29237	0.29654	0.30071	0.30486	0.30902	0.95630	0.95502	0.95372	0.95240	0.95106	72
18	0.30902	0.31316	0.31730	0.32144	0.32557	0.95106	0.94970	0.94832	0.94693	0.94552	71
19	0.32557	0.32969	0.33381	0.33792	0.34202	0.94552	0.94409	0.94264	0.94118	0.93969	70
20	0.34202	0.34612	0.35021	0.35429	0.35837	0.93969	0.93819	0.93667	0.93514	0.93358	69
21	0.35837	0.36244	0.36650	0.37056	0.37461	0.93358	0.93201	0.93042	0.92881	0.92718	68
22	0.37461	0.37865	0.38268	0.38671	0.39073	0.92718	0.92554	0.92388	0.92220	0.92050	67
23	0.39073	0.39474	0.39875	0.40275	0.40674	0.92050	0.91879	0.91706	0.91531	0.91355	66
24	0.40674	0.41072	0.41469	0.41866	0.42262	0.91355	0.91176	0.90996	0.90814	0.90631	65
25	0.42262	0.42657	0.43051	0.43445	0.43837	0.90631	0.90446	0.90259	0.90070	0.89879	64
26	0.43837	0.44229	0.44620	0.45010	0.45399	0.89879	0.89687	0.89493	0.89298	0.89101	63
27	0.45399	0.45787	0.46175	0.46561	0.46947	0.89101	0.88902	0.88701	0.88499	0.88295	62
28	0.46947	0.47332	0.47716	0.48099	0.48481	0.88295	0.88089	0.87882	0.87673	0.87462	61
29	0.48481	0.48862	0.49242	0.49622	0.50000	0.87462	0.87250	0.87036	0.86820	0.86603	60
30	0.50000	0.50377	0.50754	0.51129	0.51504	0.86603	0.86384	0.86163	0.85941	0.85717	59
31	0.51504	0.51877	0.52250	0.52621	0.52992	0.85717	0.85491	0.85264	0.85035	0.84805	58
32	0.52992	0.53361	0.53730	0.54097	0.54464	0.84805	0.84573	0.84339	0.84104	0.83867	57
33	0.54464	0.54829	0.55194	0.55557	0.55919	0.83867	0.83629	0.83389	0.83147	0.82904	56
34	0.55919	0.56280	0.56641	0.57000	0.57358	0.82904	0.82659	0.82413	0.82165	0.81915	55
35	0.57358	0.57715	0.58070	0.58425	0.58779	0.81915	0.81664	0.81412	0.81157	0.80902	54
36	0.58779	0.59131	0.59482	0.59832	0.60182	0.80902	0.80644	0.80385	0.80125	0.79864	53
37	0.60182	0.60529	0.60876	0.61222	0.61566	0.79864	0.79600	0.79335	0.79069	0.78801	52
38	0.61566	0.61909	0.62251	0.62592	0.62932	0.78801	0.78532	0.78261	0.77988	0.77715	51
39	0.62932	0.63271	0.63608	0.63944	0.64279	0.77715	0.77439	0.77162	0.76884	0.76604	50
40	0.64279	0.64612	0.64945	0.65276	0.65606	0.76604	0.76323	0.76041	0.75756	0.75471	49
41	0.65606	0.65935	0.66262	0.66588	0.66913	0.75471	0.75184	0.74895	0.74605	0.74314	48
42	0.66913	0.67237	0.67559	0.67880	0.68200	0.74314	0.74022	0.73728	0.73432	0.73135	47
43	0.68200	0.68518	0.68835	0.69151	0.69466	0.73135	0.72837	0.72537	0.72236	0.71934	46
44	0.69466	0.69779	0.70091	0.70401	0.70711	0.71934	0.71630	0.71325	0.71019	0.70711	45
	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	
	Cosines					Sines					Degrees

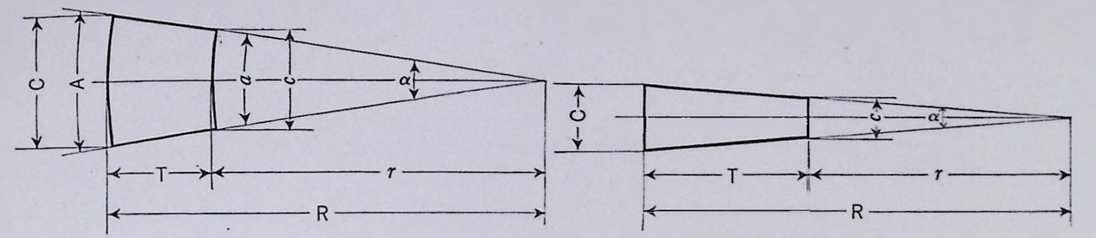
TABLE OF NATURAL TRIGONOMETRIC FUNCTIONS—Continued

Degrees	Tangents .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Cotangents .00° 0′	.25° 15′	.50° 30′	.75° 45′	1.00° 60′	Degrees
0	0.00000	0.00436	0.00873	0.01309	0.01746	Infinity	229.18	114.59	76.390	57.290	89
1	0.01746	0.02182	0.02619	0.03055	0.03492	57.290	45.829	38.188	32.730	28.636	88
2	0.03492	0.03929	0.04366	0.04803	0.05241	28.636	25.452	22.904	20.819	19.081	87
3	0.05241	0.05678	0.06116	0.06554	0.06993	19.081	17.611	16.350	15.257	14.301	86
4	0.06993	0.07431	0.07870	0.08309	0.08749	14.301	13.457	12.706	12.035	11.430	85
5	0.08749	0.09189	0.09629	0.10069	0.10510	11.430	10.883	10.385	9.9310	9.5144	84
6	0.10510	0.10952	0.11394	0.11836	0.12278	9.5144	9.1309	8.7769	8.4490	8.1443	83
7	0.12278	0.12722	0.13165	0.13609	0.14054	8.1443	7.8606	7.5958	7.3479	7.1154	82
8	0.14054	0.14499	0.14945	0.15391	0.15838	7.1154	6.8969	6.6912	6.4971	6.3138	81
9	0.15838	0.16286	0.16734	0.17183	0.17633	6.3138	6.1402	5.9758	5.8197	5.6713	80
10	0.17633	0.18083	0.18534	0.18986	0.19438	5.6713	5.5301	5.3955	5.2672	5.1446	79
11	0.19438	0.19891	0.20345	0.20800	0.21256	5.1446	5.0273	4.9152	4.8077	4.7046	78
12	0.21256	0.21712	0.22169	0.22628	0.23087	4.7046	4.6057	4.5107	4.4194	4.3315	77
13	0.23087	0.23547	0.24008	0.24470	0.24933	4.3315	4.2468	4.1653	4.0867	4.0108	76
14	0.24933	0.25397	0.25862	0.26328	0.26795	4.0108	3.9375	3.8667	3.7983	3.7321	75
15	0.26795	0.27263	0.27732	0.28203	0.28675	3.7321	3.6680	3.6059	3.5457	3.4874	74
16	0.28675	0.29147	0.29621	0.30097	0.30573	3.4874	3.4308	3.3759	3.3226	3.2709	73
17	0.30573	0.31051	0.31530	0.32010	0.32492	3.2709	3.2205	3.1716	3.1240	3.0777	72
18	0.32492	0.32975	0.33460	0.33945	0.34433	3.0777	3.0326	2.9887	2.9459	2.9042	71
19	0.34433	0.34922	0.35412	0.35904	0.36397	2.9042	2.8636	2.8239	2.7852	2.7475	70
20	0.36397	0.36892	0.37388	0.37887	0.38386	2.7475	2.7106	2.6746	2.6395	2.6051	69
21	0.38386	0.38888	0.39391	0.39896	0.40403	2.6051	2.5715	2.5386	2.5065	2.4751	68
22	0.40403	0.40911	0.41421	0.41933	0.42447	2.4751	2.4443	2.4142	2.3847	2.3559	67
23	0.42447	0.42963	0.43481	0.44001	0.44523	2.3559	2.3276	2.2998	2.2727	2.2460	66
24	0.44523	0.45047	0.45573	0.46101	0.46631	2.2460	2.2199	2.1943	2.1692	2.1445	65
25	0.46631	0.47163	0.47698	0.48234	0.48773	2.1445	2.1203	2.0965	2.0732	2.0503	64
26	0.48773	0.49315	0.49858	0.50404	0.50953	2.0503	2.0278	2.0057	1.9840	1.9626	63
27	0.50953	0.51503	0.52057	0.52613	0.53171	1.9626	1.9416	1.9210	1.9007	1.8807	62
28	0.53171	0.53732	0.54296	0.54862	0.55431	1.8807	1.8611	1.8418	1.8228	1.8040	61
29	0.55431	0.56003	0.56577	0.57155	0.57735	1.8040	1.7856	1.7675	1.7496	1.7321	60
30	0.57735	0.58318	0.58905	0.59494	0.60086	1.7321	1.7147	1.6977	1.6808	1.6643	59
31	0.60086	0.60681	0.61280	0.61882	0.62487	1.6643	1.6479	1.6319	1.6160	1.6003	58
32	0.62487	0.63095	0.63707	0.64322	0.64941	1.6003	1.5849	1.5697	1.5547	1.5399	57
33	0.64941	0.65563	0.66189	0.66818	0.67451	1.5399	1.5253	1.5108	1.4966	1.4826	56
34	0.67451	0.68088	0.68728	0.69372	0.70021	1.4826	1.4687	1.4550	1.4415	1.4281	55
35	0.70021	0.70673	0.71329	0.71990	0.72654	1.4281	1.4150	1.4019	1.3891	1.3764	54
36	0.72654	0.73323	0.73996	0.74674	0.75355	1.3764	1.3638	1.3514	1.3392	1.3270	53
37	0.75355	0.76042	0.76733	0.77428	0.78129	1.3270	1.3151	1.3032	1.2915	1.2799	52
38	0.78129	0.78834	0.79544	0.80258	0.80978	1.2799	1.2685	1.2572	1.2460	1.2349	51
39	0.80978	0.81703	0.82434	0.83169	0.83910	1.2349	1.2239	1.2131	1.2024	1.1918	50
40	0.83910	0.84656	0.85408	0.86166	0.86929	1.1918	1.1812	1.1708	1.1606	1.1504	49
41	0.86929	0.87698	0.88473	0.89253	0.90040	1.1504	1.1403	1.1303	1.1204	1.1106	48
42	0.90040	0.90834	0.91633	0.92439	0.93252	1.1106	1.1009	1.0913	1.0818	1.0724	47
43	0.93252	0.94071	0.94896	0.95729	0.96569	1.0724	1.0630	1.0538	1.0446	1.0355	46
44	0.96569	0.97416	0.98270	0.99131	1.00000	1.0355	1.0265	1.0176	1.0088	1.0000	45
	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	60′ 1.00°	45′ .75°	30′ .50°	15′ .25°	0′ .00°	
	Cotangents					Tangents					Degrees

RADIAL BRICK FORMULAS

CIRCLE TYPE RADIAL BRICK
(STANDARD CIRCLE, ROTARY KILN, CUPOLA AND SPECIAL RADIAL BRICK).

WEDGE TYPE RADIAL BRICK
(STANDARD WEDGE, ARCH, KEY AND SPECIAL RADIAL BRICK).



SYMBOLS

a = Inside arc of circle type brick.
A = Outside arc of circle type brick.
c = Inside chord of circle type brick; or chord dimension of small end of wedge type brick.
C = Outside chord of circle type brick; or chord dimension of large end of wedge type brick.
r = Inside radius of radial brick.
R = Outside radius of radial brick.
d = Inside diameter of ring formed by radial brick.
D = Outside diameter of ring formed by radial brick.
T = Radial dimension of brick.
α = Alpha, the included angle of brick.
π = Pi = 3.1416
N_r = Total number of a given radial brick required to form a ring.

FORMULAS

(1) $c = \frac{r\,C}{r+T} = \frac{r\,C}{R}$

(2) $C = \frac{(r+T)c}{r} = \frac{R\,c}{r}$

(3) $r = \frac{c\,T}{C-c}, \quad d = 2\,r$

(4) $R = r + T, \quad D = 2\,R$

(5) $\alpha = \frac{360°}{N_r}$

(6-a) *For circle type radial brick:*
$\text{Sine } \frac{1}{2}\,\alpha = \frac{C}{2\,R} = \frac{c}{2\,r}$

(6-b) *For wedge type radial brick:*
$\text{Tangent } \frac{1}{2}\,\alpha = \frac{C}{2\,R} = \frac{c}{2\,r}$

(7-a)† *For circle type radial brick:*
$c = d \text{ sine } \frac{1}{2}\,\alpha; \quad C = D \text{ sine } \frac{1}{2}\,\alpha$

(7-b) *For wedge type radial brick:*
$c = d \text{ tangent } \frac{1}{2}\,\alpha; \quad C = D \text{ tangent } \frac{1}{2}\,\alpha$

(8) $N_r = \frac{360°}{\alpha}$

(9)* $N_r = \frac{2\,\pi\,T}{C-c}$

(10)* $N_r = \frac{\pi\,D}{C} = \frac{\pi\,d}{c}$

* Approximate; close enough for most purposes.
† When N_r is known, refer to table on page 370 for value of sine $\frac{1}{2}\,\alpha$.

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USE OF RADIAL BRICK FORMULAS

1. *To find Inside Chord Dimension* (c) *when the outside chord dimension* (C), *inside radius* (r) *and radial dimension of brick* (T) *are known:*

Formula 1: $c = \frac{r\,C}{r + T}$

Multiply the inside radius (r) by the outside chord dimension (C) and divide the product by the sum of the inside radius (r) and the radial dimension of the brick (T).

Example: Let C = 9″, r = 6″, T = 4½″

Then, Inside Chord Dimension (c) $= \frac{6 \times 9}{6 + 4.5} = 5.1429'' = 5\frac{5}{32}''$

2. *To find Outside Chord Dimension* (C) *when the inside chord dimension* (c), *inside radius* (r) *and radial dimension of brick* (T) *are known:*

Formula 2: $C = \frac{(r + T)\,c}{r}$

To the inside radius (r) add the radial dimension of the brick (T); multiply the sum by the inside chord dimension (c); divide the product by the inside radius (r).

Example: Let c = 4½″, r = 6″, T = 4½″

Then, Outside Chord Dimension (C) $= \frac{(6 + 4.5)\,4.5}{6} = 7.875'' = 7\frac{7}{8}''$

3. *To find Inside Radius* (r) *of ring formed by radial brick when the dimensions of the brick are known:*

Formula 3: $r = \frac{c\,T}{C - c}$; $d = 2r$

Multiply radial dimension (T) by the inside chord dimension (c); divide the product by the difference between the chord dimensions (C − c). To find the inside diameter (d) multiply the inside radius (r) by 2.

Example: To find the inside radius of a ring formed by a 9″ No. 1 wedge brick 9″ × 4½″ × (2½″ − 1⅞″); in this case T = 9″, C = 2½″, c = 1⅞″

Then, Inside Radius (r) $= \frac{1.875 \times 9}{2.5 - 1.875} = 27'' = 2'\text{-}3''$

Inside Diameter (d) = 2 × 27″ = 54″ = 4′-6″

4. *To find Outside Radius* (R) *of ring formed by radial brick when inside radius* (r) *and the dimensions of the brick are known:*

Formula 4: R = r + T ; D = 2R

To the inside radius (r) add the radial dimension of the brick (T). To find the outside diameter (D) multiply the outside radius (R) by 2.

Example: Let r = 27″ (See example 3), T = 9″

Then, Outside Radius (R) = 27″ + 9″ = 36″ = 3′-0″

Outside Diameter (D) = 2 × 36″ = 72″ = 6′-0″

5. *To find Included Angle* (α) *of a radial brick when the number of pieces* (N_r) *required to form a ring is known:*

Formula 5: $\alpha = \frac{360°}{N_r}$

Divide 360° by the number of pieces (N_r) per ring.

Example: Let N_r = 45:

Then, Included Angle (α) $= \frac{360°}{45} = 8°$

6. *To find Included Angle* (α) *when the outside chord dimension* (C) *and outside radius* (R) *are known:*

Formula 6-a:

For circle type radial brick:

Sine ½ $\alpha = \frac{C}{2\,R}$

Divide outside chord dimension (C) by twice the outside radius (2R). The result is the sine of half the included angle (α). Determine the angle whose sine is equal to this figure by reference to a table of trigonometric functions.

Example: Let C = 6″, R = 36″: Then, Sine of ½ $\alpha = \frac{6}{2 \times 36} = 0.08333$

From table of functions on page 365, the angle having a sine of 0.08333 is 4.78°

Then, Included Angle (α) = 2 × 4.78° = 9.56° = 9° 33.6′

NOTE: The use of Formula 6-b is similar to that of Formula 6-a.

7. *To find Inside and Outside Chord Dimensions* (c *and* C) *when inside and outside diameters* (d *and* D) *and included angle* (α) *are known:*

Formula 7-a:

For circle type radial brick:

c = d sine ½ α

C = D sine ½ α

To find the inside chord dimension (c) multiply the inside diameter (d) by the sine of ½ the included angle (α); to find the outside chord dimension (C) multiply the outside diameter (D) by the sine of ½ the included angle (α).

Example: Let d = 15″; D = 24″; α = 30°

From table of functions on page 365, the sine of ½ α = the sine of 15° = 0.25882

Then, Inside Chord Dimension (c) = 15 × 0.25882 = 3.8823″ = 3⅞″

Outside Chord Dimension (C) = 24 × 0.25882 = 6.2117″ = $6\frac{7}{32}''$

NOTE: The use of Formula 7-b is similar to that of Formula 7-a.

8. *To find Number of Pieces* (N_r) *required to form a Ring when the included angle* (α) *is known:*

Formula 8: $N_r = \frac{360°}{\alpha}$

Divide 360° by the number of degrees in the included angle (α).

Example: Let α = 10°: Then, Number (N_r) required to form a ring $= \frac{360°}{10°} = 36$

9. **To find Number of Pieces* (N_r) *required to form a Ring when the dimensions of the brick are known:*

Formula 9: $N_r = \frac{2\pi\,T}{C - c}$

Multiply the radial dimension (T) by 2π (6.2832); divide the product by the difference between the chord dimensions (C − c) of the brick.

Example: Let T = 9″, C = 2½″, c = 1⅞″

Then, Number (N_r) required to form a ring $= \frac{6.2832 \times 9}{2\frac{1}{2} - 1\frac{7}{8}} = 90.4781 = 91$

10. **To find Number of Pieces* (N_r) *required to form a Ring when the outside diameter* (D) *and the outside chord dimension* (C) *are known:*

Formula 10: $N_r = \frac{\pi D}{C}$

Divide the outside circumference (πD) by the outside chord dimension (C).

Example: To find the number of 9″ No. 1 wedge brick 9″ × 4½″ × (2½″ − 1⅞″) required to form a ring. In this case D = 72″ (See example 4), C = 2½″

Then, Number (N_r) required to form a ring $= \frac{3.1416 \times 72}{2.5} = 90.4781 = 91$

*Approximate; close enough for most purposes.

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SPECIAL CIRCLE TYPE RADIAL BRICK

The following table is applicable for designing special circle type radial brick for circular linings of given outside diameters (D) when an exact number of pieces per ring is desired. The approximate outer chord dimension (C) of the radial brick is selected arbitrarily, generally as 3″, 4½″, 6″ or 9″, depending upon the diameter of the lining.

First, the approximate number of brick required to form one complete ring or course is determined by dividing the circumference (π D) by the arbitrarily selected chord dimension. The result will consist of a whole number plus a fraction. If the fraction is less than 0.5 it is usually dropped; if more than 0.5, the next larger number is generally taken. This gives the exact number of brick which will be used per ring.

It is now necessary to correct the arbitrarily chosen outer chord dimension in accordance with this exact number of brick per ring. Find this number in column 1 of the table and the corresponding "Sine of Half Angle" in column 2. Next, multiply the diameter of the lining by this "Sine of Half Angle". The result is the corrected chord dimension.

The inner or any intermediate chord dimension is obtained by multiplying the corresponding diameter by the "Sine of Half Angle".

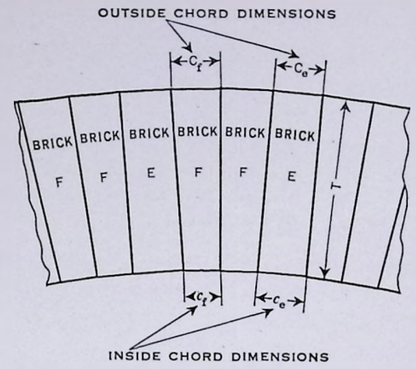
Column 1 No. of Brick per Ring	Column 2 Sine of Half Angle	Column 1 No. of Brick per Ring	Column 2 Sine of Half Angle	Column 1 No. of Brick per Ring	Column 2 Sine of Half Angle	Column 1 No. of Brick per Ring	Column 2 Sine of Half Angle
5	0.58779	29	0.10812	53	0.05924	77	0.04079
6	0.50000	30	0.10453	54	0.05815	78	0.04027
7	0.43388	31	0.10117	55	0.05709	79	0.03975
8	0.38268	32	0.09802	56	0.05607	80	0.03926
9	0.34202	33	0.09506	57	0.05508	81	0.03878
10	0.30902	34	0.09227	58	0.05414	82	0.03830
11	0.28173	35	0.08964	59	0.05322	83	0.03784
12	0.25882	36	0.08716	60	0.05234	84	0.03739
13	0.23932	37	0.08481	61	0.05147	85	0.03695
14	0.22252	38	0.08258	62	0.05065	86	0.03652
15	0.20791	39	0.08047	63	0.04985	87	0.03610
16	0.19509	40	0.07846	64	0.04907	88	0.03569
17	0.18375	41	0.07655	65	0.04832	89	0.03529
18	0.17365	42	0.07473	66	0.04758	90	0.03490
19	0.16459	43	0.07299	67	0.04687	91	0.03452
20	0.15643	44	0.07134	68	0.04618	92	0.03414
21	0.14904	45	0.06976	69	0.04552	93	0.03377
22	0.14231	46	0.06825	70	0.04486	94	0.03341
23	0.13616	47	0.06680	71	0.04423	95	0.03306
24	0.13053	48	0.06540	72	0.04362	96	0.03272
25	0.12533	49	0.06407	73	0.04302	97	0.03238
26	0.12054	50	0.06279	74	0.04244	98	0.03205
27	0.11609	51	0.06156	75	0.04188	99	0.03173
28	0.11197	52	0.06038	76	0.04132	100	0.03141

Example: Let the outside diameter of the lining (D) equal 60 inches. The lining is to be 9 inches thick, and the individual brick are to have an outside chord dimension (C) of approximately 6 inches.

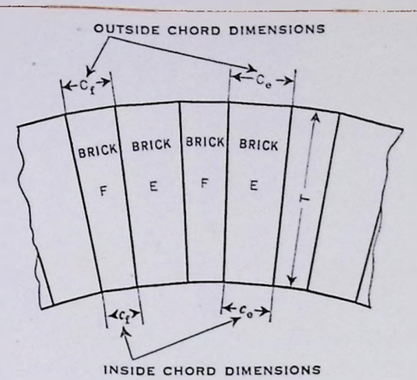
The approximate number of brick per ring is π D ÷ C = 3.1416 × 60 ÷ 6 = 31.416. The number of brick used per ring will be 31. From column 2 of the table, the "Sine of Half Angle" corresponding to 31 pieces per ring is 0.10117. The corrected outside chord dimension of the brick is the diameter multiplied by this value, or 60″ × 0.10117 which equals 6.070 = 6 1/16″.

The inside diameter is 60″ − 18″ = 42″. The inside chord = 42″ × 0.10117 = 4.249″ = 4¼″.

COMBINATIONS OF TWO SIZES OF BRICK TO FORM A RING



COMBINATION OF A STRAIGHT BRICK (E) AND A RADIAL BRICK (F) TO FORM A RING.



COMBINATION OF TWO RADIAL BRICK (E AND F) TO FORM A RING. BRICK E TURNS A LARGER DIAMETER THAN BRICK F.

SYMBOLS

E = Either a straight brick or a radial brick used with a companion brick F; when brick E is radial it turns a larger diameter than brick F.
F = A radial brick; used with a companion brick E which may be either straight or radial; in the latter case brick F turns a smaller diameter than brick E.
T = Radial dimension common to both brick E and F.
D_e = Outside diameter of ring formed by brick E.
D_f = Outside diameter of ring formed by brick F.
D_g = A given outside diameter larger than D_f; if brick E is radial, D_g must lie between D_e and D_f.
d_g = A given inside diameter.
C_e = Outside chord dimension of brick E.
C_f = Outside chord dimension of brick F.
c_e = Inside chord dimension of brick E.
c_f = Inside chord dimension of brick F.
N_e = Number of pieces of brick E, when used in combination with brick F, to form a ring having a given outside diameter D_g.
N_f = Number of pieces of brick F, when used in combination with brick E, to form a ring having a given outside diameter D_g.
N_t = Total number of pieces of brick E and F used in combination, to form a ring having a given outside diameter D_g.
N_x = Number of pieces of brick E required to form a complete ring having an outside diameter D_e.
N_y = Number of pieces of brick F required to form a complete ring having an outside diameter D_f.

FORMULAS

(11-a) $N_f = \dfrac{2\pi T}{C_f - c_f}$ (11-b) $N_e = \dfrac{\pi D_g - N_f C_f}{C_e}$ (11-c) $N_t = N_e + N_f$

(12-a) $N_t = \dfrac{\pi D_g}{C_e} = \dfrac{\pi D_g}{C_f}$ (12-b) $N_e = \dfrac{\pi d_g - N_t c_f}{c_e - c_f}$ (12-c) $N_f = N_t - N_e$

(13-a) $N_e C_e + N_f C_f = \pi D_g$ (13-b) $N_e c_e + N_f c_f = \pi d_g$ (13-c) $N_t = N_e + N_f$

(14-a) $N_e = \dfrac{N_x}{D_e - D_f}(D_g - D_f)$ (14-b) $N_f = \dfrac{N_y}{D_e - D_f}(D_e - D_e)$ (14-c) $N_t = N_e + N_f$

NOTES: 1. When one brick E is a straight and the other brick F is radial, *use Formulas 11-a, 11-b and 11-c.*
2. When both brick E and F are radial, and the outside chord dimensions (C_e and C_f) are equal, and the inside chord dimensions (c_e and c_f) are unequal, *use Formulas 12-a, 12-b, and 12-c.*
3. When both brick E and F are radial, and the outside and inside chord dimensions of brick E differ from the corresponding chord dimensions of brick F:
For a single combination *Use Formulas 13-a, 13-b and 13-c*
For a series of combinations *Use Formulas 14-a, 14-b and 14-c*

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USE OF FORMULAS FOR COMBINATIONS OF TWO SIZES OF BRICK REQUIRED TO FORM A RING

11. To find the Number of Pieces (N_e and N_t) of Straight Brick E and Radial Brick F required when used in combination to form a ring having a given inside diameter (d_g) or outside diameter (D_g):

Formula 11-a: $N_t = \dfrac{2\pi\ T}{C_t - c_t}$

To find the Number of Pieces (N_t) of Radial Brick F: multiply the radial dimension (T) by 2π (6.2832) and divide the product by the difference between the outside and inside chord dimensions ($C_t - c_t$) of the Radial brick.

Formula 11-b: $N_e = \dfrac{\pi\ D_g - N_t\ C_t}{C_e}$

To find the Number of Pieces (N_e) of Straight Brick E: from the given outside circumference ($\pi\ D_g$) subtract the product of the number of pieces (N_t) of the Radial brick F multiplied by the outside chord dimension (C_t) of brick F; divide the remainder by the outside chord dimension (C_e) of the Straight brick E.

Formula 11-c: $N_t = N_e + N_t$

To find the Total Number of Pieces (N_t): add the number of pieces (N_t) of Radial brick F to the number of pieces (N_e) of Straight brick E.

Example: To find the number of 9″ Straight brick 9″ × 4½″ × 2½″ required in combination with 9″ No. 1-X Wedge brick 9″ × 4½″ × (2½″ − 2¼″) to form a ring 15′-0″ inside diameter (d_g) or 16′-6″ outside diameter (D_g). In this case the Straight brick = E; the Wedge brick = F; d_g = 180″; D_g = 198″; $C_e = C_t$ = 2½″; c_t = 2¼″; T = 9″.

Then, Number of 9″ No. 1-X Wedge $(N_t) = \dfrac{2 \times 3.1416 \times 9}{2.5 - 2.25} = 226.195 = 227.$

Number of 9″ Straights $(N_e) = \dfrac{(3.1416 \times 198 - (227 \times 2.5)}{2.5} = 21.8147 = 22$

Total Number per ring $(N_t) = 227 + 22 = 249$

NOTE: In the example given, C_e equals C_t. However, Formulas 11-a, 11-b and 11-c are also applicable when C_e does not equal C_t.

12. To find the Number of Pieces (N_e and N_t) of two Radial Brick E and F having equal outside chord dimensions (C_e and C_t) and unequal inside chord dimensions (c_e and c_t) when the two brick are used in combination to form a ring with a given inside diameter (d_g) or outside diameter (D_g):

Formula 12-a: $N_t = \dfrac{\pi\ D_g}{C_e} = \dfrac{\pi\ D_g}{C_t}$

To find the total Number of Pieces (N_t): divide the given outside circumference ($\pi\ D_g$) by the common outside chord dimension (C_e or C_t).

Formula 12-b: $N_e = \dfrac{\pi\ d_g - N_t\ c_t}{c_e - c_t}$

To find the Number of Pieces (N_e) of the brick E which turns the larger diameter: from the given inside circumference ($\pi\ d_g$) subtract the product of the total number of pieces (N_t) multiplied by the inside chord dimension (c_t) of brick F; divide the remainder by the difference between the inside chord dimensions ($c_e - c_t$) of brick E and brick F.

Formula 12-c: $N_t = N_t - N_e$

To find the Number of Pieces (N_t) of brick F which turns the smaller diameter: subtract the number of pieces (N_e) of brick E from the total number of brick (N_t), required to form a ring.

Example: To find the number of 9″ No. 1 Wedge brick 9″ × 4½″ × (2½″ − 1⅞″) and 9″ No. 2 Wedge brick 9″ × 4½″ × (2½″ − 1½″) when used in combination to form a ring 4′-0″ inside diameter (d_g). Then the No. 1 Wedge brick = brick E; No. 2 Wedge brick = brick F; d_g = 48″; D_g = 66″; $C_e = C_t$ = 2½″; c_e = 1⅞″; c_t = 1½″.

Then, Total Number per ring $(N_t) = \dfrac{3.1416 \times 66}{2.5} = 82.9382 = 83$

Number of 9″ No. 1 Wedge $(N_e) = \dfrac{(3.1416 \times 48) - (82.9382 \times 1.5)}{1.875 - 1.5} = 70.3720 = 70$

Number of 9″ No. 2 Wedge $(N_t) = 82.9382 - 70.3720 = 12.5662 = 13$

13. To find Number of Pieces each of Two Radial Brick (E and F) having different chord dimensions at both the outside ends (C_e and C_t) and inside ends (c_e and c_t) when used in combination to form a ring of a given inside diameter (d_g) or outside diameter (D_g):

Formulas: 13-a $N_e\ C_e + N_t\ C_t = \pi\ D_g$; 13-b $N_e\ c_e + N_t\ c_t = \pi\ d_g$

To find the Number of Pieces (N_e and N_t) of brick E and F: solve the two simultaneous equations, 13-a and 13-b.

Formula: 13-c $N_t = N_e + N_t$

To find the total Number of Pieces N_t: add the number of pieces (N_e) of brick E to the number of pieces (N_t) of brick F.

The two simultaneous equations are set up as follows:

13-a The number of pieces N_e of brick E multiplied by the outside chord dimension (C_e) of brick E plus the number of pieces N_t of brick F multiplied by the outside chord dimension (C_t) of brick F equals the outside circumference ($\pi\ D_g$).

13-b The number of pieces N_e of brick E multiplied by the inside chord dimension (c_e) of brick E plus the number of pieces N_t of brick F multiplied by the inside chord dimension (c_t) of brick F equals the inside circumference ($\pi\ d_g$).

Example: Let d_g = 48″, D_g = 66″, T = 9″

Dimensions of brick E: Outside chord dimension (C_e) = 3¼″; inside chord dimension (c_e) = 2½″

Dimensions of brick F: Outside chord dimension (C_t) = 3⅜″; inside chord dimension (c_t) = 2¼″

Substituting the proper values in equations 13-a and 13-b:

13-a $3.25\ N_e + 3.375\ N_t = 3.1416 \times 66 = 207.3456$
13-b $2.5\ N_e + 2.25\ N_t = 3.1416 \times 48 = 150.7968$

Multiply equation 13-b by 1.5 and solve for N_e:

$3.25\ N_e + 3.375 N_t = 207.3456$
$3.75\ N_e + 3.375 N_t = 226.1952$
$-.5\ N_e = -18.8496$; $N_e = 37.6992$

Substituting 37.6992 for N_e in equation 13-b:

$94.2480 + 2.25 N_t = 150.7968$; $2.25 N_t = 56.5488$; $N_t = 25.1328$

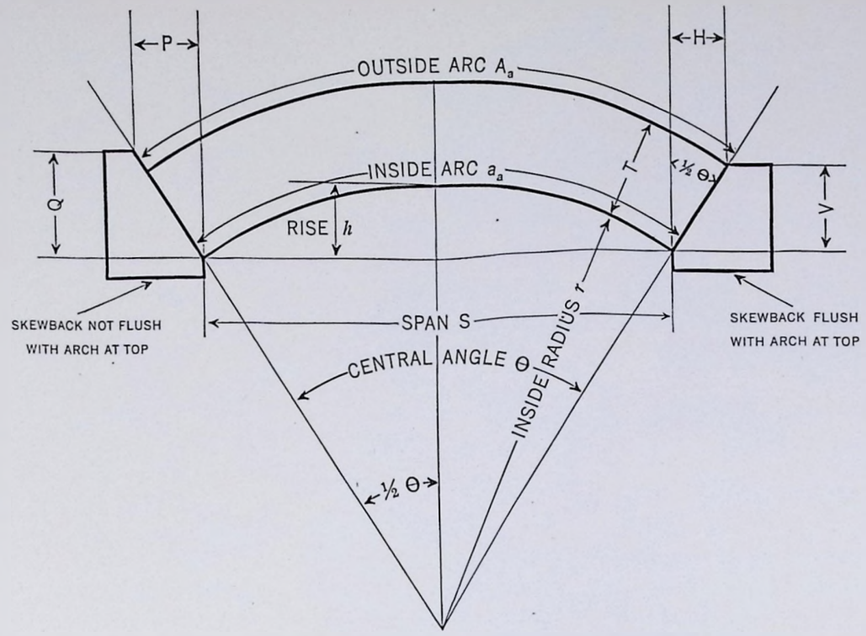
Then, Total Number of pieces $(N_t) = N_e + N_t = 37.6992 + 25.1328 = 62.8320 = 63$

Number of pieces (N_e) of brick E = 37.6992 = 38

Number of pieces (N_t) of brick F = 25.1328 = 25

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ELEMENTS OF A CIRCULAR ARC SPRUNG ARCH



SYMBOLS

a_a = Length of inside arc of arch.

A_a = Length of outside arc of arch.

R = Outside radius of arch.

S = Span of arch.

d = Rise of arch in inches per foot of span.

h = Total rise of arch.

T = Thickness of arch.

Θ = Theta, the central angle of arch.

E = Either a straight brick or a radial brick used with a companion brick F to form a course of an arch; when brick E is radial it turns a larger diameter than brick F.

F = A radial brick used with a companion brick E to form a course of an arch. E may be either a straight or a radial brick; in the latter case brick F turns a smaller diameter than brick E.

C = The outside chord dimension common to brick E and brick F.

r = Inside radius of arch.

c_e = Inside chord dimension of brick E.

c_f = Inside chord dimension of brick F.

N_e = Number of pieces of brick E required when used in combination with brick F, to form a complete ring of 360°.

N_f = Number of pieces of brick F required, when used in combination with brick E, to form a complete ring of 360°.

N_t = Total number of brick E and F required to form a complete ring of 360°.

n_e = Number of pieces of brick E required per course of arch.

n_f = Number of pieces of brick F required per course of arch.

n_t = Total number of brick E and F per course of arch.

H, V, P and Q = Skewback dimensions.

ARCH FORMULAS

(15) $r = \dfrac{\left(\frac{S}{2}\right)^2 + h^2}{2h}$, $R = r + T$

(16) $h = r - \sqrt{r^2 - \left(\frac{S}{2}\right)^2}$

(17) Sine ½ Θ $= \dfrac{S}{2r}$

(18) Cosine ½ Θ $= \dfrac{S^2 - 4h^2}{S^2 + 4h^2}$

(19) Tangent ¼ Θ $= \dfrac{2h}{S}$

(20) Tangent ¼ Θ $= \dfrac{d}{6}$

(21) Part of circle $= \dfrac{\Theta}{360°}$

(22) $d = 6$ tangent ¼ Θ

(23-a) $a_a = 2\pi r \dfrac{\Theta}{360°}$

(23-b) $A_a = 2\pi R \dfrac{\Theta}{360°}$

(24-a) $n_t = N_t \dfrac{\Theta}{360°}$

(24-b) $n_e = N_e \dfrac{\Theta}{360°}$

(24-c) $n_f = N_f \dfrac{\Theta}{360°}$

(25-a) $n_t = \dfrac{A_a}{C}$

(25-b) $n_e = \dfrac{a_a - n_t c_f}{c_e - c_f}$

(25-c) $n_f = n_t - n_e$

(26-a) $H = T$ Sine ½ Θ

(26-b) $V = T$ Cosine ½ Θ

(27) $P = Q$ Tangent ½ Θ

NOTE: Approximate formula for arches with rise of 1 to 3 inches per foot of span, $\Theta = 180 \frac{h}{S}\left(2.62 - \frac{h}{S}\right)$

ARCH CONSTANTS FOR GIVEN RISES PER FOOT OF SPAN

Rise in Inches Per Foot of Span (d)	Inside Radius (r)	Central Angle (Θ)		Inside Arc (a_a)	Difference Between Outside and Inside Arcs ($A_a - a_a$)	Skewback		
		Degrees	Part of Circle			H	V	P
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1″	1.54167 S	37° 50.9′	0.10514	1.01840 S	0.66059 T	0.32432 T	0.94595 T	0.34286 Q
1¼″	1.25208 S	47° 4.4′	0.13076	1.02868 S	0.82157 T	0.39933 T	0.91681 T	0.43557 Q
1½″	1.06250 S	56° 8.7′	0.15596	1.04117 S	0.97992 T	0.47059 T	0.88235 T	0.53333 Q
1.608″	1.00000 S	60° 00.0′	0.16667	1.04720 S	1.04720 T	0.50000 T	0.86603 T	0.57735 Q
1¾″	0.93006 S	65° 2.5′	0.18067	1.05579 S	1.13519 T	0.53760 T	0.84320 T	0.63757 Q
2″	0.83333 S	73° 44.4′	0.20483	1.07251 S	1.28701 T	0.60000 T	0.80000 T	0.75000 Q
2¼″	0.76042 S	82° 13.4′	0.22840	1.09125 S	1.43507 T	0.65753 T	0.75342 T	0.87273 Q
2.302″	0.74742 S	83° 58.5′	0.23326	1.09544 S	1.46563 T	0.66896 T	0.74329 T	0.90000 Q
2½″	0.70417 S	90° 28.8′	0.25133	1.11200 S	1.57918 T	0.71006 T	0.70414 T	1.00840 Q
2¾″	0.66004 S	98° 29.7′	0.27360	1.13464 S	1.71906 T	0.75753 T	0.65280 T	1.16044 Q
3″	0.62500 S	106° 15.6′	0.29517	1.15912 S	1.85459 T	0.80000 T	0.60000 T	1.33333 Q

NOTE: The factors in the above tables are the following functions of Θ: Column 2, ½ cosecant ½ Θ; column 4, Θ divided by 360°; column 5, ½ cosecant ½ Θ times included radians; column 6, included radians; column 7, sine ½ Θ; column 8, cosine ½ Θ; column 9, tangent ½ Θ.

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USE OF ARCH FORMULAS

15. To find Inside Radius (r) *when rise* (h) *and span* (S) *are known:*

Formula 15: $r = \dfrac{\left(\frac{S}{2}\right)^2 + h^2}{2h}$ To the square of half the span $\left(\frac{S}{2}\right)^2$ add the square of the rise $(h)^2$ and divide the sum by twice the rise (2 h).

Example: Let S = 54″, h = 9″

Then, Inside Radius (r) $= \dfrac{\left(\frac{54}{2}\right)^2 + 9^2}{18} = \dfrac{810}{18} = 45'' = 3'\text{-}9''$

16. To find Rise (h) *when inside radius* (r) *and span* (S) *are known:*

Formula 16: $h = r - \sqrt{r^2 - \left(\frac{S}{2}\right)^2}$ Subtract the square of half the span $\left(\frac{S}{2}\right)^2$ from the square of the inside radius $(r)^2$; extract the square root of the difference. Subtract this square root from the inside radius (r).

Example: Let r = 45″, S = 54″

Then, Rise (h) $= 45 - \sqrt{45^2 - 27^2} = 45'' - 36'' = 9''$

17. To find Central Angle (Θ) *when span* (S) *and inside radius* (r) *are known:*

Formula 17: Sine $\frac{1}{2}\,\Theta = \dfrac{S}{2r}$ Divide the span (S) by twice the inside radius (2 r). This gives the sine of ½ the angle (Θ). From a table of trigonometric functions determine the angle corresponding to this sine and multiply by 2 to find the angle (Θ).

Example: Let S = 54″, h = 9″, r = 45″

Then, Sine $\frac{1}{2}\,\Theta = \dfrac{54}{2 \times 45} = 0.60000$. From table of functions on page 365 the angle having a sine of 0.60000 = 36.87° = 36° 52.2′

Central Angle (Θ) = 2 × 36.87° = 73.74° = 73° 44.4′

18. To find the Cosine of ½ the Central Angle (*Cosine* ½ Θ) *when the span* (S) *and the rise* (h) *are given:*

Formula 18: Cosine $\frac{1}{2}\,\Theta = \dfrac{S^2 - 4h^2}{S^2 + 4h^2}$ From the square of the span (S^2) subtract 4 times the square of the rise ($4h^2$); divide the difference by the sum of the square of the span (S^2) plus 4 times the square of the rise ($4h^2$).

Example: Let S = 54″, h = 9″

Then the Cosine of $\frac{1}{2}\,\Theta = \dfrac{54^2 - 4 \times 9^2}{54^2 + 4 \times 9^2} = \dfrac{2916 - 324}{2916 + 324} = \dfrac{2592}{3240} = 0.8000$

19. To find Central Angle (Θ) *when the span* (S) *and rise* (h) *are known:*

Formula 19: Tangent $\frac{1}{4}\,\Theta = \dfrac{2h}{S}$ Divide twice the rise (2 h) by the span (S). This gives the tangent of ¼ the angle (Θ). From a table of trigonometric functions on page 366 determine the angle corresponding to this tangent and multiply by 4 to find the angle (Θ).

Example: Let S = 54″, h = 9″

Then, Tangent $\frac{1}{4}\,\Theta = \dfrac{2 \times 9}{54} = 0.33333$. By interpolation from figures given in table of functions on page 366, the angle having a tangent of 0.33333 = 18.435°

Central Angle (Θ) = 4 × 18.435° = 73.74° = 73° 44.4′

NOTE: When the span (S) and rise (h) are given, Θ can be determined approximately, without reference to trigonometric tables, by use of the formula:

$$\Theta = \text{approximately } 180\,\frac{h}{S}\left(2.62 - \frac{h}{S}\right)$$

Example: *Using the above example,*

$$\Theta = \text{approximately } 180\,\frac{9}{54}\left(2.62 - \frac{9}{54}\right) = 30\,(2.62 - 0.167) = 30 \times 2.453 = 73.59°$$

True value of Θ = 73.74°

Error in determination of Θ, 73.74° − 73.59° = 0.15° = 0° 09′

20. To find Central Angle (Θ) *when rise in inches per foot of span* (d) *is known:*

Formula 20: Tangent $\frac{1}{4}\,\Theta = \dfrac{d}{6}$ Divide the rise in inches per foot of span (d) by 6. This gives the tangent of ¼ the central angle (Θ). From the table of trigonometric functions on page 366 determine the corresponding angle and multiply by 4 to find the central angle.

Example: Let the rise per foot of span (d) equal 2 inches.

Then, Tangent $\frac{1}{4}\,\Theta = \dfrac{2.0}{6} = 0.33333$

From table of functions on page 366, the angle having a tangent of 0.33333 = 18.435°

Central Angle (Θ) = 4 × 18.435° = 73.74° = 73° 44.4′

21. To find Part of Circle when the central angle (Θ) *is known:*

Formula 21: Part of Circle $= \dfrac{\Theta}{360°}$ Divide the central angle Θ by 360°

Example: Let Θ = 73.74° = 73° 44.4′

Then, Part of Circle $\left(\dfrac{\Theta}{360°}\right) = \dfrac{73.74°}{360°} = 0.20483$

22. To find the Rise in Inches per Foot (d) *when the central angle* (Θ) *is known:*

Formula 22: d = 6 tangent ¼ Θ From the table of trigonometric functions on page 366 determine the tangent of ¼ the central angle (tangent ¼ Θ). The rise in inches per foot of span is 6 times this figure.

Example: Let Θ = 60°, then ¼ Θ = 15°

From table on page 366, the tangent of 15° is 0.26795.

The rise in inches per foot of span (d) = 6 × 0.26795 = 1.6077″ = $1\frac{19}{32}$″

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23. *To find Length of Arcs* (a_a *and* A_a) *when the inside and outside radii* (r *and* R) *and the central angle* (Θ) *of the arch are known:*

Formula 23-a: $a_a = 2\pi\, r \frac{\Theta}{360°}$ — To determine the inside arc (a_a) multiply the inside circumference ($2\pi r$) by the part of circle $\left(\frac{\Theta}{360°}\right)$

Formula 23-b: $A_a = 2\pi\, R \frac{\Theta}{360°}$ — To determine the outside arc (A_a) multiply the outside circumference ($2\pi R$) by the part of the circle.

Example: Let r = 45″, T = 9″, R = 54″; Θ = 73° 44.4′, $\frac{\Theta}{360°}$ = 0.20483

Then, Inside arc (a_a) = 6.2832 × 45″ × 0.20483 = 57.9145″ = 4′-9 $\frac{29}{32}$″

Outside arc (A_a) = 6.2832 × 54″ × 0.20483 = 69.4973″ = 5′-9½″

24. *To find the Number of Pieces per Course* (n_t, n_e *and* n_f) *of brick* E *and* F *when the inside radius* (r) *and the central angle* (Θ) *are known:*

Formula 24-a: $n_t = N_t \frac{\Theta}{360°}$

Formula 24-b: $n_e = N_e \frac{\Theta}{360°}$

Formula 24-c: $n_f = N_f \frac{\Theta}{360°}$

To find the Total Number (n_t) and the number of each (n_e and n_f) of the two sizes of brick E and F required per course: find the number (N_t, N_e and N_f) of brick required to form a complete ring of the given inside diameter. When brick E and F are standard sizes having equal outside chord dimensions, use the brick tables on pages 383 to 404. When brick E and F are standard sizes having unequal outside chord dimensions, or if they are special radial brick, use the formulas given on page 371. To find the numbers (n_e, n_f and n_t) required per course of arch, multiply the quantities so determined by the part of a circle $\left(\frac{\Theta}{360°}\right)$ included in the given arch.

Example: Let r = 45″, T = 9″, Inside diameter = 7′-6″, Θ = 73° 44.4′, $\frac{\Theta}{360°}$ = 0.20483

Using 9″ Wedge brick, 2½″ Series (page 31), it is seen from the table on page 388 that a complete ring of 7′-6″ inside diameter requires 76 pieces of 9″ No. 1-X Wedge brick (N_e) and 60 pieces of 9″ No. 1 Wedge brick (N_f), or a total of 136 pieces (N_t). In this case the No. 1-X Wedge brick = E, and the No. 1 Wedge brick = F.

Then, Total Number per course of arch (n_t) = 136 × 0.20483 = 27.8569 = 28
Number of 9″ No. 1-X Wedge brick (n_e) = 76 × 0.20483 = 15.5671 = 16
Number of 9″ No. 1 Wedge brick (n_f) = 60 × 0.20483 = 12.2898 = 12

25. *To find the Number of Pieces per Course* (n_t, n_e *and* n_f) *of brick* E *and* F *when the inside radius* (r) *and the inside and outside arcs* (a_a *and* A_a) *are known:*

Formula 25-a: $n_t = \frac{A_a}{C}$ — **To find the total number of pieces per course (n_t):** divide the outside arc (A_a) by the outside chord dimension (C).

Formula 25-b: $n_e = \frac{a_a - n_t\, c_f}{c_e - c_f}$ — **To find the number of pieces (n_e) of brick E** (the straight brick or the radial brick which turns the larger diameter): multiply the total number of pieces per course (n_t) by the inside chord dimension (c_f) of brick F and subtract the product from the inside arc (a_a); divide the value so found by the difference between the inside chord dimensions ($c_e - c_f$) of brick E and F.

Formula 25-c: $n_f = n_t - n_e$ — **To find the number of pieces (n_f) of brick F:** subtract the number of pieces (n_e) of brick E from the total number (n_t) per course.

Example: Let r = 45″, T = 9″, a_a = 57.9145″, A_a = 69.4973″

Using 9″ Wedge brick, 2½″ Series (page 31), it is seen from the table on page 388 that an arch for the given inside diameter of 7′-6″ requires 9″ No. 1-X Wedge brick and 9″ No. 1 Wedge brick for its construction. In this case the No. 1-X Wedge brick = E and the No. 1 Wedge brick = F.

Then, Total Number per course (n_t) = $\frac{69.4973}{2.5}$ = 27.7989 = 28

Number of 9″ No. 1-X Wedge (n_e) = $\frac{57.9145 - (27.7989 \times 1.875)}{2.25 - 1.875}$ = 15.4443 = 16

Number of 9″ No. 1 Wedge (n_f) = 27.7989 − 15.4443 = 12.3546 = 12

NOTE: The counts derived from this method are somewhat more accurate than are counts derived from the usual method (formulas 24-a, 24-b and 24-c); however, the usual method gives results which are sufficiently accurate. This method is applicable only when the outside dimensions (C) of the two brick used are equal. If they are unequal the brick count can be determined by setting up two simultaneous equations as in formulas and example 13 on page 373, substituting arcs for circumferences.

26. *To find Dimensions* (H *and* V) *of the Skewback to fit an arch when the central angle* (Θ) *and the thickness* (T) *are known:*

Formula 26-a: H = T sine ½ Θ — **To find the dimension (H):** multiply the thickness (T) by the sine of ½ the central angle (Θ).

Formula 26-b: V = T cosine ½ Θ — **To find the dimension (V):** multiply the thickness (T) by the cosine of ½ the central angle (Θ). (The sine and cosine may be found in a table of trigonometric functions).

Example: Let Θ = 73.74° = 73° 44.4′, T = 9″. From table of functions on page 365, Sine ½ Θ = sine 36.87° = 0.60000, cosine ½ Θ = cosine 36.87° = 0.80000

Then, Dimension H = 9 × 0.60000 = 5.4″ = 5 $\frac{13}{32}$″ Dimension V = 9 × 0.80000 = 7.2″ = 7 $\frac{3}{16}$″

27. *To find Dimension* (P) *of the Skewback to fit an arch when the vertical dimension* (Q) *and the central angle* (Θ) *are known:*

Formula 27: P = Q tangent ½ Θ — **To find the dimension (P):** multiply the dimension (Q) by the tangent of ½ the central angle (Θ). (The tangent may be found in a table of trigonometric functions.)

Example: Let Q = 9″, Θ = 73.74° = 73° 44.4′. From table of functions on page 366, tangent ½ Θ = tangent 36.87° = 0.75000

Then, Dimension P = 9 × 0.75000 = 6.75″ = 6¾″

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USE OF ARCH CONSTANTS

The use of the table on page 375 is illustrated by the following specific example:

Let

Span (S) = 6′-0″ = 72″ — Thickness (T) = 9″

Rise per foot of span (d) = 2″ — Total Rise (h) = 2″ × 6 = 12″

1. *To find the Arch Dimensions:*

From table:

Inside radius (r) = 0.83333 × 72″ = 60.0″ = 5′-0″ (See column 2 for factor)
(The inside radius can also be found from the table on page 415.)

Part of circle $\left(\frac{\theta}{360°}\right)$ = 0.20483 (From column 4)

Central angle (θ) = 73° 44.4′ (From column 3)

Inside arc (a_a) = 1.07251 × 72″ = 77.2207″ = 6′-5$\frac{7}{32}$″ (See column 5 for factor)

Difference between arcs ($A_a - a_a$) = 1.28701 × 9″ = 11.5831″ = 11$\frac{19}{32}$″ (See column 6 for factor)

Then outside arc (A_a) = inside arc (a_a) + difference ($A_a - a_a$) = 77.2207″ + 11.5831″ = 88.8038″ = 7′-4$\frac{13}{16}$″

2. *To find Dimensions of Skewback:*

When skewback is flush with arch at top; and T = 9″, then,

Dimension H = 0.60000 × 9″ = 5.4000″ = 5$\frac{13}{32}$″ (See column 7 for factor)
Dimension V = 0.80000 × 9″ = 7.2000″ = 7$\frac{3}{16}$″ (See column 8 for factor)

In the event that skewback is not flush with arch at top, and Q = 9″, then
Dimension (P) = 0.75000 × 9″ = 6.75000″ = 6¾″ (See column 9 for factor)

3. *To find the Number of Brick per Course of Arch:*

(a) If standard 9″ brick of the 2½″ Series are to be used, refer to table on page 415.
For a span of 6′-0″, it is shown that the following number of pieces is required per course:

9″ No. 1 Wedge — 2½″ Series	7
9″ No. 1-X Wedge — 2½″ Series	29
Total pieces	36

(b) If standard 9″ brick of the 3″ Series are to be used, refer to table on page 416.
For a span of 6′-0″, it is shown that the following number of pieces is required per course:

9″ No. 2 Wedge — 3″ Series	17
9″ No. 1 Wedge — 3″ Series	13
Total pieces	30

NOTE: The tables on pages 407 to 422 can be used only when the rise per foot of span is 1½″, 1$\frac{13}{32}$″, 2″ or 2$\frac{5}{16}$″. For any other rise, proceed as follows:

Determine the central angle θ from formula 19, page 375. Using this value, calculate the number of brick required per course of arch from formulas 24-a, 24-b and 24-c, page 375.

BRICK COMBINATIONS FOR RINGS



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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BRICK COMBINATIONS REQUIRED FOR RINGS

In estimating the quantities of brick required for the construction of circular linings, roofs and arches, the various tables on the following pages will be found useful. These tables give the combinations of brick sizes required for rings of given diameters.

In calculating the tables, fractional parts equal to or greater than one-tenth of a brick were counted as entire brick; no allowance was made for mortar or expansion joints or for size deviations of the brick. For these reasons the brick combinations shown may lay up to diameters which differ slightly from the theoretical diameters; and the number of brick required for a ring, as given in the tables, may be slightly in excess of the number actually required.

Generally, in laying a ring course of brick, it is necessary to cut the last one or two pieces to complete the ring.

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4½″ LINING—ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
0′- 6″	19	...	...	...	19
0′- 7″	18	3	...	...	21
0′- 8″	17	5	...	...	22
0′- 9″	15	8	...	...	23
0′-10″	14	10	...	...	24
0′-11″	13	13	...	...	26
1′- 0″	12	15	...	...	27
1′- 1″	10	18	...	...	28
1′- 2″	9	20	...	...	29
1′- 3″	8	23	...	...	31
1′- 4″	7	25	...	...	32
1′- 5″	5	28	...	...	33
1′- 6″	4	30	...	...	34
1′- 7″	3	33	...	...	36
1′- 8″	2	35	...	...	37
1′- 9″	...	38	...	...	38
1′-10″	...	36	3	...	39
1′-11″	...	36	5	...	41
2′- 0″	...	34	8	...	42
2′- 1″	...	33	10	...	43
2′- 2″	...	31	13	...	44
2′- 3″	...	31	15	...	46
2′- 4″	...	29	18	...	47
2′- 5″	...	28	20	...	48
2′- 6″	...	26	23	...	49
2′- 7″	...	26	25	...	51
2′- 8″	...	24	28	...	52
2′- 9″	...	23	30	...	53
2′-10″	...	21	33	...	54
2′-11″	...	20	36	...	56
3′- 0″	...	19	38	...	57
3′- 1″	...	18	40	...	58
3′- 2″	...	16	43	...	59
3′- 3″	...	15	46	...	61
3′- 4″	...	14	48	...	62
3′- 5″	...	13	50	...	63
3′- 6″	...	11	53	...	64
3′- 7″	...	10	56	...	66
3′- 8″	...	9	58	...	67
3′- 9″	...	8	60	...	68
3′-10″	...	7	63	...	70
3′-11″	...	5	66	...	71
4′- 0″	...	4	68	...	72
4′- 1″	...	3	70	...	73
4′- 2″	...	2	73	...	75
4′- 3″	...	...	76	...	76
4′- 4″	...	...	76	1	77
4′- 6″	...	...	76	4	80
4′- 8″	...	...	76	6	82
4′-10″	...	...	76	9	85
5′- 0″	...	...	76	11	87
5′- 2″	...	...	76	14	90
5′- 4″	...	...	76	16	92
5′- 6″	...	...	76	19	95
5′- 8″	...	...	76	21	97
5′-10″	...	...	76	24	100

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
6′- 0″	...	...	76	26	102
6′- 2″	...	...	76	29	105
6′- 4″	...	...	76	31	107
6′- 6″	...	...	76	34	110
6′- 8″	...	...	76	36	112
6′-10″	...	...	76	39	115
7′- 0″	...	...	76	41	117
7′- 2″	...	...	76	44	120
7′- 4″	...	...	76	46	122
7′- 6″	...	...	76	49	125
7′- 8″	...	...	76	51	127
7′-10″	...	...	76	54	130
8′- 0″	...	...	76	56	132
8′- 2″	...	...	76	59	135
8′- 4″	...	...	76	61	137
8′- 6″	...	...	76	64	140
8′- 8″	...	...	76	66	142
8′-10″	...	...	76	69	145
9′- 0″	...	...	76	71	147
9′- 2″	...	...	76	74	150
9′- 4″	...	...	76	76	152
9′- 6″	...	...	76	79	155
9′- 8″	...	...	76	81	157
9′-10″	...	...	76	84	160
10′- 0″	...	...	76	87	163
10′- 2″	...	...	76	89	165
10′- 4″	...	...	76	92	168
10′- 6″	...	...	76	94	170
10′- 8″	...	...	76	97	173
10′-10″	...	...	76	99	175
11′- 0″	...	...	76	102	178
11′- 2″	...	...	76	104	180
11′- 4″	...	...	76	107	183
11′- 6″	...	...	76	109	185
11′- 8″	...	...	76	112	188
11′-10″	...	...	76	114	190
12′- 0″	...	...	76	117	193
12′- 2″	...	...	76	119	195
12′- 4″	...	...	76	122	198
12′- 6″	...	...	76	124	200
12′- 8″	...	...	76	127	203
12′-10″	...	...	76	129	205
13′- 0″	...	...	76	132	208
13′- 2″	...	...	76	134	210
13′- 4″	...	...	76	137	213
13′- 6″	...	...	76	139	215
13′- 8″	...	...	76	142	218
13′-10″	...	...	76	144	220
14′- 0″	...	...	76	147	223
14′- 2″	...	...	76	149	225
14′- 4″	...	...	76	152	228
14′- 6″	...	...	76	154	230
14′- 8″	...	...	76	157	233
14′-10″	...	...	76	159	235
15′- 0″	...	...	76	162	238

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4½″ LINING—ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Arch	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
0′- 4½″	15	...	...	...	...	15
0′- 5″	14	1	...	...	...	15
0′- 6″	13	3	...	...	...	16
0′- 7″	12	5	...	...	...	17
0′- 8″	11	7	...	...	...	18
0′- 9″	10	9	...	...	...	19
0′-10″	8	12	...	...	...	20
0′-11″	7	14	...	...	...	21
1′- 0″	6	16	...	...	...	22
1′- 1″	5	18	...	...	...	23
1′- 2″	4	20	...	...	...	24
1′- 3″	4	22	...	...	...	26
1′- 4″	3	24	...	...	...	27
1′- 5″	1	27	...	...	...	28
1′- 6″	...	29	...	...	...	29
1′- 7″	...	28	2	...	...	30
1′- 8″	...	26	5	...	...	31
1′- 9″	...	25	7	...	...	32
1′-10″	...	24	9	...	...	33
1′-11″	...	23	11	...	...	34
2′- 0″	...	22	13	...	...	35
2′- 1″	...	21	15	...	...	36
2′- 2″	...	20	17	...	...	37
2′- 3″	...	19	19	...	...	38
2′- 4″	...	18	21	...	...	39
2′- 5″	...	17	23	...	...	40
2′- 6″	...	16	25	...	...	41
2′- 7″	...	15	27	...	...	42
2′- 8″	...	14	29	...	...	43
2′- 9″	...	13	31	...	...	44
2′-10″	...	12	33	...	...	45
2′-11″	...	10	36	...	...	46
3′- 0″	...	10	38	...	...	48
3′- 1″	...	9	40	...	...	49
3′- 2″	...	8	42	...	...	50
3′- 3″	...	7	44	...	...	51
3′- 4″	...	6	46	...	...	52
3′- 5″	...	5	48	...	...	53
3′- 6″	...	3	51	...	...	54
3′- 7″	...	2	53	...	...	55
3′- 8″	...	1	55	...	...	56
3′- 9″	...	...	57	...	...	57
3′-10″	...	...	56	2	...	58
3′-11″	...	...	55	4	...	59
4′- 0″	...	...	54	6	...	60
4′- 1″	...	...	52	9	...	61
4′- 2″	...	...	51	11	...	62
4′- 3″	...	...	50	13	...	63
4′- 4″	...	...	49	15	...	64
4′- 5″	...	...	48	17	...	65

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Arch	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
4′- 6″	...	...	47	19	...	66
4′- 7″	...	...	46	21	...	67
4′- 8″	...	...	45	23	...	68
4′- 9″	...	...	44	26	...	70
4′-10″	...	...	43	28	...	71
4′-11″	...	...	42	30	...	72
5′- 0″	...	...	41	32	...	73
5′- 1″	...	...	40	34	...	74
5′- 2″	...	...	39	36	...	75
5′- 3″	...	...	38	38	...	76
5′- 4″	...	...	37	40	...	77
5′- 5″	...	...	36	42	...	78
5′- 6″	...	...	35	44	...	79
5′- 7″	...	...	34	46	...	80
5′- 8″	...	...	33	48	...	81
5′- 9″	...	...	32	50	...	82
5′-10″	...	...	31	52	...	83
5′-11″	...	...	29	55	...	84
6′- 0″	...	...	28	57	...	85
6′- 1″	...	...	27	59	...	86
6′- 2″	...	...	26	61	...	87
6′- 3″	...	...	25	63	...	88
6′- 4″	...	...	24	65	...	89
6′- 5″	...	...	23	67	...	90
6′- 6″	...	...	22	70	...	92
6′- 7″	...	...	21	72	...	93
6′- 8″	...	...	20	74	...	94
6′- 9″	...	...	19	76	...	95
6′-10″	...	...	18	78	...	96
6′-11″	...	...	17	80	...	97
7′- 0″	...	...	16	82	...	98
7′- 1″	...	...	15	84	...	99
7′- 2″	...	...	14	86	...	100
7′- 3″	...	...	13	88	...	101
7′- 4″	...	...	12	90	...	102
7′- 5″	...	...	11	92	...	103
7′- 6″	...	...	10	94	...	104
7′- 7″	...	...	9	96	...	105
7′- 8″	...	...	7	99	...	106
7′- 9″	...	...	6	101	...	107
7′-10″	...	...	5	103	...	108
7′-11″	...	...	4	105	...	109
8′- 0″	...	...	3	107	...	110
8′- 1″	...	...	2	109	...	111
8′- 2″	...	...	1	111	...	112
8′- 3″	...	...	...	113	...	113
8′- 6″	...	...	...	113	4	117
9′- 0″	...	...	...	113	10	123
10′- 0″	...	...	...	113	22	135
11′- 0″	...	...	...	113	35	148
12′- 0″	...	...	...	113	48	161
13′- 0″	...	...	...	113	60	173
14′- 0″	...	...	...	113	73	186
15′- 0″	...	...	...	113	85	198

4½″ LINING—CIRCLE BRICK

9″ x 4½″ x 2½″ or 9″ x 4½″ x 3″ *

Diameter Inside Brickwork	Number Required Per Ring					
	24-33 Circle	36-45 Circle	48-57 Circle	60-69 Circle	72-81 Circle	Total
2′- 0″	12	...	...	...	...	12
2′- 1″	10	2	...	...	...	12
2′- 2″	10	3	...	...	...	13
2′- 3″	9	4	...	...	...	13
2′- 4″	7	6	...	...	...	13
2′- 5″	7	7	...	...	...	14
2′- 6″	6	8	...	...	...	14
2′- 7″	5	9	...	...	...	14
2′- 8″	4	11	...	...	...	15
2′- 9″	3	12	...	...	...	15
2′-10″	2	13	...	...	...	15
2′-11″	1	15	...	...	...	16
3′- 0″	...	16	...	...	...	16
3′- 1″	...	14	2	...	...	16
3′- 2″	...	13	4	...	...	17
3′- 3″	...	12	5	...	...	17
3′- 4″	...	11	7	...	...	18
3′- 5″	...	9	9	...	...	18
3′- 6″	...	8	10	...	...	18
3′- 7″	...	7	12	...	...	19
3′- 8″	...	6	13	...	...	19
3′- 9″	...	4	15	...	...	19
3′-10″	...	4	16	...	...	20
3′-11″	...	2	18	...	...	20
4′- 0″	...	...	20	...	...	20
4′- 1″	...	...	20	1	...	21
4′- 2″	...	...	18	3	...	21
4′- 3″	...	...	16	5	...	21
4′- 4″	...	...	14	8	...	22
4′- 5″	...	...	12	10	...	22
4′- 6″	...	...	10	12	...	22
4′- 7″	...	...	8	15	...	23
4′- 8″	...	...	6	17	...	23
4′- 9″	...	...	4	19	...	23
4′-10″	...	...	3	21	...	24
4′-11″	...	...	1	23	...	24
5′- 0″	...	...	...	24	...	24
5′- 1″	...	...	...	21	4	25
5′- 2″	...	...	...	19	6	25
5′- 3″	...	...	...	17	9	26
5′- 4″	...	...	...	15	11	26
5′- 5″	...	...	...	13	13	26
5′- 6″	...	...	...	12	15	27
5′- 7″	...	...	...	10	17	27
5′- 8″	...	...	...	8	19	27
5′- 9″	...	...	...	6	22	28
5′-10″	...	...	...	4	24	28
5′-11″	...	...	...	2	26	28

Diameter Inside Brickwork	Number Required Per Ring					
	72-81 Circle	84-93 Circle	96-105 Circle	108-117 Circle	120-129 Circle	Total
6′- 0″	29	...	...	...	...	29
6′- 1″	26	3	...	...	...	29
6′- 2″	23	6	...	...	...	29
6′- 3″	21	9	...	...	...	30
6′- 4″	19	11	...	...	...	30
6′- 5″	16	14	...	...	...	30
6′- 6″	14	17	...	...	...	31
6′- 7″	11	20	...	...	...	31
6′- 8″	9	22	...	...	...	31
6′- 9″	7	25	...	...	...	32
6′-10″	4	28	...	...	...	32
6′-11″	2	31	...	...	...	33
7′- 0″	...	33	...	...	...	33
7′- 1″	...	28	5	...	...	33
7′- 2″	...	26	8	...	...	34
7′- 3″	...	23	11	...	...	34
7′- 4″	...	20	14	...	...	34
7′- 5″	...	17	18	...	...	35
7′- 6″	...	14	21	...	...	35
7′- 7″	...	11	24	...	...	35
7′- 8″	...	8	28	...	...	36
7′- 9″	...	5	31	...	...	36
7′-10″	...	2	34	...	...	36
7′-11″	...	...	37	...	...	37
8′- 0″	...	...	37	...	...	37
8′- 1″	...	...	30	7	...	37
8′- 2″	...	...	28	10	...	38
8′- 3″	...	...	25	13	...	38
8′- 4″	...	...	23	15	...	38
8′- 5″	...	...	20	19	...	39
8′- 6″	...	...	18	21	...	39
8′- 7″	...	...	15	24	...	39
8′- 8″	...	...	13	27	...	40
8′- 9″	...	...	10	30	...	40
8′-10″	...	...	8	33	...	41
8′-11″	...	...	5	36	...	41
9′- 0″	...	...	...	41	...	41
9′- 1″	...	...	...	41	1	42
9′- 2″	...	...	...	37	5	42
9′- 3″	...	...	...	34	8	42
9′- 4″	...	...	...	30	13	43
9′- 5″	...	...	...	27	16	43
9′- 6″	...	...	...	23	20	43
9′- 7″	...	...	...	20	24	44
9′- 8″	...	...	...	16	28	44
9′- 9″	...	...	...	13	31	44
9′-10″	...	...	...	9	36	45
9′-11″	...	...	...	6	39	45
10′- 0″	...	...	...	...	45	45

* NOTE: 9″ x 4½″ x 3″ Circle Brick are specified by inserting "3" in the name thus, 24-33-3 Circle.

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6″ LINING—ARCH BRICK

12″ x 6″ x 3″ or 13½″ x 6″ x 3″

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
2′- 0″	38	...	...	...	38
2′- 1″	37	2	...	...	39
2′- 2″	36	4	...	...	40
2′- 3″	35	6	...	...	41
2′- 4″	34	8	...	...	42
2′- 5″	32	11	...	...	43
2′- 6″	31	13	...	...	44
2′- 7″	30	15	...	...	45
2′- 8″	29	17	...	...	46
2′- 9″	29	19	...	...	48
2′-10″	28	21	...	...	49
2′-11″	27	23	...	...	50
3′- 0″	26	25	...	...	51
3′- 1″	24	28	...	...	52
3′- 2″	23	30	...	...	53
3′- 3″	22	32	...	...	54
3′- 4″	21	34	...	...	55
3′- 5″	20	36	...	...	56
3′- 6″	19	38	...	...	57
3′- 7″	18	40	...	...	58
3′- 8″	17	42	...	...	59
3′- 9″	16	44	...	...	60
3′-10″	15	46	...	...	61
3′-11″	14	48	...	...	62
4′- 0″	13	50	...	...	63
4′- 1″	12	52	...	...	64
4′- 2″	11	54	...	...	65
4′- 3″	9	57	...	...	66
4′- 4″	8	59	...	...	67
4′- 5″	7	61	...	...	68
4′- 6″	7	63	...	...	70
4′- 7″	6	65	...	...	71
4′- 8″	5	67	...	...	72
4′- 9″	4	69	...	...	73
4′-10″	2	72	...	...	74
4′-11″	1	74	...	...	75
5′- 0″	...	76	...	...	76
5′- 1″	...	75	2	...	77
5′- 2″	...	74	4	...	78
5′- 3″	...	72	7	...	79
5′- 4″	...	71	9	...	80
5′- 5″	...	70	11	...	81
5′- 6″	...	69	13	...	82
5′- 7″	...	68	15	...	83
5′- 8″	...	67	17	...	84
5′- 9″	...	66	19	...	85
5′-10″	...	65	21	...	86
5′-11″	...	64	23	...	87
6′- 0″	...	63	25	...	88
6′- 1″	...	62	27	...	89
6′- 2″	...	61	29	...	90
6′- 3″	...	60	32	...	92
6′- 4″	...	59	34	...	93
6′- 5″	...	58	36	...	94
6′- 6″	...	57	38	...	95
6′- 7″	...	56	40	...	96
6′- 8″	...	55	42	...	97

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Arch	No. 2 Arch	No. 1 Arch	Straight	Total
6′- 9″	...	54	44	...	98
6′-10″	...	53	46	...	99
6′-11″	...	52	48	...	100
7′- 0″	...	51	50	...	101
7′- 1″	...	49	53	...	102
7′- 2″	...	48	55	...	103
7′- 3″	...	47	57	...	104
7′- 4″	...	46	59	...	105
7′- 5″	...	45	61	...	106
7′- 6″	...	44	63	...	107
7′- 7″	...	43	65	...	108
7′- 8″	...	42	67	...	109
7′- 9″	...	41	69	...	110
7′-10″	...	40	71	...	111
7′-11″	...	39	73	...	112
8′- 0″	...	38	75	...	113
8′- 1″	...	37	78	...	115
8′- 2″	...	36	80	...	116
8′- 3″	...	35	82	...	117
8′- 4″	...	34	84	...	118
8′- 5″	...	33	86	...	119
8′- 6″	...	32	88	...	120
8′- 7″	...	31	90	...	121
8′- 8″	...	30	92	...	122
8′- 9″	...	29	94	...	123
8′-10″	...	27	97	...	124
8′-11″	...	26	99	...	125
9′- 0″	...	25	101	...	126
9′- 1″	...	24	103	...	127
9′- 2″	...	23	105	...	128
9′- 3″	...	22	107	...	129
9′- 4″	...	21	109	...	130
9′- 5″	...	20	111	...	131
9′- 6″	...	19	113	...	132
9′- 7″	...	18	115	...	133
9′- 8″	...	17	117	...	134
9′- 9″	...	16	119	...	135
9′-10″	...	15	122	...	137
9′-11″	...	14	124	...	138
10′- 0″	...	13	126	...	139
10′- 1″	...	12	128	...	140
10′- 2″	...	11	130	...	141
10′- 3″	...	10	132	...	142
10′- 4″	...	9	134	...	143
10′- 5″	...	8	136	...	144
10′- 6″	...	7	138	...	145
10′- 7″	...	5	141	...	146
10′- 8″	...	4	143	...	147
10′- 9″	...	3	145	...	148
10′-10″	...	2	147	...	149
10′-11″	...	1	149	...	150
11′- 0″	...	...	151	...	151
12′- 0″	...	...	151	13	164
13′- 0″	...	...	151	25	176
14′- 0″	...	...	151	38	189
15′- 0″	...	...	151	50	201

6″ LINING—ROTARY KILN OR CUPOLA BLOCKS

9″ x 6″ x 4″

Diameter Inside Brickwork	Number Required Per Ring		
	30-42	36-48	Total
2′- 6″	15	..	15
2′- 7″	13	2	15
2′- 8″	10	6	16
2′- 9″	8	8	16
2′-10″	5	11	16
2′-11″	3	14	17
	36-48	42-54	
3′- 0″	17	..	17
3′- 1″	14	4	18
3′- 2″	11	7	18
3′- 3″	8	10	18
3′- 4″	6	13	19
3′- 5″	3	16	19
	42-54	48-60	
3′- 6″	19	..	19
3′- 7″	16	4	20
3′- 8″	12	8	20
3′- 9″	9	11	20
3′-10″	6	15	21
3′-11″	2	19	21
	48-60	54-66	
4′- 0″	21	..	21
4′- 1″	17	5	22
4′- 2″	14	8	22
4′- 3″	10	12	22
4′- 4″	8	15	23
4′- 5″	5	18	23
	54-66	60-72	
4′- 6″	23	..	23
4′- 7″	21	3	24
4′- 8″	17	7	24
4′- 9″	13	11	24
4′-10″	9	16	25
4′-11″	4	21	25
	60-72	66-78	
5′- 0″	26	..	26
5′- 1″	22	4	26
5′- 2″	18	8	26
5′- 3″	14	13	27
5′- 4″	10	17	27
5′- 5″	6	21	27

Diameter Inside Brickwork	Number Required Per Ring		
	66-78	72-84	Total
5′- 6″	28	..	28
5′- 7″	25	3	28
5′- 8″	21	7	28
5′- 9″	16	13	29
5′-10″	11	18	29
5′-11″	6	23	29
	72-84	78-90	
6′- 0″	30	..	30
6′- 1″	26	4	30
6′- 2″	22	8	30
6′- 3″	18	13	31
6′- 4″	13	18	31
6′- 5″	9	22	31
	78-90	84-96	
6′- 6″	32	..	32
6′- 7″	32	..	32
6′- 8″	26	7	33
6′- 9″	19	14	33
6′-10″	13	20	33
6′-11″	7	27	34
	84-96	90-102	
7′- 0″	34	..	34
7′- 1″	28	6	34
7′- 2″	22	13	35
7′- 3″	16	19	35
7′- 4″	10	25	35
7′- 5″	4	32	36
	90-102	96-108	
7′- 6″	36	..	36
7′- 7″	28	8	36
7′- 8″	23	14	37
7′- 9″	17	20	37
7′-10″	11	26	37
7′-11″	6	32	38
	96-108	102-114	
8′- 0″	38	..	38
8′- 1″	32	6	38
8′- 2″	28	11	39
8′- 3″	22	17	39
8′- 4″	17	22	39
8′- 5″	12	28	40

Diameter Inside Brickwork	Number Required Per Ring		
	102-114	108-120	Total
8′- 6″	40	..	40
8′- 7″	41	..	41
8′- 8″	32	9	41
8′- 9″	22	19	41
8′-10″	12	30	42
8′-11″	2	40	42
	108-120	114-126	
9′- 0″	42	..	42
9′- 1″	33	10	43
9′- 2″	28	15	43
9′- 3″	24	19	43
9′- 4″	19	25	44
9′- 5″	14	30	44
	114-126	120-132	
9′- 6″	44	..	44
9′- 7″	45	..	45
9′- 8″	45	..	45
9′- 9″	36	9	45
9′-10″	27	19	46
9′-11″	18	28	46
	120-132	123-135	
10′- 0″	46	..	46
10′- 1″	47	..	47
10′- 2″	..	47	47
	123-135	126-138	
10′- 3″	48	..	48
10′- 4″	20	28	48
10′- 5″	11	37	48
	126-138	132-144	
10′- 6″	49	..	49
10′- 7″	42	7	49
10′- 8″	34	15	49
10′- 9″	26	24	50
10′-10″	17	33	50
10′-11″	8	42	50
	132-144	138-150	
11′- 0″	51	..	51
11′- 1″	42	9	51
11′- 2″	34	17	51
11′- 3″	27	25	52
11′- 4″	18	34	52
11′- 5″	10	42	52
11′- 6″	..	53	53

NOTE: In orders, the complete names of the blocks desired should be given, as for example "30-42 RKB" or "30-42 Cupola".

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9″ LINING—WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
2′- 3″	57	...	...	...	57
2′- 4″	55	3	...	...	58
2′- 5″	52	7	...	...	59
2′- 6″	51	10	...	...	61
2′- 7″	48	14	...	...	62
2′- 8″	46	17	...	...	63
2′- 9″	44	20	...	...	64
2′-10″	42	24	...	...	66
2′-11″	40	27	...	...	67
3′- 0″	38	30	...	...	68
3′- 1″	36	34	...	...	70
3′- 2″	34	37	...	...	71
3′- 3″	32	40	...	...	72
3′- 4″	29	44	...	...	73
3′- 5″	28	47	...	...	75
3′- 6″	25	51	...	...	76
3′- 7″	23	54	...	...	77
3′- 8″	21	57	...	...	78
3′- 9″	19	61	...	...	80
3′-10″	17	64	...	...	81
3′-11″	15	67	...	...	82
4′- 0″	13	70	...	...	83
4′- 1″	11	74	...	...	85
4′- 2″	9	77	...	...	86
4′- 3″	6	81	...	...	87
4′- 4″	4	84	...	...	88
4′- 5″	2	88	...	...	90
4′- 6″	...	91	...	...	91
4′- 7″	...	90	2	...	92
4′- 8″	...	89	4	...	93
4′- 9″	...	88	7	...	95
4′-10″	...	87	9	...	96
4′-11″	...	86	11	...	97
5′- 0″	...	85	13	...	98
5′- 1″	...	85	15	...	100
5′- 2″	...	84	17	...	101
5′- 3″	...	83	19	...	102
5′- 4″	...	82	21	...	103
5′- 5″	...	82	23	...	105
5′- 6″	...	81	25	...	106
5′- 7″	...	80	27	...	107
5′- 8″	...	79	29	...	108
5′- 9″	...	78	32	...	110
5′-10″	...	77	34	...	111
5′-11″	...	76	36	...	112
6′- 0″	...	75	38	...	113
6′- 1″	...	75	40	...	115
6′- 2″	...	74	42	...	116
6′- 3″	...	73	44	...	117
6′- 4″	...	72	47	...	119
6′- 5″	...	72	48	...	120

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
6′- 6″	...	71	50	...	121
6′- 7″	...	70	52	...	122
6′- 8″	...	69	55	...	124
6′- 9″	...	68	57	...	125
6′-10″	...	67	59	...	126
6′-11″	...	66	61	...	127
7′- 0″	...	66	63	...	129
7′- 1″	...	65	65	...	130
7′- 2″	...	64	67	...	131
7′- 3″	...	63	69	...	132
7′- 4″	...	62	72	...	134
7′- 5″	...	61	74	...	135
7′- 6″	...	60	76	...	136
7′- 7″	...	59	78	...	137
7′- 8″	...	59	80	...	139
7′- 9″	...	58	82	...	140
7′-10″	...	57	84	...	141
7′-11″	...	56	86	...	142
8′- 0″	...	56	88	...	144
8′- 1″	...	55	90	...	145
8′- 2″	...	54	92	...	146
8′- 3″	...	53	94	...	147
8′- 4″	...	52	97	...	149
8′- 5″	...	51	99	...	150
8′- 6″	...	50	101	...	151
8′- 7″	...	49	103	...	152
8′- 8″	...	49	105	...	154
8′- 9″	...	48	107	...	155
8′-10″	...	47	109	...	156
8′-11″	...	46	111	...	157
9′- 0″	...	46	113	...	159
9′- 1″	...	45	115	...	160
9′- 2″	...	44	117	...	161
9′- 3″	...	43	120	...	163
9′- 4″	...	42	122	...	164
9′- 5″	...	41	124	...	165
9′- 6″	...	40	126	...	166
9′- 7″	...	40	128	...	168
9′- 8″	...	39	130	...	169
9′- 9″	...	38	132	...	170
9′-10″	...	37	134	...	171
9′-11″	...	36	137	...	173
10′- 0″	...	35	139	...	174
10′- 1″	...	35	140	...	175
10′- 2″	...	34	142	...	176
10′- 3″	...	33	145	...	178
10′- 4″	...	32	147	...	179
10′- 5″	...	31	149	...	180

9″ LINING—WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″—CONTINUED

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
10′- 6″	...	30	151	...	181
10′- 7″	...	30	153	...	183
10′- 8″	...	29	155	...	184
10′- 9″	...	28	157	...	185
10′-10″	...	27	159	...	186
10′-11″	...	26	162	...	188
11′- 0″	...	25	164	...	189
11′- 1″	...	24	166	...	190
11′- 2″	...	23	168	...	191
11′- 3″	...	23	170	...	193
11′- 4″	...	22	172	...	194
11′- 5″	...	21	174	...	195
11′- 6″	...	20	176	...	196
11′- 7″	...	20	178	...	198
11′- 8″	...	19	180	...	199
11′- 9″	...	18	182	...	200
11′-10″	...	17	184	...	201
11′-11″	...	16	187	...	203
12′- 0″	...	15	189	...	204
12′- 1″	...	14	191	...	205
12′- 2″	...	13	193	...	206
12′- 3″	...	13	195	...	208
12′- 4″	...	12	197	...	209
12′- 5″	...	11	199	...	210
12′- 6″	...	10	202	...	212
12′- 7″	...	10	203	...	213
12′- 8″	...	9	205	...	214
12′- 9″	...	8	207	...	215
12′-10″	...	7	210	...	217
12′-11″	...	6	212	...	218
13′- 0″	...	5	214	...	219
13′- 1″	...	4	216	...	220
13′- 2″	...	4	218	...	222
13′- 3″	...	3	220	...	223
13′- 4″	...	2	222	...	224
13′- 5″	...	1	224	...	225
13′- 6″	...	...	227	...	227
13′- 7″	...	...	227	1	228
13′- 8″	...	...	227	2	229
13′- 9″	...	...	227	3	230
13′-10″	...	...	227	5	232
13′-11″	...	...	227	6	233
14′- 0″	...	...	227	7	234
14′- 6″	...	...	227	15	242
15′- 0″	...	...	227	22	249
15′- 6″	...	...	227	30	257
16′- 0″	...	...	227	37	264
16′- 6″	...	...	227	45	272
17′- 0″	...	...	227	52	279
17′- 6″	...	...	227	60	287
18′- 0″	...	...	227	67	294
18′- 6″	...	...	227	75	302

Diameter Inside Brickwork	Number Required Per Ring				
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Straight	Total
19′- 0″	...	...	227	83	310
19′- 6″	...	...	227	90	317
20′- 0″	...	...	227	98	325
20′- 6″	...	...	227	105	332
21′- 0″	...	...	227	113	340
21′- 6″	...	...	227	120	347
22′- 0″	...	...	227	128	355
22′- 6″	...	...	227	135	362
23′- 0″	...	...	227	143	370
23′- 6″	...	...	227	150	377
24′- 0″	...	...	227	158	385
24′- 6″	...	...	227	165	392
25′- 0″	...	...	227	173	400
25′- 6″	...	...	227	181	408
26′- 0″	...	...	227	188	415
26′- 6″	...	...	227	196	423
27′- 0″	...	...	227	203	430
27′- 6″	...	...	227	211	438
28′- 0″	...	...	227	218	445
28′- 6″	...	...	227	226	453
29′- 0″	...	...	227	233	460
29′- 6″	...	...	227	241	468
30′- 0″	...	...	227	248	475
30′- 6″	...	...	227	256	483
31′- 0″	...	...	227	263	490
31′- 6″	...	...	227	271	498
32′- 0″	...	...	227	279	506
32′- 6″	...	...	227	286	513
33′- 0″	...	...	227	294	521
33′- 6″	...	...	227	301	528
34′- 0″	...	...	227	309	536
34′- 6″	...	...	227	316	543
35′- 0″	...	...	227	324	551
35′- 6″	...	...	227	331	558
36′- 0″	...	...	227	339	566
36′- 6″	...	...	227	346	573
37′- 0″	...	...	227	354	581
37′- 6″	...	...	227	362	589
38′- 0″	...	...	227	369	596
38′- 6″	...	...	227	377	604
39′- 0″	...	...	227	384	611
39′- 6″	...	...	227	392	619
40′- 0″	...	...	227	399	626
40′- 6″	...	...	227	407	634
41′- 0″	...	...	227	414	641
41′- 6″	...	...	227	422	649
42′- 0″	...	...	227	429	656
42′- 6″	...	...	227	437	664
43′- 0″	...	...	227	444	671
43′- 6″	...	...	227	452	679
44′- 0″	...	...	227	460	687
44′- 6″	...	...	227	467	694
45′- 0″	...	...	227	475	702

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9″ LINING — WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2 and 3 arch brick for the corresponding wedge brick.

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
3′- 0″	57	...	...	...	57
3′- 1″	56	2	...	...	58
3′- 2″	55	4	...	...	59
3′- 3″	54	6	...	...	60
3′- 4″	52	9	...	...	61
3′- 5″	51	11	...	...	62
3′- 6″	50	13	...	...	63
3′- 7″	49	15	...	...	64
3′- 8″	48	17	...	...	65
3′- 9″	47	19	...	...	66
3′-10″	46	21	...	...	67
3′-11″	45	23	...	...	68
4′- 0″	44	26	...	...	70
4′- 1″	43	28	...	...	71
4′- 2″	42	30	...	...	72
4′- 3″	41	32	...	...	73
4′- 4″	40	34	...	...	74
4′- 5″	39	36	...	...	75
4′- 6″	38	38	...	...	76
4′- 7″	37	40	...	...	77
4′- 8″	36	42	...	...	78
4′- 9″	35	44	...	...	79
4′-10″	34	46	...	...	80
4′-11″	33	48	...	...	81
5′- 0″	32	50	...	...	82
5′- 1″	31	52	...	...	83
5′- 2″	29	55	...	...	84
5′- 3″	28	57	...	...	85
5′- 4″	27	59	...	...	86
5′- 5″	26	61	...	...	87
5′- 6″	25	63	...	...	88
5′- 7″	24	65	...	...	89
5′- 8″	23	67	...	...	90
5′- 9″	22	70	...	...	92
5′-10″	21	72	...	...	93
5′-11″	20	74	...	...	94
6′- 0″	19	76	...	...	95
6′- 1″	18	78	...	...	96
6′- 2″	17	80	...	...	97
6′- 3″	16	82	...	...	98
6′- 4″	15	84	...	...	99
6′- 5″	14	86	...	...	100
6′- 6″	13	88	...	...	101
6′- 7″	12	90	...	...	102
6′- 8″	11	92	...	...	103
6′- 9″	10	94	...	...	104
6′-10″	9	96	...	...	105
6′-11″	7	99	...	...	106

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
7′- 0″	6	101	...	...	107
7′- 1″	5	103	...	...	108
7′- 2″	4	105	...	...	109
7′- 3″	3	107	...	...	110
7′- 4″	2	109	...	...	111
7′- 5″	1	111	...	...	112
7′- 6″	...	113	...	...	113
7′- 7″	...	112	3	...	115
7′- 8″	...	111	5	...	116
7′- 9″	...	110	7	...	117
7′-10″	...	109	9	...	118
7′-11″	...	108	11	...	119
8′- 0″	...	107	13	...	120
8′- 1″	...	106	15	...	121
8′- 2″	...	105	17	...	122
8′- 3″	...	104	19	...	123
8′- 4″	...	103	21	...	124
8′- 5″	...	102	23	...	125
8′- 6″	...	101	25	...	126
8′- 7″	...	100	27	...	127
8′- 8″	...	99	29	...	128
8′- 9″	...	97	32	...	129
8′-10″	...	96	34	...	130
8′-11″	...	95	36	...	131
9′- 0″	...	94	38	...	132
9′- 1″	...	93	40	...	133
9′- 2″	...	92	42	...	134
9′- 3″	...	91	44	...	135
9′- 4″	...	90	47	...	137
9′- 5″	...	89	49	...	138
9′- 6″	...	88	51	...	139
9′- 7″	...	87	53	...	140
9′- 8″	...	86	55	...	141
9′- 9″	...	85	57	...	142
9′-10″	...	84	59	...	143
9′-11″	...	83	61	...	144
10′- 0″	...	82	63	...	145
10′- 1″	...	81	65	...	146
10′- 2″	...	80	67	...	147
10′- 3″	...	79	69	...	148
10′- 4″	...	78	71	...	149
10′- 5″	...	77	73	...	150
10′- 6″	...	76	75	...	151
10′- 7″	...	74	78	...	152
10′- 8″	...	73	80	...	153
10′- 9″	...	72	82	...	154
10′-10″	...	71	84	...	155
10′-11″	...	70	86	...	156

9″ LINING — WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″ — CONTINUED

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2 and 3 arch brick for the corresponding wedge brick.

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
11′- 0″	...	69	88	...	157
11′- 1″	...	69	90	...	159
11′- 2″	...	67	93	...	160
11′- 3″	...	66	95	...	161
11′- 4″	...	65	97	...	162
11′- 5″	...	64	99	...	163
11′- 6″	...	63	101	...	164
11′- 7″	...	62	103	...	165
11′- 8″	...	61	105	...	166
11′- 9″	...	60	107	...	167
11′-10″	...	59	109	...	168
11′-11″	...	58	111	...	169
12′- 0″	...	57	113	...	170
12′- 1″	...	56	115	...	171
12′- 2″	...	55	117	...	172
12′- 3″	...	54	119	...	173
12′- 4″	...	52	122	...	174
12′- 5″	...	51	124	...	175
12′- 6″	...	50	126	...	176
12′- 7″	...	49	128	...	177
12′- 8″	...	48	130	...	178
12′- 9″	...	47	132	...	179
12′-10″	...	47	134	...	181
12′-11″	...	45	137	...	182
13′- 0″	...	44	139	...	183
13′- 1″	...	43	141	...	184
13′- 2″	...	42	143	...	185
13′- 3″	...	41	145	...	186
13′- 4″	...	40	147	...	187
13′- 5″	...	39	149	...	188
13′- 6″	...	38	151	...	189
13′- 7″	...	37	153	...	190
13′- 8″	...	36	155	...	191
13′- 9″	...	35	157	...	192
13′-10″	...	34	159	...	193
13′-11″	...	33	161	...	194
14′- 0″	...	32	163	...	195
14′- 1″	...	30	166	...	196
14′- 2″	...	29	168	...	197
14′- 3″	...	28	170	...	198
14′- 4″	...	27	172	...	199
14′- 5″	...	26	174	...	200
14′- 6″	...	25	176	...	201
14′- 7″	...	25	178	...	203
14′- 8″	...	23	181	...	204
14′- 9″	...	22	183	...	205
14′-10″	...	21	185	...	206
14′-11″	...	20	187	...	207
15′- 0″	...	19	189	...	208
15′- 1″	...	18	191	...	209
15′- 2″	...	17	193	...	210
15′- 3″	...	16	195	...	211
15′- 4″	...	15	197	...	212
15′- 5″	...	14	199	...	213

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Straight	Total
15′- 6″	...	13	201	...	214
15′- 7″	...	12	203	...	215
15′- 8″	...	11	205	...	216
15′- 9″	...	10	207	...	217
15′-10″	...	8	210	...	218
15′-11″	...	7	212	...	219
16′- 0″	...	6	214	...	220
16′- 1″	...	5	216	...	221
16′- 2″	...	4	218	...	222
16′- 3″	...	3	220	...	223
16′- 4″	...	3	222	...	225
16′- 5″	...	1	225	...	226
16′- 6″	...	...	227	...	227
17′- 0″	...	...	227	6	233
17′- 6″	...	...	227	12	239
18′- 0″	...	...	227	18	245
18′- 6″	...	...	227	25	252
19′- 0″	...	...	227	31	258
19′- 6″	...	...	227	37	264
20′- 0″	...	...	227	44	271
20′- 6″	...	...	227	50	277
21′- 0″	...	...	227	56	283
21′- 6″	...	...	227	62	289
22′- 0″	...	...	227	69	296
22′- 6″	...	...	227	75	302
23′- 0″	...	...	227	81	308
23′- 6″	...	...	227	88	315
24′- 0″	...	...	227	94	321
24′- 6″	...	...	227	100	327
25′- 0″	...	...	227	106	333
25′- 6″	...	...	227	113	340
26′- 0″	...	...	227	119	346
26′- 6″	...	...	227	125	352
27′- 0″	...	...	227	132	359
27′- 6″	...	...	227	138	365
28′- 0″	...	...	227	144	371
28′- 6″	...	...	227	150	377
29′- 0″	...	...	227	157	384
29′- 6″	...	...	227	163	390
30′- 0″	...	...	227	169	396
30′- 6″	...	...	227	176	403
31′- 0″	...	...	227	182	409
31′- 6″	...	...	227	188	415
32′- 0″	...	...	227	194	421
32′- 6″	...	...	227	201	428
33′- 0″	...	...	227	207	434
33′- 6″	...	...	227	213	440
34′- 0″	...	...	227	220	447
34′- 6″	...	...	227	226	453
35′- 0″	...	...	227	232	459
35′- 6″	...	...	227	238	465
36′- 0″	...	...	227	245	472
36′- 6″	...	...	227	251	478

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9″ LINING—KEY BRICK

9″ x 4½″ x 2½″ or 9″ x 4½″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Key	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
1′- 6″	26	...	...	...	...	26
1′- 8″	23	4	...	...	...	27
1′-10″	20	8	...	...	...	28
2′- 0″	17	13	...	...	...	30
2′- 2″	14	17	...	...	...	31
2′- 4″	12	21	...	...	...	33
2′- 6″	9	25	...	...	...	34
2′- 8″	6	29	...	...	...	35
2′-10″	3	34	...	...	...	37
3′- 0″	...	38	...	...	...	38
3′- 2″	...	35	4	...	...	39
3′- 4″	...	32	9	...	...	41
3′- 6″	...	29	13	...	...	42
3′- 8″	...	27	17	...	...	44
3′-10″	...	24	21	...	...	45
4′- 0″	...	21	25	...	...	46
4′- 2″	...	18	30	...	...	48
4′- 4″	...	15	34	...	...	49
4′- 6″	...	13	38	...	...	51
4′- 8″	...	10	42	...	...	52
4′-10″	...	7	46	...	...	53
5′- 0″	...	4	51	...	...	55
5′- 2″	...	1	55	...	...	56
5′- 3″	...	...	57	...	...	57
5′- 4″	...	...	56	2	...	58
5′- 6″	...	...	55	4	...	59
5′- 8″	...	...	53	7	...	60
5′-10″	...	...	52	10	...	62
6′- 0″	...	...	50	13	...	63
6′- 2″	...	...	49	16	...	65
6′- 4″	...	...	48	18	...	66
6′- 6″	...	...	46	21	...	67
6′- 8″	...	...	45	24	...	69
6′-10″	...	...	43	27	...	70
7′- 0″	...	...	42	30	...	72
7′- 2″	...	...	41	32	...	73
7′- 4″	...	...	39	35	...	74
7′- 6″	...	...	38	38	...	76
7′- 8″	...	...	36	41	...	77
7′-10″	...	...	35	44	...	79
8′- 0″	...	...	34	46	...	80
8′- 2″	...	...	32	49	...	81
8′- 4″	...	...	31	52	...	83
8′- 6″	...	...	29	55	...	84
8′- 8″	...	...	28	58	...	86
8′-10″	...	...	27	60	...	87
9′- 0″	...	...	25	63	...	88
9′- 2″	...	...	24	66	...	90
9′- 4″	...	...	22	69	...	91
9′- 6″	...	...	21	72	...	93
9′- 8″	...	...	20	74	...	94
9′-10″	...	...	18	77	...	95
10′- 0″	...	...	17	80	...	97
10′- 2″	...	...	15	83	...	98
10′- 4″	...	..	14	86	...	100

Diameter Inside Brickwork	Number Required Per Ring					
	No. 4 Key	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
10′- 6″	...	...	13	88	...	101
10′- 8″	...	...	11	91	...	102
10′-10″	...	...	10	94	...	104
11′- 0″	...	...	9	96	...	105
11′- 2″	...	...	7	100	...	107
11′- 4″	...	...	6	102	...	108
11′- 6″	...	...	4	105	...	109
11′- 8″	...	...	3	108	...	111
11′-10″	...	...	2	110	...	112
12′- 0″	...	...	...	113	...	113
12′- 6″	...	...	...	113	5	118
13′- 0″	...	...	...	113	9	122
13′- 6″	...	...	...	113	13	126
14′- 0″	...	...	...	113	17	130
14′- 6″	...	...	...	113	21	134
15′- 0″	...	...	...	113	26	139
15′- 6″	...	...	...	113	30	143
16′- 0″	...	...	...	113	34	147
16′- 6″	...	...	...	113	38	151
17′- 0″	...	...	...	113	42	155
17′- 6″	...	...	...	113	47	160
18′- 0″	...	...	...	113	51	164
18′- 6″	...	...	...	113	55	168
19′- 0″	...	...	...	113	59	172
19′- 6″	...	...	...	113	63	176
20′- 0″	...	...	...	113	68	181
20′- 6″	...	...	...	113	72	185
21′- 0″	...	...	...	113	76	189
21′- 6″	...	...	...	113	80	193
22′- 0″	...	...	...	113	84	197
22′- 6″	...	...	...	113	88	201
23′- 0″	...	...	...	113	93	206
23′- 6″	...	...	...	113	97	210
24′- 0″	...	...	...	113	101	214
24′- 6″	...	...	...	113	105	218
25′- 0″	...	...	...	113	109	222
25′- 6″	...	...	...	113	114	227
26′- 0″	...	...	...	113	118	231
26′- 6″	...	...	...	113	122	235
27′- 0″	...	...	...	113	126	239
27′- 6″	...	...	...	113	130	243
28′- 0″	...	...	...	113	135	248
28′- 6″	...	...	...	113	139	252
29′- 0″	...	...	...	113	143	256
29′- 6″	...	...	...	113	147	260
30′- 0″	...	...	...	113	151	264
30′- 6″	...	...	...	113	155	268
31′- 0″	...	...	...	113	160	273
31′- 6″	...	...	...	113	164	277
32′- 0″	...	...	...	113	168	281
32′- 6″	...	...	...	113	172	285
33′- 0″	...	...	...	113	176	289
33′- 6″	...	...	...	113	181	294
34′- 0″	...	...	...	113	185	298
35′- 0″	...	...	...	113	193	306

9″ LINING—KEY BRICK

9″ x 6″ x 2½″ or 9″ x 6″ x 3″

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
1′- 6″	19	...	...	...	19
1′- 8″	18	2	...	...	20
1′-10″	18	3	...	...	21
2′- 0″	17	5	...	...	22
2′- 2″	16	7	...	...	23
2′- 4″	15	9	...	...	24
2′- 6″	15	11	...	...	26
2′- 8″	14	13	...	...	27
2′-10″	14	14	...	...	28
3′- 0″	13	16	...	...	29
3′- 2″	12	18	...	...	30
3′- 4″	12	19	...	...	31
3′- 6″	11	21	...	...	32
3′- 8″	10	23	...	...	33
3′-10″	9	25	...	...	34
4′- 0″	9	26	...	...	35
4′- 2″	8	28	...	...	36
4′- 4″	7	30	...	...	37
4′- 6″	7	31	...	...	38
4′- 8″	6	33	...	...	39
4′-10″	5	35	...	...	40
5′- 0″	5	36	...	...	41
5′- 2″	4	38	...	...	42
5′- 4″	3	40	...	...	43
5′- 6″	2	42	...	...	44
5′- 8″	2	43	...	...	45
5′-10″	1	45	...	...	46
6′- 0″	...	48	...	...	48
6′- 2″	...	47	2	...	49
6′- 4″	...	46	4	...	50
6′- 6″	...	45	6	...	51
6′- 8″	...	44	8	...	52
6′-10″	...	43	10	...	53
7′- 0″	...	41	13	...	54
7′- 2″	...	40	15	...	55
7′- 4″	...	39	17	...	56
7′- 6″	...	38	19	...	57
7′- 8″	...	37	21	...	58
7′-10″	...	36	23	...	59
8′- 0″	...	34	26	...	60
8′- 2″	...	33	28	...	61
8′- 4″	...	32	30	...	62
8′- 6″	...	31	32	...	63
8′- 8″	...	30	34	...	64
8′-10″	...	28	37	...	65
9′- 0″	...	27	39	...	66
9′- 2″	...	26	41	...	67
9′- 4″	...	25	43	...	68
9′- 6″	...	24	46	...	70
9′- 8″	...	23	48	...	71
9′-10″	...	22	50	...	72

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
10′- 0″	...	21	52	...	73
10′- 2″	...	19	55	...	74
10′- 4″	...	18	57	...	75
10′- 6″	...	17	59	...	76
10′- 8″	...	16	61	...	77
10′-10″	...	15	63	...	78
11′- 0″	...	13	66	...	79
11′- 2″	...	12	68	...	80
11′- 4″	...	11	70	...	81
11′- 6″	...	10	72	...	82
11′- 8″	...	9	74	...	83
11′-10″	...	8	76	...	84
12′- 0″	...	6	79	...	85
12′- 2″	...	5	81	...	86
12′- 4″	...	4	83	...	87
12′- 6″	...	3	85	...	88
12′- 8″	...	2	87	...	89
12′-10″	...	...	90	...	90
13′- 0″	...	...	91	...	91
13′- 6″	...	...	91	4	95
14′- 0″	...	...	91	7	98
14′- 6″	...	...	91	10	101
15′- 0″	...	...	91	13	104
15′- 6″	...	...	91	16	107
16′- 0″	...	...	91	19	110
16′- 6″	...	...	91	22	113
17′- 0″	...	...	91	26	117
17′- 6″	...	...	91	29	120
18′- 0″	...	...	91	32	123
18′- 6″	...	...	91	35	126
19′- 0″	...	...	91	38	129
19′- 6″	...	...	91	41	132
20′- 0″	...	...	91	44	135
20′- 6″	...	...	91	48	139
21′- 0″	...	...	91	51	142
21′- 6″	...	...	91	54	145
22′- 0″	...	...	91	57	148
22′- 6″	...	...	91	60	151
23′- 0″	...	...	91	63	154
23′- 6″	...	...	91	66	157
24′- 0″	...	...	91	70	161
24′- 6″	...	...	91	73	164
25′- 0″	...	...	91	76	167
26′- 0″	...	...	91	82	173
27′- 0″	...	...	91	88	179
28′- 0″	...	...	91	95	186
29′- 0″	...	...	91	101	192
30′- 0″	...	...	91	107	198
31′- 0″	...	...	91	114	205
32′- 0″	...	...	91	120	211
33′- 0″	...	...	91	126	217
34′- 0″	...	...	91	132	223
35′- 0″	...	...	91	139	230

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9″ LINING — ROTARY KILN BLOCKS*

9″ x 9″ x 4″

Diameter Inside Brickwork	Number Required Per Ring		
	48-66	54-72	Total
4′- 0″	23	..	23
4′- 1″	18	6	24
4′- 2″	14	10	24
4′- 3″	11	13	24
4′- 4″	7	18	25
4′- 5″	4	21	25
	54-72	60-78	
4′- 6″	26	..	26
4′- 7″	22	4	26
4′- 8″	18	8	26
4′- 9″	14	13	27
4′-10″	10	17	27
4′-11″	6	21	27
	60-78	66-84	
5′- 0″	28	..	28
5′- 1″	25	3	28
5′- 2″	20	8	28
5′- 3″	15	14	29
5′- 4″	9	20	29
5′- 5″	3	26	29
	66-84	72-90	
5′- 6″	30	..	30
5′- 7″	22	8	30
5′- 8″	17	13	30
5′- 9″	12	19	31
5′-10″	7	24	31
5′-11″	2	29	31
	72-90	78-96	
6′- 0″	32	..	32
6′- 1″	24	8	32
6′- 2″	19	14	33
6′- 3″	14	19	33
6′- 4″	10	23	33
6′- 5″	5	29	34
	78-96	84-102	
6′- 6″	34	..	34
6′- 7″	28	6	34
6′- 8″	22	13	35
6′- 9″	16	19	35
6′-10″	10	25	35
6′-11″	4	32	36

Diameter Inside Brickwork	Number Required Per Ring		
	84-102	90-108	Total
7′- 0″	36	..	36
7′- 1″	28	8	36
7′- 2″	23	14	37
7′- 3″	17	20	37
7′- 4″	11	26	37
7′- 5″	6	32	38
	90-108	96-114	
7′- 6″	38	..	38
7′- 7″	32	6	38
7′- 8″	28	11	39
7′- 9″	22	17	39
7′-10″	17	22	39
7′-11″	12	28	40
	96-114	102-120	
8′- 0″	40	..	40
8′- 1″	41	..	41
8′- 2″	34	7	41
8′- 3″	27	14	41
8′- 4″	20	22	42
8′- 5″	12	30	42
	102-120	108-126	
8′- 6″	42	..	42
8′- 7″	39	4	43
8′- 8″	32	11	43
8′- 9″	25	18	43
8′-10″	18	26	44
8′-11″	10	34	44
	108-126	114-132	
9′- 0″	44	..	44
9′- 1″	41	4	45
9′- 2″	34	11	45
9′- 3″	27	18	45
9′- 4″	20	26	46
9′- 5″	13	33	46
	114-132	117-135	
9′- 6″	46	..	46
9′- 7″	46	1	47
9′- 8″	32	15	47

Diameter Inside Brickwork	Number Required Per Ring		
	117-135	120-138	Total
9′- 9″	48	..	48
9′-10″	48	..	48
9′-11″	..	48	48
	120-138	123-141	
10′- 0″	49	..	49
10′- 1″	15	34	49
10′- 2″	1	48	49
	123-141	126-144	
10′- 3″	50	..	50
10′- 4″	25	25	50
10′- 5″	13	37	50
	126-144	132-150	
10′- 6″	51	..	51
10′- 7″	38	13	51
10′- 8″	26	25	51
10′- 9″	14	38	52
10′-10″	2	50	52
10′-11″	..	52	52
	132-150	138-156	
11′- 0″	53	..	53
11′- 1″	35	18	53
11′- 2″	29	24	53
11′- 3″	24	30	54
11′- 4″	18	36	54
11′- 5″	12	43	55
	138-156	144-162	
11′- 6″	55	..	55
11′- 7″	55	..	55
11′- 8″	45	11	56
11′- 9″	34	22	56
11′-10″	22	34	56
11′-11″	12	45	57
	144-162	150-168	
12′- 0″	57	..	57
12′- 1″	46	11	57
12′- 2″	35	23	58
12′- 3″	24	34	58
12′- 4″	13	45	58
12′- 5″	3	56	59
12′- 6″	..	59	59

*NOTE: In orders, the complete names of the blocks desired should be given, as for example "48-66 RKB".

12″ LINING — WEDGE BRICK

12″ x 4½″ x 3″, 12″ x 6″ x 3″ or 12″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No.1-X* Wedge	Straight	Total
4′- 0″	76	...	...	...	...	76
4′- 3″	72	7	...	...	...	79
4′- 6″	69	13	...	...	...	82
4′- 9″	66	19	...	...	...	85
5′- 0″	63	25	...	...	...	88
5′- 3″	60	32	...	...	...	92
5′- 6″	57	38	...	...	...	95
5′- 9″	54	44	...	...	...	98
6′- 0″	51	50	...	...	...	101
6′- 3″	47	57	...	...	...	104
6′- 6″	44	63	...	...	...	107
6′- 9″	41	69	...	...	...	110
7′- 0″	38	75	...	...	...	113
7′- 3″	35	82	...	...	...	117
7′- 6″	32	88	...	...	...	120
7′- 9″	29	94	...	...	...	123
8′- 0″	25	101	...	...	...	126
8′- 3″	22	107	...	...	...	129
8′- 6″	19	113	...	...	...	132
8′- 9″	16	119	...	...	...	135
9′- 0″	13	126	...	...	...	139
9′- 3″	10	132	...	...	...	142
9′- 6″	7	138	...	...	...	145
9′- 9″	3	145	...	...	...	148
10′- 0″	...	151	...	...	...	151
10′- 3″	...	148	6	...	...	154
10′- 6″	...	144	13	...	...	157
10′- 9″	...	142	19	...	...	161
11′- 0″	...	139	25	...	...	164
11′- 3″	...	135	32	...	...	167
11′- 6″	...	132	38	...	...	170
11′- 9″	...	129	44	...	...	173
12′- 0″	...	126	50	...	...	176
12′- 3″	...	122	57	...	...	179
12′- 6″	...	120	63	...	...	183
12′- 9″	...	117	69	...	...	186
13′- 0″	...	113	76	...	...	189
13′- 3″	...	110	82	...	...	192
13′- 6″	...	107	88	...	...	195
13′- 9″	...	104	94	...	...	198
14′- 0″	...	101	100	...	...	201
14′- 3″	...	98	107	...	...	205
14′- 6″	...	95	113	...	...	208
14′- 9″	...	91	120	...	...	211
15′- 0″	...	88	126	...	...	214
15′- 3″	...	85	132	...	...	217
15′- 6″	...	82	138	...	...	220
15′- 9″	...	79	144	...	...	223

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No.1-X* Wedge	Straight	Total
16′- 0″	...	76	151	...	...	227
16′- 3″	...	73	157	...	...	230
16′- 6″	...	69	164	...	...	233
16′- 9″	...	66	170	...	...	236
17′- 0″	...	63	176	...	...	239
17′- 3″	...	60	182	...	...	242
17′- 6″	...	57	188	...	...	245
17′- 9″	...	54	195	...	...	249
18′- 0″	...	51	201	...	...	252
18′- 3″	...	47	208	...	...	255
18′- 6″	...	44	214	...	...	258
18′- 9″	...	41	220	...	...	261
19′- 0″	...	38	226	...	...	264
19′- 3″	...	35	232	...	...	267
19′- 6″	...	32	239	...	...	271
19′- 9″	...	29	245	...	...	274
20′- 0″	...	25	252	...	...	277
20′- 3″	...	22	258	...	...	280
20′- 6″	...	19	264	...	...	283
20′- 9″	...	16	270	...	...	286
21′- 0″	...	13	276	...	...	289
21′- 3″	...	10	283	...	...	293
21′- 6″	...	7	289	...	...	296
21′- 9″	...	3	296	...	...	299
22′- 0″	...	..	302	...	...	302
22′- 3″	...	...	299	6	...	305
22′- 6″	...	...	295	13	...	308
22′- 9″	...	...	292	19	...	311
23′- 0″	...	...	289	26	...	315
23′- 3″	...	...	286	32	...	318
23′- 6″	...	...	283	38	...	321
23′- 9″	...	...	280	44	...	324
24′- 0″	...	...	277	50	...	327
24′- 3″	...	...	273	57	...	330
24′- 6″	...	...	270	63	...	333
24′- 9″	...	...	267	70	...	337
25′- 0″	...	...	264	76	...	340
25′- 3″	...	...	261	82	...	343
25′- 6″	...	...	258	88	...	346
25′- 9″	...	...	255	94	...	349
26′- 0″	...	...	251	101	...	352
26′- 3″	...	...	248	107	...	355
26′- 6″	...	...	245	114	...	359
26′- 9″	...	...	242	120	...	362
27′- 0″	...	...	239	126	...	365
27′- 3″	...	...	236	132	...	368
27′- 6″	...	...	233	138	...	371
27′- 9″	...	...	229	145	...	374

*NOTE: The No. 1-X Wedge is standard in Silica Material only. For Fireclay Material, in the case of diameters over 22′-0″, use combinations of No. 1 Wedge and Straight brick. The quantity of No. 1 Wedge brick remains constant at 302. The quantity of Straight brick is determined by subtracting 302 from the quantity given in the column "Total".

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12″ LINING—WEDGE BRICK

12″ x 4½″ x 3″, 12″ x 6″ x 3″ or 12″ x 9″ x 3″ — CONTINUED

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No.1-X* Wedge	Straight	Total
28′- 0″	...	...	226	151	...	377
28′- 3″	...	...	223	158	...	381
28′- 6″	...	...	220	164	...	384
28′- 9″	...	...	217	170	...	387
29′- 0″	...	...	214	176	...	390
29′- 3″	...	...	211	182	...	393
29′- 6″	...	...	207	189	...	396
29′- 9″	...	...	204	195	...	399
30′- 0″	...	...	202	201	...	403
30′- 3″	...	...	198	208	...	406
30′- 6″	...	...	195	214	...	409
30′- 9″	...	...	192	220	...	412
31′- 0″	...	...	189	226	...	415
31′- 3″	...	...	185	233	...	418
31′- 6″	...	...	182	239	...	421
31′- 9″	...	...	180	245	...	425
32′- 0″	...	...	176	252	...	428
32′- 3″	...	...	173	258	...	431
32′- 6″	...	...	170	264	...	434
32′- 9″	...	...	167	270	...	437
33′- 0″	...	...	163	277	...	440
33′- 3″	...	...	160	283	...	443
33′- 6″	...	...	158	289	...	447
33′- 9″	...	...	154	296	...	450
34′- 0″	...	...	151	302	...	453
34′- 3″	...	...	148	308	...	456
34′- 6″	...	...	145	314	...	459
34′- 9″	...	...	141	321	...	462
35′- 0″	...	...	138	327	...	465
35′- 3″	...	...	135	333	...	468
35′- 6″	...	...	132	340	...	472
35′- 9″	...	...	129	346	...	475
36′- 0″	...	...	126	352	...	478
36′- 3″	...	...	123	358	...	481
36′- 6″	...	...	119	365	...	484
36′- 9″	...	...	116	371	...	487
37′- 0″	...	...	113	377	...	490
37′- 3″	...	...	110	384	...	494
37′- 6″	...	...	107	390	...	497
37′- 9″	...	...	104	396	...	500
38′- 0″	...	...	101	402	...	503
38′- 3″	...	...	97	409	...	506
38′- 6″	...	...	94	415	...	509
38′- 9″	...	...	91	421	...	512
39′- 0″	...	...	88	428	...	516
39′- 3″	...	...	85	434	...	519
39′- 6″	...	...	82	440	...	522
39′- 9″	...	...	79	446	...	525
40′- 0″	...	...	76	452	...	528
40′- 3″	...	...	72	459	...	531
40′- 6″	...	...	69	465	...	534
40′- 9″	...	...	66	472	...	538
41′- 0″	...	...	63	478	...	541
41′- 3″	...	...	60	484	...	544
41′- 6″	...	...	57	490	...	547
41′- 9″	...	...	54	496	...	550
42′- 0″	...	...	50	503	...	553
42′- 3″	...	...	47	509	...	556
42′- 6″	...	...	44	516	...	560
42′- 9″	...	...	41	522	...	563
43′- 0″	...	...	38	528	...	566
43′- 3″	...	...	35	534	...	569
43′- 6″	...	...	32	540	...	572
43′- 9″	...	...	28	547	...	575
44′- 0″	...	...	25	553	...	578
44′- 3″	...	...	22	560	...	582
44′- 6″	...	...	19	566	...	585
44′- 9″	...	...	16	572	...	588
45′- 0″	...	...	13	578	...	591
45′- 3″	...	...	10	584	...	594
45′- 6″	...	...	6	591	...	597
45′- 9″	...	...	3	597	...	600
46′- 0″	...	...	...	604	...	604
46′- 3″	...	...	...	604	3	607
46′- 6″	...	...	...	604	6	610
46′- 9″	...	...	...	604	9	613
47′- 0″	...	...	...	604	12	616
47′- 3″	...	...	...	604	15	619
47′- 6″	...	...	...	604	18	622
47′- 9″	...	...	...	604	22	626
48′- 0″	...	...	...	604	25	629
48′- 3″	...	...	...	604	28	632
48′- 6″	...	...	...	604	31	635
48′- 9″	...	...	...	604	34	638
49′- 0″	...	...	...	604	37	641
49′- 6″	...	...	...	604	44	648
50′- 0″	...	...	...	604	50	654
50′- 6″	...	...	...	604	56	660
51′- 0″	...	...	...	604	62	666
51′- 6″	...	...	...	604	69	673
52′- 0″	...	...	...	604	75	679
52′- 6″	...	...	...	604	81	685
53′- 0″	...	...	...	604	88	692
53′- 6″	...	...	...	604	94	698
54′- 0″	...	...	...	604	100	704
54′- 6″	...	...	...	604	106	710

*NOTE: The No. 1-X Wedge is standard in Silica Material only. For Fireclay Material, in the case of diameters over 22′-0″, use combinations of No. 1 Wedge and Straight brick. The quantity of No. 1 Wedge brick remains constant at 302. The quantity of Straight brick is determined by subtracting 302 from the quantity given in the column "Total".

12″ LINING—KEY BRICK

12″ x 6″ x 3″

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Key	No. 1 Key	Straight	Total
10′- 0″	76	...	...	76
10′- 2″	75	2	...	77
10′- 4″	74	4	...	78
10′- 6″	72	7	...	79
10′- 8″	71	9	...	80
10′-10″	70	11	...	81
11′- 0″	69	13	...	82
11′- 2″	68	15	...	83
11′- 4″	67	17	...	84
11′- 6″	66	19	...	85
11′- 8″	65	21	...	86
11′-10″	64	23	...	87
12′- 0″	63	25	...	88
12′- 2″	62	27	...	89
12′- 4″	61	29	...	90
12′- 6″	60	32	...	92
12′- 8″	59	34	...	93
12′-10″	58	36	...	94
13′- 0″	57	38	...	95
13′- 2″	56	40	...	96
13′- 4″	55	42	...	97
13′- 6″	54	44	...	98
13′- 8″	53	46	...	99
13′-10″	52	48	...	100
14′- 0″	51	50	...	101
14′- 2″	49	53	...	102
14′- 4″	48	55	...	103
14′- 6″	47	57	...	104
14′- 8″	46	59	...	105
14′-10″	45	61	...	106
15′- 0″	44	63	...	107
15′- 2″	43	65	...	108
15′- 4″	42	67	...	109
15′- 6″	41	69	...	110
15′- 8″	40	71	...	111
15′-10″	39	73	...	112
16′- 0″	38	75	...	113
16′- 2″	37	78	...	115
16′- 4″	36	80	...	116
16′- 6″	35	82	...	117
16′- 8″	34	84	...	118
16′-10″	33	86	...	119
17′- 0″	32	88	...	120
17′- 2″	31	90	...	121
17′- 4″	30	92	...	122
17′- 6″	29	94	...	123
17′- 8″	27	97	...	124
17′-10″	26	99	...	125
18′- 0″	25	101	...	126
18′- 2″	24	103	...	127
18′- 4″	23	105	...	128
18′- 6″	22	107	...	129
18′- 8″	21	109	...	130
18′-10″	20	111	...	131
19′- 0″	19	113	...	132
19′- 2″	18	115	...	133
19′- 4″	17	117	...	134
19′- 6″	16	119	...	135
19′- 8″	15	122	...	137
19′-10″	14	124	...	138
20′- 0″	13	126	...	139
20′- 2″	12	128	...	140
20′- 4″	11	130	...	141
20′- 6″	10	132	...	142
20′- 8″	9	134	...	143
20′-10″	8	136	...	144
21′- 0″	7	138	...	145
21′- 2″	5	141	...	146
21′- 4″	4	143	...	147
21′- 6″	3	145	...	148
21′- 8″	2	147	...	149
21′-10″	1	149	...	150
22′- 0″	...	151	...	151
22′- 2″	...	151	1	152
22′- 4″	...	151	2	153
22′- 6″	...	151	3	154
23′- 0″	...	151	6	157
23′- 6″	...	151	10	161
24′- 0″	...	151	13	164
24′- 6″	...	151	16	167
25′- 0″	...	151	19	170
25′- 6″	...	151	22	173
26′- 0″	...	151	25	176
26′- 6″	...	151	28	179
27′- 0″	...	151	32	183
27′- 6″	...	151	35	186
28′- 0″	...	151	38	189
28′- 6″	...	151	41	192
29′- 0″	...	151	44	195
29′- 6″	...	151	47	198
30′- 0″	...	151	50	201
30′- 6″	...	151	54	205
31′- 0″	...	151	57	208
31′- 6″	...	151	60	211
32′- 0″	...	151	63	214
32′- 6″	...	151	66	217
33′- 0″	...	151	69	220
33′- 6″	...	151	72	223
34′- 0″	...	151	76	227
34′- 6″	...	151	79	230
35′- 0″	...	151	82	233
35′- 6″	...	151	85	236
36′- 0″	...	151	88	239
36′- 6″	...	151	91	242
37′- 0″	...	151	94	245
37′- 6″	...	151	98	249
38′- 0″	...	151	101	252
38′- 6″	...	151	104	255

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13½″ LINING — WEDGE BRICK

13½″ x 4½″ x 3″, 13½″ x 6″ x 3″ or 13½″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X* Wedge	Straight	Total
4′- 6″	85	...	...	...	...	85
4′- 9″	82	6	...	...	...	88
5′- 0″	79	13	...	...	...	92
5′- 3″	76	19	...	...	...	95
5′- 6″	73	25	...	...	...	98
5′- 9″	69	32	...	...	...	101
6′- 0″	66	38	...	...	...	104
6′- 3″	63	44	...	...	...	107
6′- 6″	60	50	...	...	...	110
6′- 9″	57	56	...	...	...	113
7′- 0″	54	63	...	...	...	117
7′- 3″	51	69	...	...	...	120
7′- 6″	47	76	...	...	...	123
7′- 9″	44	82	...	...	...	126
8′- 0″	41	88	...	...	...	129
8′- 3″	38	94	...	...	...	132
8′- 6″	35	100	...	...	...	135
8′- 9″	32	107	...	...	...	139
9′- 0″	29	113	...	...	...	142
9′- 3″	25	120	...	...	...	145
9′- 6″	22	126	...	...	...	148
9′- 9″	19	132	...	...	...	151
10′- 0″	16	138	...	...	...	154
10′- 3″	13	144	...	...	...	157
10′- 6″	10	151	...	...	...	161
10′- 9″	7	157	...	...	...	164
11′- 0″	3	164	...	...	...	167
11′- 3″	...	170	...	...	...	170
11′- 6″	...	167	6	...	...	173
11′- 9″	...	163	13	...	...	176
12′- 0″	...	160	19	...	...	179
12′- 3″	...	157	26	...	...	183
12′- 6″	...	154	32	...	...	186
12′- 9″	...	151	38	...	...	189
13′- 0″	...	148	44	...	...	192
13′- 3″	...	145	50	...	...	195
13′- 6″	...	141	57	...	...	198
13′- 9″	...	138	63	...	...	201
14′- 0″	...	135	70	...	...	205
14′- 3″	...	132	76	...	...	208
14′- 6″	...	129	82	...	...	211
14′- 9″	...	126	88	...	...	214
15′- 0″	...	123	94	...	...	217
15′- 3″	...	119	101	...	...	220
15′- 6″	...	116	107	...	...	223
15′- 9″	...	113	114	...	...	227
16′- 0″	...	110	120	...	...	230
16′- 3″	...	107	126	...	...	233
16′- 6″	...	104	132	...	...	236
16′- 9″	...	101	138	...	...	239
17′- 0″	...	97	145	...	...	242
17′- 3″	...	94	151	...	...	245
17′- 6″	...	92	157	...	...	249
17′- 9″	...	88	164	...	...	252
18′- 0″	...	85	170	...	...	255
18′- 3″	...	82	176	...	...	258
18′- 6″	...	79	182	...	...	261
18′- 9″	...	75	189	...	...	264
19′- 0″	...	72	195	...	...	267
19′- 3″	...	70	201	...	...	271
19′- 6″	...	66	208	...	...	274
19′- 9″	...	63	214	...	...	277
20′- 0″	...	60	220	...	...	280
20′- 3″	...	57	226	...	...	283
20′- 6″	...	53	233	...	...	286
20′- 9″	...	50	239	...	...	289
21′- 0″	...	48	245	...	...	293
21′- 3″	...	44	252	...	...	296
21′- 6″	...	41	258	...	...	299
21′- 9″	...	38	264	...	...	302
22′- 0″	...	35	270	...	...	305
22′- 3″	...	31	277	...	...	308
22′- 6″	...	28	283	...	...	311
22′- 9″	...	26	289	...	...	315
23′- 0″	...	22	296	...	...	318
23′- 3″	...	19	302	...	...	321
23′- 6″	...	16	308	...	...	324
23′- 9″	...	13	314	...	...	327
24′- 0″	...	9	321	...	...	330
24′- 3″	...	6	327	...	...	333
24′- 6″	...	4	333	...	...	337
24′- 9″	...	...	340	...	...	340
25′- 0″	...	...	336	7	...	343
25′- 3″	...	...	333	13	...	346
25′- 6″	...	...	330	19	...	349
25′- 9″	...	...	327	25	...	352
26′- 0″	...	...	324	31	...	355
26′- 3″	...	...	321	38	...	359
26′- 6″	...	...	318	44	...	362
26′- 9″	...	...	314	51	...	365
27′- 0″	...	...	311	57	...	368
27′- 3″	...	...	308	63	...	371
27′- 6″	...	...	305	69	...	374
27′- 9″	...	...	302	75	...	377

*NOTE: The No. 1-X Wedge is standard in Silica Material only. For Fireclay Material, in the case of diameters over 24′-9″, use combinations of No. 1 Wedge and Straight brick. The quantity of No. 1 Wedge brick remains constant at 340. The quantity of Straight brick is determined by subtracting 340 from the quantity given in the column "Total".

13½″ LINING — WEDGE BRICK

13½″ x 4½″ x 3″, 13½″ x 6″ x 3″ or 13½″ x 9″ x 3″ — CONTINUED

Diameter Inside Brickwork	Number Required Per Ring					
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	No. 1-X* Wedge	Straight	Total
28′- 0″	...	...	299	82	...	381
28′- 3″	...	...	296	88	...	384
28′- 6″	...	...	292	95	...	387
28′- 9″	...	...	289	101	...	390
29′- 0″	...	...	286	107	...	393
29′- 3″	...	...	283	113	...	396
29′- 6″	...	...	280	119	...	399
29′- 9″	...	...	277	126	...	403
30′- 0″	...	...	274	132	...	406
30′- 3″	...	...	270	139	...	409
30′- 6″	...	...	267	145	...	412
30′- 9″	...	...	264	151	...	415
31′- 0″	...	...	261	157	...	418
31′- 3″	...	...	258	163	...	421
31′- 6″	...	...	255	170	...	425
31′- 9″	...	...	252	176	...	428
32′- 0″	...	...	248	183	...	431
32′- 3″	...	...	245	189	...	434
32′- 6″	...	...	242	195	...	437
32′- 9″	...	...	239	201	...	440
33′- 0″	...	...	236	207	...	443
33′- 3″	...	...	233	214	...	447
33′- 6″	...	...	230	220	...	450
33′- 9″	...	...	227	226	...	453
34′- 0″	...	...	223	233	...	456
34′- 3″	...	...	220	239	...	459
34′- 6″	...	...	217	245	...	462
34′- 9″	...	...	214	251	...	465
35′- 0″	...	...	210	258	...	468
35′- 3″	...	...	208	264	...	472
35′- 6″	...	...	205	270	...	475
35′- 9″	...	...	201	277	...	478
36′- 0″	...	...	198	283	...	481
36′- 3″	...	...	195	289	...	484
36′- 6″	...	...	192	295	...	487
36′- 9″	...	...	188	302	...	490
37′- 0″	...	...	186	308	...	494
37′- 3″	...	...	183	314	...	497
37′- 6″	...	...	179	321	...	500
37′- 9″	...	...	176	327	...	503
38′- 0″	...	...	173	333	...	506
38′- 3″	...	...	170	339	...	509
38′- 6″	...	...	166	346	...	512
38′- 9″	...	...	164	352	...	516
39′- 0″	...	...	161	358	...	519
39′- 3″	...	...	157	365	...	522
39′- 6″	...	...	154	371	...	525
39′- 9″	...	...	151	377	...	528
40′- 0″	...	...	148	383	...	531
40′- 3″	...	...	144	390	...	534
40′- 6″	...	...	142	396	...	538
40′- 9″	...	...	139	402	...	541
41′- 0″	...	...	135	409	...	544
41′- 3″	...	...	132	415	...	547
41′- 6″	...	...	129	421	...	550
41′- 9″	...	...	126	427	...	553
42′- 0″	...	...	122	434	...	556
42′- 3″	...	...	120	440	...	560
42′- 6″	...	...	117	446	...	563
42′- 9″	...	...	113	453	...	566
43′- 0″	...	...	110	459	...	569
43′- 3″	...	...	107	465	...	572
43′- 6″	...	...	104	471	...	575
43′- 9″	...	...	101	477	...	578
44′- 0″	...	...	98	484	...	582
44′- 3″	...	...	95	490	...	585
44′- 6″	...	...	91	497	...	588
44′- 9″	...	...	88	503	...	591
45′- 0″	...	...	85	509	...	594
45′- 3″	...	...	82	515	...	597
45′- 6″	...	...	79	521	...	600
45′- 9″	...	...	76	528	...	604
46′- 0″	...	...	73	534	...	607
46′- 3″	...	...	69	541	...	610
46′- 6″	...	...	66	547	...	613
46′- 9″	...	...	63	553	...	616
47′- 0″	...	...	60	559	...	619
47′- 3″	...	...	57	565	...	622
47′- 6″	...	...	54	572	...	626
47′- 9″	...	...	51	578	...	629
48′- 0″	...	...	47	585	...	632
48′- 3″	...	...	44	591	...	635
48′- 6″	...	...	41	597	...	638
48′- 9″	...	...	38	603	...	641
49′- 0″	...	...	35	609	...	644
49′- 3″	...	...	32	616	...	648
49′- 6″	...	...	29	622	...	651
49′- 9″	...	...	25	629	...	654
50′- 0″	...	...	22	635	...	657
50′- 3″	...	...	19	641	...	660
50′- 6″	...	...	16	647	...	663
50′- 9″	...	...	13	653	...	666
51′- 0″	...	...	10	660	...	670
51′- 3″	...	...	7	666	...	673
51′- 6″	...	...	3	673	...	676
51′- 9″	...	...	...	679	...	679

*NOTE: The No. 1-X Wedge is standard in Silica Material only. For Fireclay Material, in the case of diameters over 24′-9″, use combinations of No. 1 Wedge and Straight brick. The quantity of No. 1 Wedge brick remains constant at 340. The quantity of Straight brick is determined by subtracting 340 from the quantity given in the column "Total".

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13½″ LINING—KEY BRICK

13½″ x 6″ x 2½″ or 13½″ x 6″ x 3″

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
2′- 3″	29	...	...	...	29
2′- 4″	28	1	...	...	29
2′- 6″	26	4	...	...	30
2′- 8″	25	6	...	...	31
2′-10″	24	8	...	...	32
3′- 0″	23	10	...	...	33
3′- 2″	21	13	...	...	34
3′- 4″	20	15	...	...	35
3′- 6″	19	18	...	...	37
3′- 8″	18	20	...	...	38
3′-10″	17	22	...	...	39
4′- 0″	16	24	...	...	40
4′- 2″	14	27	...	...	41
4′- 4″	13	29	...	...	42
4′- 6″	12	31	...	...	43
4′- 8″	11	33	...	...	44
4′-10″	9	36	...	...	45
5′- 0″	8	38	...	...	46
5′- 2″	7	40	...	...	47
5′- 4″	6	42	...	...	48
5′- 6″	4	45	...	...	49
5′- 8″	3	47	...	...	50
5′-10″	2	49	...	...	51
6′- 0″	...	52	...	...	52
6′- 2″	...	51	2	...	53
6′- 4″	...	49	5	...	54
6′- 6″	...	48	7	...	55
6′- 8″	...	46	10	...	56
6′-10″	...	44	13	...	57
7′- 0″	...	43	16	...	59
7′- 2″	...	41	19	...	60
7′- 4″	...	40	21	...	61
7′- 6″	...	38	24	...	62
7′- 8″	...	36	27	...	63
7′-10″	...	35	29	...	64
8′- 0″	...	33	32	...	65
8′- 2″	...	31	35	...	66
8′- 4″	...	30	37	...	67
8′- 6″	...	28	40	...	68
8′- 8″	...	26	43	...	69
8′-10″	...	24	46	...	70
9′- 0″	...	23	48	...	71
9′- 2″	...	21	51	...	72
9′- 4″	...	19	54	...	73
9′- 6″	...	18	56	...	74
9′- 8″	...	16	59	...	75
9′-10″	...	14	62	...	76
10′- 0″	...	13	64	...	77
10′- 2″	...	11	67	...	78
10′- 4″	...	9	70	...	79
10′- 6″	...	8	73	...	81
10′- 8″	...	6	76	...	82
10′-10″	...	5	78	...	83

Diameter Inside Brickwork	Number Required Per Ring				
	No. 3 Key	No. 2 Key	No. 1 Key	Straight	Total
11′- 0″	...	3	81	...	84
11′- 2″	...	1	84	...	85
11′- 3″	...	...	85	...	85
11′- 6″	...	...	85	2	87
12′- 0″	...	...	85	5	90
12′- 6″	...	...	85	8	93
13′- 0″	...	...	85	11	96
13′- 6″	...	...	85	14	99
14′- 0″	...	...	85	18	103
14′- 6″	...	...	85	21	106
15′- 0″	...	...	85	24	109
15′- 6″	...	...	85	27	112
16′- 0″	...	...	85	30	115
16′- 6″	...	...	85	33	118
17′- 0″	...	...	85	36	121
17′- 6″	...	...	85	39	124
18′- 0″	...	...	85	43	128
18′- 6″	...	...	85	46	131
19′- 0″	...	...	85	49	134
19′- 6″	...	...	85	52	137
20′- 0″	...	...	85	55	140
20′- 6″	...	...	85	58	143
21′- 0″	...	...	85	61	146
21′- 6″	...	...	85	65	150
22′- 0″	...	...	85	68	153
22′- 6″	...	...	85	71	156
23′- 0″	...	...	85	74	159
23′- 6″	...	...	85	77	162
24′- 0″	...	...	85	80	165
24′- 6″	...	...	85	83	168
25′- 0″	...	...	85	87	172
25′- 6″	...	...	85	90	175
26′- 0″	...	...	85	93	178
26′- 6″	...	...	85	96	181
27′- 0″	...	...	85	99	184
27′- 6″	...	...	85	102	187
28′- 0″	...	...	85	105	190
28′- 6″	...	...	85	109	194
29′- 0″	...	...	85	112	197
29′- 6″	...	...	85	115	200
30′- 0″	...	...	85	118	203
30′- 6″	...	...	85	121	206
31′- 0″	...	...	85	124	209
31′- 6″	...	...	85	127	212
32′- 0″	...	...	85	131	216
33′- 0″	...	...	85	137	222
34′- 0″	...	...	85	143	228
35′- 0″	...	...	85	149	234
36′- 0″	...	...	85	156	241
37′- 0″	...	...	85	162	247
38′- 0″	...	...	85	168	253
39′- 0″	...	...	85	175	260
40′- 0″	...	...	85	181	266

15″ LINING—WEDGE BRICK

15″ x 6″ x 3″ or 15″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring			
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
5′- 0″	95	...	...	95
5′- 1″	94	2	...	96
5′- 3″	91	7	...	98
5′- 6″	88	13	...	101
5′- 9″	85	19	...	104
6′- 0″	82	25	...	107
6′- 3″	79	31	...	110
6′- 6″	75	38	...	113
6′- 9″	73	44	...	117
7′- 0″	69	51	...	120
7′- 3″	66	57	...	123
7′- 6″	63	63	...	126
7′- 9″	60	69	...	129
8′- 0″	57	75	...	132
8′- 3″	53	82	...	135
8′- 6″	51	88	...	139
8′- 9″	47	95	...	142
9′- 0″	44	101	...	145
9′- 3″	41	107	...	148
9′- 6″	38	113	...	151
9′- 9″	35	119	...	154
10′- 0″	31	126	...	157
10′- 3″	29	132	...	161
10′- 6″	25	139	...	164
10′- 9″	22	145	...	167
11′- 0″	19	151	...	170
11′- 3″	16	157	...	173
11′- 6″	13	163	...	176
11′- 9″	9	170	...	179
12′- 0″	7	176	...	183
12′- 3″	3	183	...	186
12′- 6″	...	189	...	189
12′- 9″	...	186	6	192
13′- 0″	...	182	13	195
13′- 3″	...	179	19	198
13′- 6″	...	176	25	201
13′- 9″	...	173	32	205
14′- 0″	...	170	38	208
14′- 3″	...	167	44	211
14′- 6″	...	164	50	214
14′- 9″	...	160	57	217
15′- 0″	...	157	63	220
15′- 3″	...	154	69	223
15′- 6″	...	151	76	227
15′- 9″	...	148	82	230
16′- 0″	...	145	88	233
16′- 3″	...	142	94	236
16′- 6″	...	138	101	239
16′- 9″	...	135	107	242

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
17′- 0″	132	113	...	245
17′- 3″	129	120	...	249
17′- 6″	126	126	...	252
17′- 9″	123	132	...	255
18′- 0″	120	138	...	258
18′- 3″	116	145	...	261
18′- 6″	113	151	...	264
18′- 9″	110	157	...	267
19′- 0″	107	164	...	271
19′- 3″	104	170	...	274
19′- 6″	101	176	...	277
19′- 9″	98	182	...	280
20′- 0″	94	189	...	283
20′- 3″	91	195	...	286
20′- 6″	88	201	...	289
20′- 9″	85	208	...	293
21′- 0″	82	214	...	296
21′- 3″	79	220	...	299
21′- 6″	76	226	...	302
21′- 9″	72	233	...	305
22′- 0″	69	239	...	308
22′- 3″	66	245	...	311
22′- 6″	63	252	...	315
22′- 9″	60	258	...	318
23′- 0″	57	264	...	321
23′- 3″	54	270	...	324
23′- 6″	50	277	...	327
23′- 9″	47	283	...	330
24′- 0″	44	289	...	333
24′- 3″	41	296	...	337
24′- 6″	38	302	...	340
24′- 9″	35	308	...	343
25′- 0″	32	314	...	346
25′- 3″	28	321	...	349
25′- 6″	25	327	...	352
25′- 9″	22	333	...	355
26′- 0″	19	340	...	359
26′- 3″	16	346	...	362
26′- 6″	13	352	...	365
26′- 9″	10	358	...	368
27′- 0″	6	365	...	371
27′- 3″	3	371	...	374
27′- 6″	...	377	...	377
27′- 9″	...	374	7	381
28′- 0″	...	371	13	384
28′- 3″	...	368	19	387
28′- 6″	...	365	25	390
28′- 9″	...	361	32	393

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15″ LINING—WEDGE BRICK

15″ x 6″ x 3″ or 15″ x 9″ x 3″—CONTINUED

Diameter Inside Brickwork	Number Required Per Ring			Diameter Inside Brickwork	Number Required Per Ring			
	No. 1 Wedge	No. 1-X Wedge	Total		No. 1 Wedge	No. 1-X Wedge	Straight	Total
29′- 0″	358	38	396	43′- 0″	182	390	...	572
29′- 3″	355	44	399	43′- 3″	179	396	...	575
29′- 6″	352	51	403	43′- 6″	176	402	...	578
29′- 9″	349	57	406	43′- 9″	173	409	...	582
30′- 0″	346	63	409	44′- 0″	170	415	...	585
30′- 3″	343	69	412	44′- 3″	167	421	...	588
30′- 6″	339	76	415	44′- 6″	164	427	...	591
30′- 9″	336	82	418	44′- 9″	160	434	...	594
31′- 0″	333	88	421	45′- 0″	157	440	...	597
31′- 3″	330	95	425	45′- 3″	154	446	...	600
31′- 6″	327	101	428	45′- 6″	151	453	...	604
31′- 9″	324	107	431	45′- 9″	148	459	...	607
32′- 0″	321	113	434	46′- 0″	145	465	...	610
32′- 3″	317	120	437	46′- 3″	142	471	...	613
32′- 6″	314	126	440	46′- 6″	138	478	...	616
32′- 9″	311	132	443	46′- 9″	135	484	...	619
33′- 0″	308	139	447	47′- 0″	132	490	...	622
33′- 3″	305	145	450	47′- 3″	129	497	...	626
33′- 6″	302	151	453	47′- 6″	126	503	...	629
33′- 9″	299	157	456	47′- 9″	123	509	...	632
34′- 0″	295	164	459	48′- 0″	120	515	...	635
34′- 3″	292	170	462	48′- 3″	116	522	...	638
34′- 6″	289	176	465	48′- 6″	113	528	...	641
34′- 9″	286	182	468	48′- 9″	110	534	...	644
35′- 0″	283	189	472	49′- 0″	107	541	...	648
35′- 3″	280	195	475	49′- 3″	104	547	...	651
35′- 6″	277	201	478	49′- 6″	101	553	...	654
35′- 9″	273	208	481	49′- 9″	98	559	...	657
36′- 0″	270	214	484	50′- 0″	94	566	...	660
36′- 3″	267	220	487	50′- 3″	91	572	...	663
36′- 6″	264	226	490	50′- 6″	88	578	...	666
36′- 9″	261	233	494	50′- 9″	85	585	...	670
37′- 0″	258	239	497	51′- 0″	82	591	...	673
37′- 3″	255	245	500	51′- 3″	79	597	...	676
37′- 6″	252	251	503	51′- 6″	76	603	...	679
37′- 9″	248	258	506	51′- 9″	72	610	...	682
38′- 0″	245	264	509	52′- 0″	69	616	...	685
38′- 3″	242	270	512	52′- 3″	66	622	...	688
38′- 6″	239	277	516	52′- 6″	63	629	...	692
38′- 9″	236	283	519	52′- 9″	60	635	...	695
39′- 0″	233	289	522	53′- 0″	57	641	...	698
39′- 3″	230	295	525	53′- 3″	54	647	...	701
39′- 6″	226	302	528	53′- 6″	50	654	...	704
39′- 9″	223	308	531	53′- 9″	47	660	...	707
40′- 0″	220	314	534	54′- 0″	44	666	...	710
40′- 3″	217	321	538	54′- 3″	41	673	...	714
40′- 6″	214	327	541	54′- 6″	38	679	...	717
40′- 9″	211	333	544	54′- 9″	35	685	...	720
41′- 0″	208	339	547	55′- 0″	32	691	...	723
41′- 3″	204	346	550	55′- 6″	25	704	...	729
41′- 6″	201	352	553	56′- 0″	19	717	...	736
41′- 9″	198	358	556	56′- 6″	13	729	...	742
42′- 0″	195	365	560	57′- 0″	6	742	...	748
42′- 3″	192	371	563	57′- 6″	...	754	...	754
42′- 6″	189	377	566	58′- 0″	...	754	7	761
42′- 9″	186	383	569	58′- 6″	...	754	13	767

18″ LINING—WEDGE BRICK

18″ x 6″ x 3″ or 18″ x 9″ x 3″

Diameter Inside Brickwork	Number Required Per Ring				Diameter Inside Brickwork	Number Required Per Ring			
	No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total		No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
6′- 0″	113	...	...	113	18′- 0″	189	75	...	264
6′- 1″	112	3	...	115	18′- 3″	185	82	...	267
6′- 2″	111	5	...	116	18′- 6″	183	88	...	271
6′- 3″	110	7	...	117	18′- 9″	179	95	...	274
6′- 6″	107	13	...	120					
6′- 9″	104	19	...	123	19′- 0″	176	101	...	277
					19′- 3″	173	107	...	280
7′- 0″	101	25	...	126	19′- 6″	170	113	...	283
7′- 3″	97	32	...	129	19′- 9″	167	119	...	286
7′- 6″	94	38	...	132					
7′- 9″	91	44	...	135	20′- 0″	163	126	...	289
					20′- 3″	161	132	...	293
8′- 0″	88	51	...	139	20′- 6″	157	139	...	296
8′- 3″	85	57	...	142	20′- 9″	154	145	...	299
8′- 6″	82	63	...	145					
8′- 9″	79	69	...	148	21′- 0″	151	151	...	302
					21′- 3″	148	157	...	305
9′- 0″	76	75	...	151	21′- 6″	145	163	...	308
9′- 3″	72	82	...	154	21′- 9″	141	170	...	311
9′- 6″	69	88	...	157					
9′- 9″	66	95	...	161	22′- 0″	139	176	...	315
					22′- 3″	135	183	...	318
10′- 0″	63	101	...	164	22′- 6″	132	189	...	321
10′- 3″	60	107	...	167	22′- 9″	129	195	...	324
10′- 6″	57	113	...	170					
10′- 9″	54	119	...	173	23′- 0″	126	201	...	327
					23′- 3″	123	207	...	330
11′- 0″	50	126	...	176	23′- 6″	119	214	...	333
11′- 3″	47	132	...	179	23′- 9″	117	220	...	337
11′- 6″	44	139	...	183					
11′- 9″	41	145	...	186	24′- 0″	113	227	...	340
					24′- 3″	110	233	...	343
12′- 0″	38	151	...	189	24′- 6″	107	239	...	346
12′- 3″	35	157	...	192	24′- 9″	104	245	...	349
12′- 6″	32	163	...	195					
12′- 9″	28	170	...	198	25′- 0″	101	251	...	352
					25′- 3″	97	258	...	355
13′- 0″	25	176	...	201	25′- 6″	95	264	...	359
13′- 3″	22	183	...	205	25′- 9″	91	271	...	362
13′- 6″	19	189	...	208					
13′- 9″	16	195	...	211	26′- 0″	88	277	...	365
					26′- 3″	85	283	...	368
14′- 0″	13	201	...	214	26′- 6″	82	289	...	371
14′- 3″	10	207	...	217	26′- 9″	79	295	...	374
14′- 6″	6	214	...	220					
14′- 9″	3	220	...	223	27′- 0″	75	302	...	377
					27′- 3″	73	308	...	381
15′- 0″	...	227	...	227	27′- 6″	69	315	...	384
15′- 3″	...	223	7	230	27′- 9″	66	321	...	387
15′- 6″	...	220	13	233					
15′- 9″	...	217	19	236	28′- 0″	63	327	...	390
					28′- 3″	60	333	...	393
16′- 0″	...	214	25	239	28′- 6″	57	339	...	396
16′- 3″	...	211	31	242	28′- 9″	53	346	...	399
16′- 6″	...	207	38	245					
16′- 9″	...	205	44	249	29′- 0″	51	352	...	403
					29′- 3″	47	359	...	406
17′- 0″	...	201	51	252	29′- 6″	44	365	...	409
17′- 3″	...	198	57	255	29′- 9″	41	371	...	412
17′- 6″	...	195	63	258					
17′- 9″	...	192	69	261					

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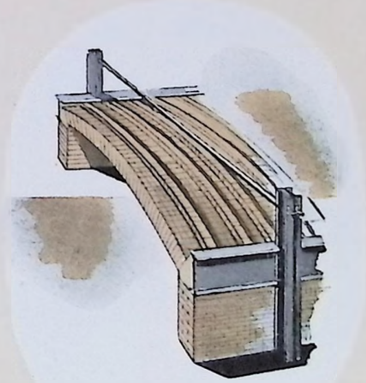
18″ LINING—WEDGE BRICK

18″ x 6″ x 3″ or 18″ x 9″ x 3″ — CONTINUED

Diameter Inside Brickwork	Number Required Per Ring			
	No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
30′- 0″	38	377	...	415
30′- 3″	35	383	...	418
30′- 6″	31	390	...	421
30′- 9″	29	396	...	425
31′- 0″	26	402	...	428
31′- 3″	22	409	...	431
31′- 6″	19	415	...	434
31′- 9″	16	421	...	437
32′- 0″	13	427	...	440
32′- 3″	9	434	...	443
32′- 6″	7	440	...	447
32′- 9″	4	446	...	450
33′- 0″	...	453	...	453
33′- 3″	...	449	7	456
33′- 6″	...	446	13	459
33′- 9″	...	443	19	462
34′- 0″	...	440	25	465
34′- 3″	...	437	31	468
34′- 6″	...	434	38	472
34′- 9″	...	431	44	475
35′- 0″	...	427	51	478
35′- 3″	...	424	57	481
35′- 6″	...	421	63	484
35′- 9″	...	418	69	487
36′- 0″	...	415	75	490
36′- 3″	...	412	82	494
36′- 6″	...	409	88	497
36′- 9″	...	406	94	500
37′- 0″	...	402	101	503
37′- 3″	...	399	107	506
37′- 6″	...	396	113	509
37′- 9″	...	393	119	512
38′- 0″	...	390	126	516
38′- 3″	...	387	132	519
38′- 6″	...	384	138	522
38′- 9″	...	380	145	525
39′- 0″	...	377	151	528
39′- 3″	...	374	157	531
39′- 6″	...	371	163	534
39′- 9″	...	368	170	538
40′- 0″	...	365	176	541
40′- 3″	...	362	182	544
40′- 6″	...	358	189	547
40′- 9″	...	355	195	550
41′- 0″	...	352	201	553
41′- 3″	...	349	207	556
41′- 6″	...	346	214	560
41′- 9″	...	343	220	563
42′- 0″	...	340	226	566
42′- 3″	...	336	233	569
42′- 6″	...	333	239	572
42′- 9″	...	330	245	575

Diameter Inside Brickwork	Number Required Per Ring			
	No. 1 Wedge	No. 1-X Wedge	Straight	Total
43′- 0″	327	251	...	578
43′- 3″	324	258	...	582
43′- 6″	321	264	...	585
43′- 9″	318	270	...	588
44′- 0″	314	277	...	591
44′- 3″	311	283	...	594
44′- 6″	308	289	...	597
44′- 9″	305	295	...	600
45′- 0″	302	302	...	604
45′- 3″	299	308	...	607
45′- 6″	296	314	...	610
45′- 9″	292	321	...	613
46′- 0″	289	327	...	616
46′- 6″	283	339	...	622
47′- 0″	277	352	...	629
47′- 6″	270	365	...	635
48′- 0″	264	377	...	641
48′- 6″	258	390	...	648
49′- 0″	252	402	...	654
49′- 6″	245	415	...	660
50′- 0″	239	427	...	666
50′- 6″	233	440	...	673
51′- 0″	226	453	...	679
51′- 6″	220	465	...	685
52′- 0″	214	478	...	692
52′- 6″	208	490	...	698
53′- 0″	201	503	...	704
53′- 6″	195	515	...	710
54′- 0″	189	528	...	717
54′- 6″	182	541	...	723
55′- 0″	176	553	...	729
55′- 6″	170	566	...	736
56′- 0″	164	578	...	742
56′- 6″	157	591	...	748
57′- 0″	151	603	...	754
57′- 6″	145	616	...	761
58′- 0″	138	629	...	767
58′- 6″	132	641	...	773
59′- 0″	126	654	...	780
59′- 6″	120	666	...	786
60′- 0″	113	679	...	792
61′- 0″	101	704	...	805
62′- 0″	88	729	...	817
63′- 0″	76	754	...	830
64′- 0″	63	779	...	842
65′- 0″	51	804	...	855
66′- 0″	38	829	...	867
67′- 0″	25	855	...	880
68′- 0″	13	880	...	893
69′- 0″	...	905	...	905
70′- 0″	...	905	13	918
71′- 0″	...	905	25	930

BRICK COMBINATIONS FOR ARCHES



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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BRICK COMBINATIONS REQUIRED FOR ARCHES

In estimating the quantities of brick required for the construction of arches, the various tables on the following pages will be found useful. These tables give the combinations of brick sizes required for arches of given spans and rises.

In calculating the tables, fractional parts equal to or greater than one-tenth of a brick were counted as entire brick; no allowance was made for mortar or expansion joints or for size deviations of the brick. For these reasons, the number of brick required for an arch as given in the tables may be slightly in excess of the number actually required.

Generally, in laying an arch course of brick, it is necessary to cut one or two pieces to complete the course.

INDEX TO TABLES

Description	2½″ Brick Sizes	3″ Brick Sizes
4½″ Arch Thickness	Page	Page
1½″ Rise per foot of span	407	407
1 19/32″ Rise per foot of span (60° central angle)	408	408
2″ Rise per foot of span	409	409
2 5/16″ Rise per foot of span	410	410
9″ Arch Thickness		
1½″ Rise per foot of span	411	412
1 19/32″ Rise per foot of span (60° central angle)	413	414
2″ Rise per foot of span	415	416
2 5/16″ Rise per foot of span	417	418
12″ Arch Thickness		
1 19/32″ Rise per foot of span (60° central angle)		419
13½″ Arch Thickness		
1 19/32″ Rise per foot of span (60° central angle)		420
15″ Arch Thickness		
1 19/32″ Rise per foot of span (60° central angle)		421
18″ Arch Thickness		
1 19/32″ Rise per foot of span (60° central angle)		422

4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

1½″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
1′- 0″	1 1/2″	1′- 0 3/4″	5	2	..	7
1′- 1″	1 5/8″	1′- 1 13/16″	5	3	..	8
1′- 2″	1 3/4″	1′- 2 7/8″	4	4	..	8
1′- 3″	1 7/8″	1′- 3 15/16″	4	4	..	8
1′- 4″	2″	1′- 5″	4	5	..	9
1′- 5″	2 1/8″	1′- 6 1/16″	3	6	..	9
1′- 6″	2 1/4″	1′- 7 1/8″	3	7	..	10
1′- 7″	2 3/8″	1′- 8 3/16″	2	8	..	10
1′- 8″	2 1/2″	1′- 9 1/4″	2	8	..	10
1′- 9″	2 5/8″	1′-10 5/16″	1	10	..	11
1′-10″	2 3/4″	1′-11 3/8″	1	10	..	11
1′-11″	2 7/8″	2′- 0 7/16″	1	11	..	12
2′- 0″	3″	2′- 1 1/2″	..	12	..	12
2′- 3″	3 3/8″	2′- 4 11/16″	..	12	1	13
2′- 6″	3 3/4″	2′- 7 7/8″	..	12	3	15
2′- 9″	4 1/8″	2′-11 1/16″	..	12	4	16
3′- 0″	4 1/2″	3′- 2 1/4″	..	12	5	17
3′- 3″	4 7/8″	3′- 5 7/16″	..	12	6	18
3′- 6″	5 1/4″	3′- 8 5/8″	..	12	8	20
3′- 9″	5 5/8″	3′-11 13/16″	..	12	9	21
4′- 0″	6″	4′- 3″	..	12	10	22
4′- 3″	6 3/8″	4′- 6 3/16″	..	12	11	23
4′- 6″	6 3/4″	4′- 9 3/8″	..	12	13	25
4′- 9″	7 1/8″	5′- 0 9/16″	..	12	14	26
5′- 0″	7 1/2″	5′- 3 3/4″	..	12	15	27
5′- 3″	7 7/8″	5′- 6 15/16″	..	12	16	28
5′- 6″	8 1/4″	5′-10 1/8″	..	12	18	30
5′- 9″	8 5/8″	6′- 1 5/16″	..	12	19	31
6′- 0″	9″	6′- 4 1/2″	..	12	20	32
6′- 3″	9 3/8″	6′- 7 11/16″	..	12	21	33
6′- 6″	9 3/4″	6′-10 7/8″	..	12	23	35

4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

1½″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	1 1/2″	1′- 0 3/4″	3	3	..	6
1′- 1″	1 5/8″	1′- 1 13/16″	3	3	..	6
1′- 2″	1 3/4″	1′- 2 7/8″	3	4	..	7
1′- 3″	1 7/8″	1′- 3 15/16″	2	5	..	7
1′- 4″	2″	1′- 5″	2	5	..	7
1′- 5″	2 1/8″	1′- 6 1/16″	2	6	..	8
1′- 6″	2 1/4″	1′- 7 1/8″	1	7	..	8
1′- 7″	2 3/8″	1′- 8 3/16″	1	7	..	8
1′- 8″	2 1/2″	1′- 9 1/4″	1	8	..	9
1′- 9″	2 5/8″	1′-10 5/16″	..	9	..	9
1′-10″	2 3/4″	1′-11 3/8″	..	9	1	10
1′-11″	2 7/8″	2′- 0 7/16″	..	8	2	10
2′- 0″	3″	2′- 1 1/2″	..	8	2	10
2′- 1″	3 1/8″	2′- 2 9/16″	..	8	3	11
2′- 2″	3 1/4″	2′- 3 5/8″	..	7	4	11
2′- 3″	3 3/8″	2′- 4 11/16″	..	7	4	11
2′- 4″	3 1/2″	2′- 5 3/4″	..	7	5	12
2′- 5″	3 5/8″	2′- 6 13/16″	..	6	6	12
2′- 6″	3 3/4″	2′- 7 7/8″	..	6	6	12
2′- 7″	3 7/8″	2′- 8 15/16″	..	6	7	13
2′- 8″	4″	2′-10″	..	5	8	13
2′- 9″	4 1/8″	2′-11 1/16″	..	5	8	13
2′-10″	4 1/4″	3′- 0 1/8″	..	5	9	14
2′-11″	4 3/8″	3′- 1 5/16″	..	4	10	14
3′- 0″	4 1/2″	3′- 2 1/4″	4	10	..	14
3′- 1″	4 5/8″	3′- 3 5/16″	4	11	..	15
3′- 2″	4 3/4″	3′- 4 3/8″	3	12	..	15
3′- 3″	4 7/8″	3′- 5 7/16″	3	12	..	15
3′- 4″	5″	3′- 6 1/2″	3	13	..	16
3′- 5″	5 1/8″	3′- 7 9/16″	2	14	..	16
3′- 6″	5 1/4″	3′- 8 5/8″	2	14	..	16
3′- 7″	5 3/8″	3′- 9 11/16″	2	15	..	17
3′- 8″	5 1/2″	3′-10 3/4″	1	16	..	17
3′- 9″	5 5/8″	3′-11 13/16″	..	17	..	17
3′-10″	5 3/4″	4′- 0 7/8″	..	18	..	18
3′-11″	5 7/8″	4′- 1 15/16″	..	18	..	18
4′- 0″	6″	4′- 3″	..	18	1	19
4′- 3″	6 3/8″	4′- 6 3/16″	..	18	2	20
4′- 6″	6 3/4″	4′- 9 3/8″	..	18	3	21
4′- 9″	7 1/8″	5′- 0 9/16″	..	18	4	22
5′- 0″	7 1/2″	5′- 3 3/4″	..	18	5	23
5′- 3″	7 7/8″	5′- 6 15/16″	..	18	6	24
5′- 6″	8 1/4″	5′-10 1/8″	..	18	7	25
5′- 9″	8 5/8″	6′- 1 5/16″	..	18	8	26
6′- 0″	9″	6′- 4 1/2″	..	18	9	27
6′- 6″	9 3/4″	6′-10 7/8″	..	18	11	29

For skewback illustration see page 57.

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4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

1 19/32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
1′- 0″	1 19/32″	1′- 0″	6	1	..	7
1′- 1″	1 3/4″	1′- 1″	6	2	..	8
1′- 2″	1 7/8″	1′- 2″	5	3	..	8
1′- 3″	2″	1′- 3″	5	4	..	9
1′- 4″	2 5/32″	1′- 4″	4	5	..	9
1′- 5″	2 9/32″	1′- 5″	4	5	..	9
1′- 6″	2 13/32″	1′- 6″	3	7	..	10
1′- 7″	2 17/32″	1′- 7″	3	7	..	10
1′- 8″	2 11/16″	1′- 8″	3	8	..	11
1′- 9″	2 13/16″	1′- 9″	2	9	..	11
1′-10″	2 15/16″	1′-10″	2	10	..	12
1′-11″	3 3/32″	1′-11″	1	11	..	12
2′- 0″	3 7/32″	2′- 0″	1	11	..	12
2′- 1″	3 11/32″	2′- 1″	1	12	..	13
2′- 2″	3 15/32″	2′- 2″	..	13	..	13
2′- 3″	3 5/8″	2′- 3″	..	13	1	14
2′- 6″	4 1/32″	2′- 6″	..	13	2	15
2′- 9″	4 7/16″	2′- 9″	..	13	3	16
3′- 0″	4 13/16″	3′- 0″	..	13	4	17
3′- 3″	5 7/32″	3′- 3″	..	13	6	19
3′- 6″	5 5/8″	3′- 6″	..	13	7	20
3′- 9″	6 1/32″	3′- 9″	..	13	8	21
4′- 0″	6 7/16″	4′- 0″	..	13	9	22
4′- 3″	6 27/32″	4′- 3″	..	13	11	24
4′- 6″	7 1/4″	4′- 6″	..	13	12	25
4′- 9″	7 5/8″	4′- 9″	..	13	13	26
5′- 0″	8 1/32″	5′- 0″	..	13	14	27
5′- 3″	8 7/16″	5′- 3″	..	13	16	29
5′- 6″	8 27/32″	5′- 6″	..	13	17	30
5′- 9″	9 1/4″	5′- 9″	..	13	18	31
6′- 0″	9 21/32″	6′- 0″	..	13	19	32
6′- 3″	10 1/16″	6′- 3″	..	13	21	34
6′- 6″	10 7/16″	6′- 6″	..	13	22	35

4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

1 19/32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	1 19/32″	1′- 0″	4	2	..	6
1′- 1″	1 3/4″	1′- 1″	4	3	..	7
1′- 2″	1 7/8″	1′- 2″	3	4	..	7
1′- 3″	2″	1′- 3″	3	4	..	7
1′- 4″	2 5/32″	1′- 4″	3	5	..	8
1′- 5″	2 9/32″	1′- 5″	2	6	..	8
1′- 6″	2 13/32″	1′- 6″	2	6	..	8
1′- 7″	2 17/32″	1′- 7″	2	7	..	9
1′- 8″	2 11/16″	1′- 8″	1	8	..	9
1′- 9″	2 13/16″	1′- 9″	1	8	..	9
1′-10″	2 15/16″	1′-10″	1	9	..	10
1′-11″	3 3/32″	1′-11″	..	9	1	10
2′- 0″	3 7/32″	2′- 0″	..	9	1	10
2′- 1″	3 11/32″	2′- 1″	..	9	2	11
2′- 2″	3 15/32″	2′- 2″	..	8	3	11
2′- 3″	3 9/16″	2′- 3″	..	8	3	11
2′- 4″	3 3/4″	2′- 4″	..	8	4	12
2′- 5″	3 7/8″	2′- 5″	..	7	5	12
2′- 6″	4 1/32″	2′- 6″	..	7	5	12
2′- 7″	4 5/32″	2′- 7″	..	7	6	13
2′- 8″	4 9/32″	2′- 8″	..	6	7	13
2′- 9″	4 7/16″	2′- 9″	..	6	7	13
2′-10″	4 9/16″	2′-10″	..	6	8	14
2′-11″	4 11/16″	2′-11″	..	5	9	14
3′- 0″	4 13/16″	3′- 0″	5	10	..	15
3′- 1″	4 31/32″	3′- 1″	5	10	..	15
3′- 2″	5 3/32″	3′- 2″	4	11	..	15
3′- 3″	5 7/32″	3′- 3″	4	12	..	16
3′- 4″	5 11/32″	3′- 4″	4	12	..	16
3′- 5″	5 1/2″	3′- 5″	3	13	..	16
3′- 6″	5 5/8″	3′- 6″	3	14	..	17
3′- 7″	5 3/4″	3′- 7″	2	15	..	17
3′- 8″	5 29/32″	3′- 8″	2	15	..	17
3′- 9″	6 1/32″	3′- 9″	2	16	..	18
3′-10″	6 5/32″	3′-10″	1	17	..	18
3′-11″	6 9/32″	3′-11″	1	17	..	18
4′- 0″	6 7/16″	4′- 0″	1	18	..	19
4′- 1″	6 9/16″	4′- 1″	..	19	..	19
4′- 2″	6 11/16″	4′- 2″	..	19	..	19
4′- 3″	6 27/32″	4′- 3″	..	19	1	20
4′- 6″	7 1/4″	4′- 6″	..	19	2	21
5′- 0″	8 1/32″	5′- 0″	..	19	4	23
5′- 6″	8 27/32″	5′- 6″	..	19	6	25
6′- 0″	9 21/32″	6′- 0″	..	19	8	27
6′- 6″	10 7/16″	6′- 6″	..	19	10	29

†More exactly 1.608″

For skewback illustration see page 58.

4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

2″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Arch	No. 1 Arch	Straight	Total
1′- 0″	2″	10″	8	..	..	8
1′- 1″	2 5/32″	10 27/32″	8	..	..	8
1′- 2″	2 11/32″	11 21/32″	7	2	..	9
1′- 3″	2 1/2″	1′- 0 1/2″	7	2	..	9
1′- 4″	2 21/32″	1′- 1 11/32″	7	3	..	10
1′- 5″	2 27/32″	1′- 2 5/32″	6	4	..	10
1′- 6″	3″	1′- 3″	5	5	..	10
1′- 7″	3 5/32″	1′- 3 27/32″	5	6	..	11
1′- 8″	3 11/32″	1′- 4 21/32″	5	6	..	11
1′- 9″	3 1/2″	1′- 5 1/2″	4	8	..	12
1′-10″	3 21/32″	1′- 6 11/32″	4	8	..	12
1′-11″	3 27/32″	1′- 7 5/32″	4	9	..	13
2′- 0″	4″	1′- 8″	3	10	..	13
2′- 1″	4 5/32″	1′- 8 27/32″	2	11	..	13
2′- 2″	4 11/32″	1′- 9 21/32″	2	12	..	14
2′- 3″	4 1/2″	1′-10 1/2″	2	12	..	14
2′- 4″	4 21/32″	1′-11 11/32″	1	14	..	15
2′- 5″	4 27/32″	2′- 0 5/32″	1	14	..	15
2′- 6″	5″	2′- 1″	..	15	..	16
2′- 9″	5 1/2″	2′- 3 1/2″	..	16	1	17
3′- 0″	6″	2′- 6″	..	16	2	18
3′- 3″	6 1/2″	2′- 8 1/2″	..	16	3	19
3′- 6″	7″	2′-11″	..	16	5	21
3′- 9″	7 1/2″	3′- 1 1/2″	..	16	6	22
4′- 0″	8″	3′- 4″	..	16	7	23
4′- 3″	8 1/2″	3′- 6 1/2″	..	16	9	25
4′- 6″	9″	3′- 9″	..	16	10	26
4′- 9″	9 1/2″	3′-11 1/2″	..	16	11	27
5′- 0″	10″	4′- 2″	..	16	12	28
5′- 3″	10 1/2″	4′- 4 1/2″	..	16	14	30
5′- 6″	11″	4′- 7″	..	16	15	31
5′- 9″	11 1/2″	4′- 9 1/2″	..	16	16	32
6′- 0″	1′-0″	5′- 0″	..	16	18	34
6′- 3″	1′-0 1/2″	5′- 2 1/2″	..	16	19	35
6′- 6″	1′-1″	5′- 5″	..	16	20	36

4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

2″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	2″	10″	6	1	..	7
1′- 1″	2 5/32″	10 27/32″	5	2	..	7
1′- 2″	2 11/32″	11 21/32″	5	2	..	7
1′- 3″	2 1/2″	1′- 0 1/2″	5	3	..	8
1′- 4″	2 21/32″	1′- 1 11/32″	4	4	..	8
1′- 5″	2 27/32″	1′- 2 5/32″	4	4	..	8
1′- 6″	3″	1′- 3″	4	5	..	9
1′- 7″	3 5/32″	1′- 3 27/32″	3	6	..	9
1′- 8″	3 11/32″	1′- 4 21/32″	2	7	..	9
1′- 9″	3 1/2″	1′- 5 1/2″	2	8	..	10
1′-10″	3 21/32″	1′- 6 11/32″	2	8	..	10
1′-11″	3 27/32″	1′- 7 5/32″	2	9	..	11
2′- 0″	4″	1′- 8″	1	10	..	11
2′- 1″	4 5/32″	1′- 8 27/32″	1	10	..	11
2′- 2″	4 11/32″	1′- 9 21/32″	1	11	..	12
2′- 3″	4 1/2″	1′-10 1/2″	..	12	..	12
2′- 4″	4 21/32″	1′-11 11/32″	..	11	1	12
2′- 5″	4 27/32″	2′- 0 5/32″	..	11	2	13
2′- 6″	5″	2′- 1″	..	11	2	13
2′- 7″	5 5/32″	2′- 1 27/32″	..	10	3	13
2′- 8″	5 11/32″	2′- 2 21/32″	..	10	4	14
2′- 9″	5 1/2″	2′- 3 1/2″	10	4	..	14
2′-10″	5 21/32″	2′- 4 11/32″	9	5	..	14
2′-11″	5 27/32″	2′- 5 5/32″	9	6	..	15
3′- 0″	6″	2′- 6″	8	7	..	15
3′- 2″	6 11/32″	2′- 7 21/32″	8	8	..	16
3′- 4″	6 21/32″	2′- 9 11/32″	7	10	..	17
3′- 6″	7″	2′-11″	6	11	..	17
3′- 8″	7 11/32″	3′- 0 21/32″	6	12	..	18
3′-10″	7 21/32″	3′- 2 11/32″	5	14	..	19
4′- 0″	8″	3′- 4″	4	15	..	19
4′- 2″	8 11/32″	3′- 5 21/32″	3	17	..	20
4′- 4″	8 21/32″	3′- 7 11/32″	3	18	..	21
4′- 6″	9″	3′- 9″	2	20	..	22
4′- 8″	9 11/32″	3′-10 21/32″	1	21	..	22
4′-10″	9 21/32″	4′- 0 11/32″	1	22	..	23
4′-11″	9 27/32″	4′- 1 5/32″	..	23	..	23
5′- 0″	10″	4′- 2″	..	23	1	24
5′- 6″	11″	4′- 7″	..	23	3	26
6′- 0″	1′-0″	5′- 0″	..	23	5	28
6′- 6″	1′-1″	5′- 5″	..	23	7	30

For skewback illustration see page 57.

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4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 2½″ or 13½″ x 4½″ x 2½″

2 5/16″† RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
0′- 6″	1 5/32″	4 1/2″	4	2	..	6
0′- 7″	1 11/32″	5 1/32″	3	3	..	6
0′- 8″	1 17/32″	5 31/32″	3	4	..	7
0′- 9″	1 23/32″	6 23/32″	2	5	..	7
0′-10″	1 29/32″	7 15/32″	2	5	..	7
0′-11″	2 1/8″	8 7/32″	2	6	..	8
1′- 0″	2 5/16″	8 31/32″	1	7	..	8
1′- 1″	2 1/2″	9 23/32″	1	8	..	9
1′- 2″	2 11/16″	10 15/32″	..	9	..	9
1′- 3″	2 7/8″	11 7/32″	..	9	1	10
1′- 4″	3 1/16″	11 31/32″	..	8	2	10
1′- 5″	3 1/4″	1′- 0 23/32″	..	7	3	10
1′- 6″	3 15/32″	1′- 1 15/32″	..	7	4	11
1′- 7″	3 21/32″	1′- 2 3/16″	..	7	4	11
1′- 8″	3 27/32″	1′- 2 15/16″	..	6	6	12
1′- 9″	4 1/32″	1′- 3 11/16″	..	6	6	12
1′-10″	4 7/32″	1′- 4 7/16″	..	6	7	13
1′-11″	4 13/32″	1′- 5 3/16″	..	5	8	13
2′- 0″	4 19/32″	1′- 5 15/16″	..	5	9	14
2′- 1″	4 25/32″	1′- 6 11/16″	..	4	10	14
2′- 2″	5″	1′- 7 7/16″	..	4	10	14
2′- 3″	5 3/16″	1′- 8 3/16″	..	3	12	15
2′- 4″	5 3/8″	1′- 8 15/16″	..	3	12	15
2′- 5″	5 9/16″	1′- 9 11/16″	..	3	13	16
2′- 6″	5 3/4″	1′-10 7/16″	..	2	14	16
2′- 7″	5 15/16″	1′-11 5/32″	..	2	15	17
2′- 8″	6 1/8″	1′-11 29/32″	..	1	16	17
2′- 9″	6 11/32″	2′- 0 21/32″	..	..	17	17
2′-10″	6 17/32″	2′- 1 13/32″	..	..	18	18
2′-11″	6 23/32″	2′- 2 5/32″	..	..	18	18
3′- 0″	6 29/32″	2′- 2 29/32″	..	18	1	19
3′- 1″	7 3/32″	2′- 3 21/32″	..	18	1	19
3′- 2″	7 9/32″	2′- 4 13/32″	..	18	2	20
3′- 3″	7 15/32″	2′- 5 5/32″	..	18	2	20
3′- 4″	7 11/16″	2′- 5 29/32″	..	18	3	21
3′- 5″	7 7/8″	2′- 6 21/32″	..	18	3	21
3′- 6″	8 1/16″	2′- 7 13/32″	..	18	3	21
4′- 0″	9 7/32″	2′-11 7/8″	..	18	6	24
4′- 6″	10 3/8″	3′- 4 3/8″	..	18	9	27
5′- 0″	11 1/2″	3′- 8 27/32″	..	18	11	29
5′- 6″	1′- 0 21/32″	4′- 1 11/32″	..	18	14	32
6′- 0″	1′- 1 13/16″	4′- 5 13/16″	..	18	17	35
6′- 6″	1′- 2 31/32″	4′-10 5/16″	..	18	19	37

4½″ ARCH THICKNESS—ARCH BRICK

9″ x 4½″ x 3″ or 13½″ x 4½″ x 3″

2 5/16″† RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Arch	No. 2 Arch	No. 1 Arch	Total
1′- 0″	2 5/16″	8 31/32″	7	..	..	7
1′- 1″	2 1/2″	9 23/32″	6	1	..	7
1′- 2″	2 11/16″	10 15/32″	6	2	..	8
1′- 3″	2 7/8″	11 7/32″	6	2	..	8
1′- 4″	3 1/16″	11 31/32″	5	3	..	8
1′- 5″	3 1/4″	1′- 0 23/32″	5	4	..	9
1′- 6″	3 15/32″	1′- 1 15/32″	5	4	..	9
1′- 7″	3 21/32″	1′- 2 3/16″	4	6	..	10
1′- 8″	3 27/32″	1′- 2 15/16″	4	6	..	10
1′- 9″	4 1/32″	1′- 3 11/16″	3	7	..	10
1′-10″	4 7/32″	1′- 4 7/16″	3	8	..	11
1′-11″	4 13/32″	1′- 5 3/16″	3	8	..	11
2′- 0″	4 19/32″	1′- 5 15/16″	2	9	..	11
2′- 1″	4 25/32″	1′- 6 11/16″	2	10	..	12
2′- 2″	5″	1′- 7 7/16″	2	10	..	12
2′- 3″	5 3/16″	1′- 8 3/16″	1	11	..	12
2′- 4″	5 3/8″	1′- 8 15/16″	1	12	..	13
2′- 6″	5 3/4″	1′-10 7/16″	..	14	..	14
2′- 8″	6 1/8″	1′-11 29/32″	..	13	1	14
2′-10″	6 17/32″	2′- 1 13/32″	..	12	3	15
3′- 0″	6 29/32″	2′- 2 29/32″	11	5	..	16
3′- 2″	7 9/32″	2′- 4 13/32″	10	6	..	16
3′- 4″	7 11/16″	2′- 5 29/32″	10	7	..	17
3′- 6″	8 1/16″	2′- 7 13/32″	9	9	..	18
3′- 8″	8 7/16″	2′- 8 7/8″	8	11	..	19
3′-10″	8 13/16″	2′-10 3/8″	7	12	..	19
4′- 0″	9 1/32″	2′-11 7/8″	7	13	..	20
4′- 2″	9 19/32″	3′- 1 3/8″	6	15	..	21
4′- 4″	9 31/32″	3′- 2 7/8″	6	16	..	22
4′- 6″	10 3/8″	3′- 4 3/8″	5	17	..	22
4′- 8″	10 3/4″	3′- 5 27/32″	4	19	..	23
4′-10″	11 1/8″	3′- 7 11/32″	3	21	..	24
5′- 0″	11 1/2″	3′- 8 27/32″	3	22	..	25
5′- 2″	11 29/32″	3′-10 11/32″	2	23	..	25
5′- 4″	1′- 0 9/32″	3′-11 27/32″	1	25	..	26
5′- 6″	1′- 0 31/32″	4′- 1 11/32″	..	27	..	27
5′- 8″	1′- 1 1/16″	4′- 2 13/16″	..	27	..	27
5′-10″	1′- 1 7/16″	4′- 4 5/16″	..	27	1	28
6′- 0″	1′- 1 13/16″	4′- 5 13/16″	..	27	2	29
6′- 6″	1′- 2 31/32″	4′-10 5/16″	..	27	4	31

†More exactly 2.302″

For skewback illustration see page 57.

9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

1½″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	2 1/4″	1′- 7 1/8″	5	6	..	11
		1′- 8 3/16″	5	7	..	12
1′- 7″	2 3/8″	1′- 9 1/4″	4	8	..	12
1′- 8″	2 1/2″	1′-10 5/16″	3	10	..	13
1′- 9″	2 5/8″	1′-11 3/8″	3	10	..	13
1′-10″	2 3/4″	2′- 0 7/16″	2	12	..	14
1′-11″	2 7/8″					
2′- 0″	3″	2′- 1 1/2″	1	13	..	14
		2′- 2 9/16″	..	14	..	14
2′- 1″	3 1/8″	2′- 3 5/8″	..	14	1	15
2′- 2″	3 1/4″	2′- 4 11/16″	..	14	1	15
2′- 3″	3 3/8″	2′- 5 3/4″	..	14	2	16
2′- 4″	3 1/2″	2′- 6 13/16″	..	13	3	16
2′- 5″	3 5/8″					
2′- 6″	3 3/4″	2′- 7 7/8″	..	13	3	16
		2′- 8 15/16″	..	13	4	17
2′- 7″	3 7/8″	2′-10″	..	12	5	17
2′- 8″	4″	2′-11 1/16″	..	12	6	18
2′- 9″	4 1/8″	3′- 0 1/8″	..	12	6	18
2′-10″	4 1/4″	3′- 1 3/16″	..	12	7	19
2′-11″	4 3/8″					
3′- 0″	4 1/2″	3′- 2 1/4″	..	11	8	19
		3′- 3 5/16″	..	11	8	19
3′- 1″	4 5/8″	3′- 4 3/8″	..	11	9	20
3′- 2″	4 3/4″	3′- 5 7/16″	..	10	10	20
3′- 3″	4 7/8″	3′- 6 1/2″	..	10	11	21
3′- 4″	5″	3′- 7 9/16″	..	10	11	21
3′- 5″	5 1/8″					
3′- 6″	5 1/4″	3′- 8 5/8″	..	10	11	21
		3′- 9 11/16″	..	10	12	22
3′- 7″	5 3/8″	3′-10 3/4″	..	9	13	22
3′- 8″	5 1/2″	3′-11 13/16″	..	9	14	23
3′- 9″	5 5/8″	4′- 0 7/8″	..	9	14	23
3′-10″	5 3/4″	4′- 1 15/16″	..	9	15	24
3′-11″	5 7/8″					
4′- 0″	6″	4′- 3″	..	8	16	24
		4′- 4 1/16″	..	8	16	24
4′- 1″	6 1/8″	4′- 5 1/8″	..	8	17	25
4′- 2″	6 1/4″	4′- 6 3/16″	..	7	18	25
4′- 3″	6 3/8″	4′- 7 1/4″	..	7	19	26
4′- 4″	6 1/2″	4′- 8 5/16″	..	7	19	26
4′- 5″	6 5/8″					
4′- 6″	6 3/4″	4′- 9 3/8″	..	6	20	26
		4′-10 7/16″	..	6	21	27
4′- 7″	6 7/8″	4′-11 1/2″	..	6	21	27
4′- 8″	7″	5′- 0 9/16″	..	6	22	28
4′- 9″	7 1/8″	5′- 1 5/8″	..	5	23	28
4′-10″	7 1/4″	5′- 2 11/16″	..	5	23	28
4′-11″	7 3/8″					
5′- 0″	7 1/2″	5′- 3 3/4″	..	5	24	29
5′- 1″	7 5/8″	5′- 4 13/16″	..	4	25	29
5′- 2″	7 3/4″	5′- 5 7/8″	..	4	26	30
5′- 3″	7 7/8″	5′- 6 15/16″	..	4	26	30
5′- 4″	8″	5′- 8″	..	4	27	31
5′- 5″	8 1/8″	5′- 9 1/16″	..	3	28	31

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge Straight	Total
5′- 6″	8 1/4″	5′-10 1/8″	3	28	.. 31
5′- 7″	8 3/8″	5′-11 3/16″	3	29	.. 32
5′- 8″	8 1/2″	6′- 0 1/4″	2	30	.. 32
5′- 9″	8 5/8″	6′- 1 5/16″	2	31	.. 33
5′-10″	8 3/4″	6′- 2 3/8″	2	31	.. 33
5′-11″	8 7/8″	6′- 3 7/16″	1	32	.. 33
6′- 0″	9″	6′- 4 1/2″	1	33	.. 34
6′- 1″	9 1/8″	6′- 5 9/16″	1	33	.. 34
6′- 2″	9 1/4″	6′- 6 5/8″	1	34	.. 35
6′- 3″	9 3/8″	6′- 7 11/16″	..	35	.. 35
6′- 4″	9 1/2″	6′- 8 3/4″	..	36	.. 36
6′- 5″	9 5/8″	6′- 9 13/16″	..	36	.. 36
6′- 6″	9 3/4″	6′-10 7/8″	..	36	.. 36
6′- 9″	10 1/8″	7′- 2 1/16″	..	36	2 38
7′- 0″	10 1/2″	7′- 5 1/4″	..	36	3 39
7′- 3″	10 7/8″	7′- 8 7/16″	..	36	4 40
7′- 6″	11 1/4″	7′-11 5/8″	..	36	5 41
7′- 9″	11 5/8″	8′- 2 13/16″	..	36	7 43
8′- 0″	1′- 0″	8′- 6″	..	36	8 44
8′- 3″	1′- 0 3/8″	8′- 9 3/16″	..	36	9 45
8′- 6″	1′- 0 3/4″	9′- 0 3/8″	..	36	10 46
8′- 9″	1′- 1 1/8″	9′- 3 9/16″	..	36	12 48
9′- 0″	1′- 1 1/2″	9′- 6 3/4″	..	36	13 49
9′- 3″	1′- 1 7/8″	9′- 9 15/16″	..	36	14 50
9′- 6″	1′- 2 1/4″	10′- 1 1/8″	..	36	15 51
9′- 9″	1′- 2 5/8″	10′- 4 5/16″	..	36	17 53
10′- 0″	1′- 3″	10′- 7 1/2″	..	36	18 54
10′- 3″	1′- 3 3/8″	10′-10 11/16″	..	36	19 55
10′- 6″	1′- 3 3/4″	11′- 1 7/8″	..	36	20 56
10′- 9″	1′- 4 1/8″	11′- 5 1/16″	..	36	22 58
11′- 0″	1′- 4 1/2″	11′- 8 1/4″	..	36	23 59
11′- 3″	1′- 4 7/8″	11′-11 7/16″	..	36	24 60
11′- 6″	1′- 5 1/4″	12′- 2 5/8″	..	36	25 61
11′- 9″	1′- 5 5/8″	12′- 5 13/16″	..	36	27 63
12′- 0″	1′- 6″	12′- 9″	..	36	28 64
12′- 3″	1′- 6 3/8″	13′- 0 3/16″	..	36	29 65
12′- 6″	1′- 6 3/4″	13′- 3 3/8″	..	36	30 66
12′- 9″	1′- 7 1/8″	13′- 6 9/16″	..	36	32 68
13′- 0″	1′- 7 1/2″	13′- 9 3/4″	..	36	33 69
13′- 3″	1′- 7 7/8″	14′- 0 15/16″	..	36	34 70
13′- 6″	1′- 8 1/4″	14′- 4 1/8″	..	36	35 71
13′- 9″	1′- 8 5/8″	14′- 7 5/16″	..	36	37 73
14′- 0″	1′- 9″	14′-10 1/2″	..	36	38 74
14′- 3″	1′- 9 3/8″	15′- 1 11/16″	..	36	39 75
14′- 6″	1′- 9 3/4″	15′- 4 7/8″	..	36	40 76
14′- 9″	1′-10 1/8″	15′- 8 1/16″	..	36	42 78
15′- 0″	1′-10 1/2″	15′-11 1/4″	..	36	43 79

For skewback illustration see page 57.

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9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

1½″ RISE PER FOOT OF SPAN

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2 and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1′- 6″	2 ¼″	1′- 7 ⅛″	9	1	..	10
1′- 7″	2 ⅜″	1′- 8 ¾₁₆″	8	2	..	10
1′- 8″	2 ½″	1′- 9 ¼″	8	2	..	10
1′- 9″	2 ⅝″	1′-10 ⅝₁₆″	8	3	..	11
1′-10″	2 ¾″	1′-11 ⅜″	7	4	..	11
1′-11″	2 ⅞″	2′- 0 ⅞₁₆″	7	4	..	11
2′- 0″	3″	2′- 1 ½″	7	5	..	12
2′- 1″	3 ⅛″	2′- 2 ⅝₁₆″	6	6	..	12
2′- 2″	3 ¼″	2′- 3 ⅝″	6	6	..	12
2′- 3″	3 ⅜″	2′- 4 ¹¹⁄₁₆″	6	7	..	13
2′- 4″	3 ½″	2′- 5 ¾″	5	8	..	13
2′- 5″	3 ⅝″	2′- 6 ¹³⁄₁₆″	5	8	..	13
2′- 6″	3 ¾″	2′- 7 ⅞″	5	9	..	14
2′- 7″	3 ⅞″	2′- 8 ¹⁵⁄₁₆″	4	10	..	14
2′- 8″	4″	2′-10″	4	10	..	14
2′- 9″	4 ⅛″	2′-11 ⅛₁₆″	4	11	..	15
2′-10″	4 ¼″	3′- 0 ⅛″	3	12	..	15
2′-11″	4 ⅜″	3′- 1 ⅜₁₆″	3	12	..	15
3′- 0″	4 ½″	3′- 2 ¼″	3	13	..	16
3′- 1″	4 ⅝″	3′- 3 ⅝₁₆″	2	14	..	16
3′- 2″	4 ¾″	3′- 4 ⅜″	2	15	..	17
3′- 3″	4 ⅞″	3′- 5 ⅛₁₆″	1	16	..	17
3′- 4″	5″	3′- 6 ½″	1	16	..	17
3′- 5″	5 ⅛″	3′- 7 ⁹⁄₁₆″	1	17	..	18
3′- 6″	5 ¼″	3′- 8 ⅝″	..	18	..	18
3′- 7″	5 ⅜″	3′- 9 ¹¹⁄₁₆″	..	18	..	18
3′- 8″	5 ½″	3′-10 ¾″	..	17	2	19
3′- 9″	5 ⅝″	3′-11 ¹³⁄₁₆″	..	17	2	19
3′-10″	5 ¾″	4′- 0 ⅞″	..	16	3	19
3′-11″	5 ⅞″	4′- 1 ¹⁵⁄₁₆″	..	16	4	20
4′- 0″	6″	4′- 3″	..	16	4	20
4′- 1″	6 ⅛″	4′- 4 ⅛₁₆″	..	15	5	20
4′- 2″	6 ¼″	4′- 5 ⅛″	..	15	6	21
4′- 3″	6 ⅜″	4′- 6 ³⁄₁₆″	..	15	6	21
4′- 4″	6 ½″	4′- 7 ¼″	..	14	7	21
4′- 5″	6 ⅝″	4′- 8 ⅝₁₆″	..	14	8	22
4′- 6″	6 ¾″	4′- 9 ⅜″	..	14	8	22
4′- 7″	6 ⅞″	4′-10 ⁷⁄₁₆″	..	13	9	22
4′- 8″	7″	4′-11 ½″	..	13	10	23
4′- 9″	7 ⅛″	5′- 0 ⁹⁄₁₆″	..	13	10	23
4′-10″	7 ¼″	5′- 1 ⅝″	..	12	11	23
4′-11″	7 ⅜″	5′- 2 ¹¹⁄₁₆″	..	12	12	24
5′- 0″	7 ½″	5′- 3 ¾″	..	12	12	24
5′- 1″	7 ⅝″	5′- 4 ¹³⁄₁₆″	..	12	13	25
5′- 2″	7 ¾″	5′- 5 ⅞″	..	11	14	25
5′- 3″	7 ⅞″	5′- 6 ¹⁵⁄₁₆″	..	11	14	25
5′- 4″	8″	5′- 8″	..	11	15	26
5′- 5″	8 ⅛″	5′- 9 ¹⁄₁₆″	..	10	16	26

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
5′- 6″	8 ¼″	5′-10 ⅛″	10	16	..	26
5′- 7″	8 ⅜″	5′-11 ³⁄₁₆″	9	18	..	27
5′- 8″	8 ½″	6′- 0 ¼″	9	18	..	27
5′- 9″	8 ⅝″	6′- 1 ⁵⁄₁₆″	8	19	..	27
5′-10″	8 ¾″	6′- 2 ⅜″	8	20	..	28
5′-11″	8 ⅞″	6′- 3 ⁷⁄₁₆″	8	20	..	28
6′- 0″	9″	6′- 4 ½″	7	21	..	28
6′- 1″	9 ⅛″	6′- 5 ⁹⁄₁₆″	7	22	..	29
6′- 2″	9 ¼″	6′- 6 ⅝″	7	22	..	29
6′- 3″	9 ⅜″	6′- 7 ¹¹⁄₁₆″	6	23	..	29
6′- 4″	9 ½″	6′- 8 ¾″	6	24	..	30
6′- 5″	9 ⅝″	6′- 9 ¹³⁄₁₆″	6	24	..	30
6′- 6″	9 ¾″	6′-10 ⅞″	5	25	..	30
6′- 7″	9 ⅞″	6′-11 ¹⁵⁄₁₆″	5	26	..	31
6′- 8″	10″	7′- 1″	5	26	..	31
6′- 9″	10 ⅛″	7′- 2 ⅛″	4	27	..	31
6′-10″	10 ¼″	7′- 3 ⅓″	4	28	..	32
6′-11″	10 ⅜″	7′- 4 ³⁄₁₆″	4	28	..	32
7′- 0″	10 ½″	7′- 5 ¼″	3	29	..	32
7′- 1″	10 ⅝″	7′- 6 ⁵⁄₁₆″	3	30	..	33
7′- 2″	10 ¾″	7′- 7 ⅜″	3	30	..	33
7′- 3″	10 ⅞″	7′- 8 ⁷⁄₁₆″	3	31	..	34
7′- 4″	11″	7′- 9 ½″	2	32	..	34
7′- 5″	11 ⅛″	7′-10 ⁹⁄₁₆″	2	32	..	34
7′- 6″	11 ¼″	7′-11 ⅝″	2	33	..	35
7′- 7″	11 ⅜″	8′- 0 ¹¹⁄₁₆″	1	34	..	35
7′- 8″	11 ½″	8′- 1 ¾″	1	34	..	35
7′- 9″	11 ⅝″	8′- 2 ¹³⁄₁₆″	..	36	..	36
7′-10″	11 ¾″	8′- 3 ⅞″	..	36	..	36
7′-11″	11 ⅞″	8′- 4 ¹⁵⁄₁₆″	..	36	..	36
8′- 0″	1′- 0″	8′- 6″	..	36	1	37
8′- 6″	1′- 0 ¾″	9′- 0 ⅜″	..	36	3	39
9′- 0″	1′- 1 ½″	9′- 6 ¾″	..	36	5	41
9′- 6″	1′- 2 ¼″	10′- 1 ⅛″	..	36	7	43
10′- 0″	1′- 3″	10′- 7 ½″	..	36	9	45
10′- 6″	1′- 3 ¾″	11′- 1 ⅞″	..	36	11	47
11′- 0″	1′- 4 ½″	11′- 8 ¼″	..	36	13	49
11′- 6″	1′- 5 ¼″	12′- 2 ⅝″	..	36	15	51
12′- 0″	1′- 6″	12′- 9″	..	36	17	53
12′- 6″	1′- 6 ¾″	13′- 3 ⅜″	..	36	19	55
13′- 0″	1′- 7 ½″	13′- 9 ¾″	..	36	21	57
13′- 6″	1′- 8 ¼″	14′- 4 ⅛″	..	36	24	60
14′- 0″	1′- 9″	14′-10 ½″	..	36	26	62
14′- 6″	1′- 9 ¾″	15′- 4 ⅞″	..	36	28	64
15′- 0″	1′-10 ½″	15′-11 ¼″	..	36	30	66

For skewback illustration see page 57.

9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

1 19/32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	2 13/32″	1′- 6″	7	5	..	12
1′- 7″	2 17/32″	1′- 7″	6	6	..	12
1′- 8″	2 11/16″	1′- 8″	5	8	..	13
1′- 9″	2 13/16″	1′- 9″	4	9	..	13
1′-10″	2 15/16″	1′-10″	3	10	..	13
1′-11″	3 3/32″	1′-11″	3	11	..	14
2′- 0″	3 7/32″	2′- 0″	2	12	..	14
2′- 1″	3 11/32″	2′- 1″	2	13	..	15
2′- 2″	3 15/32″	2′- 2″	1	14	..	15
2′- 3″	3 5/8″	2′- 3″	..	15	..	15
2′- 4″	3 3/4″	2′- 4″	..	15	1	16
2′- 5″	3 7/8″	2′- 5″	..	15	1	16
2′- 6″	4 1/32″	2′- 6″	..	15	2	17
2′- 7″	4 5/32″	2′- 7″	..	14	3	17
2′- 8″	4 9/32″	2′- 8″	..	14	4	18
2′- 9″	4 13/32″	2′- 9″	..	14	4	18
2′-10″	4 9/16″	2′-10″	..	13	5	18
2′-11″	4 11/16″	2′-11″	..	13	6	19
3′- 0″	4 13/16″	3′- 0″	..	13	6	19
3′- 1″	4 31/32″	3′- 1″	..	13	7	20
3′- 2″	5 3/32″	3′- 2″	..	12	8	20
3′- 3″	5 7/32″	3′- 3″	..	12	9	21
3′- 4″	5 11/32″	3′- 4″	..	12	9	21
3′- 5″	5 1/2″	3′- 5″	..	11	10	21
3′- 6″	5 5/8″	3′- 6″	..	11	11	22
3′- 7″	5 3/4″	3′- 7″	..	11	11	22
3′- 8″	5 29/32″	3′- 8″	..	11	12	23
3′- 9″	6 1/32″	3′- 9″	..	10	13	23
3′-10″	6 5/32″	3′-10″	..	10	13	23
3′-11″	6 9/32″	3′-11″	..	10	14	24
4′- 0″	6 7/16″	4′- 0″	..	9	15	24
4′- 1″	6 9/16″	4′- 1″	..	9	16	25
4′- 2″	6 11/16″	4′- 2″	..	9	16	25
4′- 3″	6 27/32″	4′- 3″	..	9	17	26
4′- 4″	6 31/32″	4′- 4″	..	8	18	26
4′- 5″	7 3/32″	4′- 5″	..	8	18	26
4′- 6″	7 1/4″	4′- 6″	..	8	19	27
4′- 7″	7 3/8″	4′- 7″	..	7	20	27
4′- 8″	7 1/2″	4′- 8″	..	7	21	28
4′- 9″	7 5/8″	4′- 9″	..	7	21	28
4′-10″	7 25/32″	4′-10″	..	6	22	28
4′-11″	7 29/32″	4′-11″	..	6	23	29
5′- 0″	8 1/32″	5′- 0″	..	6	23	29
5′- 1″	8 5/32″	5′- 1″	..	6	24	30
5′- 2″	8 9/32″	5′- 2″	..	5	25	30
5′- 3″	8 13/32″	5′- 3″	..	5	26	31
5′- 4″	8 9/16″	5′- 4″	..	5	26	31
5′- 5″	8 23/32″	5′- 5″	..	4	27	31

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
5′- 6″	8 27/32″	5′- 6″	4	28	..	32
5′- 7″	8 31/32″	5′- 7″	4	28	..	32
5′- 8″	9 1/8″	5′- 8″	4	29	..	33
5′- 9″	9 1/4″	5′- 9″	4	29	..	33
5′-10″	9 3/8″	5′-10″	3	30	..	33
5′-11″	9 1/2″	5′-11″	3	31	..	34
6′- 0″	9 21/32″	6′- 0″	3	31	..	34
6′- 1″	9 25/32″	6′- 1″	3	32	..	35
6′- 2″	9 29/32″	6′- 2″	2	33	..	35
6′- 3″	10 1/16″	6′- 3″	2	34	..	36
6′- 4″	10 3/16″	6′- 4″	2	34	..	36
6′- 5″	10 5/16″	6′- 5″	1	35	..	36
6′- 6″	10 7/16″	6′- 6″	1	36	..	37
6′- 7″	10 19/32″	6′- 7″	1	36	..	37
6′- 8″	10 23/32″	6′- 8″	1	37	..	38
6′- 9″	10 27/32″	6′- 9″	..	38	..	38
7′- 0″	11 1/4″	7′- 0″	..	38	1	39
7′- 3″	11 21/32″	7′- 3″	..	38	3	41
7′- 6″	1′- 0 1/16″	7′- 6″	..	38	4	42
7′- 9″	1′- 0 15/32″	7′- 9″	..	38	5	43
8′- 0″	1′- 0 7/8″	8′- 0″	..	38	6	44
8′- 3″	1′- 1 1/4″	8′- 3″	..	38	8	46
8′- 6″	1′- 1 21/32″	8′- 6″	..	38	9	47
8′- 9″	1′- 2 1/16″	8′- 9″	..	38	10	48
9′- 0″	1′- 2 15/32″	9′- 0″	..	38	11	49
9′- 3″	1′- 2 7/8″	9′- 3″	..	38	13	51
9′- 6″	1′- 3 9/32″	9′- 6″	..	38	14	52
9′- 9″	1′- 3 11/16″	9′- 9″	..	38	15	53
10′- 0″	1′- 4 1/16″	10′- 0″	..	38	16	54
10′- 3″	1′- 4 15/32″	10′- 3″	..	38	18	56
10′- 6″	1′- 4 7/8″	10′- 6″	..	38	19	57
10′- 9″	1′- 5 9/32″	10′- 9″	..	38	20	58
11′- 0″	1′- 5 11/16″	11′- 0″	..	38	21	59
11′- 3″	1′- 6 3/32″	11′- 3″	..	38	23	61
11′- 6″	1′- 6 1/2″	11′- 6″	..	38	24	62
11′- 9″	1′- 6 7/8″	11′- 9″	..	38	25	63
12′- 0″	1′- 7 9/32″	12′- 0″	..	38	26	64
12′- 3″	1′- 7 11/16″	12′- 3″	..	38	28	66
12′- 6″	1′- 8 3/32″	12′- 6″	..	38	29	67
12′- 9″	1′- 8 1/2″	12′- 9″	..	38	30	68
13′- 0″	1′- 8 29/32″	13′- 0″	..	38	32	70
13′- 6″	1′- 9 11/16″	13′- 6″	..	38	34	72
14′- 0″	1′-10 1/2″	14′- 0″	..	38	37	75
14′- 6″	1′-11 5/16″	14′- 6″	..	38	39	77
15′- 0″	2′- 0 1/8″	15′- 0″	..	38	42	80

†More exactly 1.608″

For skewback illustration see page 58.

9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

1 19/32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2 and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1′- 6″	2 13/32″	1′- 6″	10	..	..	10
1′- 7″	2 17/32″	1′- 7″	9	1	..	10
1′- 8″	2 11/16″	1′- 8″	9	2	..	11
1′- 9″	2 13/16″	1′- 9″	9	2	..	11
1′-10″	2 15/16″	1′-10″	8	3	..	11
1′-11″	3 3/32″	1′-11″	8	4	..	12
2′- 0″	3 7/32″	2′- 0″	8	4	..	12
2′- 1″	3 11/32″	2′- 1″	7	5	..	12
2′- 2″	3 15/32″	2′- 2″	7	6	..	13
2′- 3″	3 5/8″	2′- 3″	7	6	..	13
2′- 4″	3 3/4″	2′- 4″	6	7	..	13
2′- 5″	3 7/8″	2′- 5″	6	8	..	14
2′- 6″	4 1/32″	2′- 6″	5	9	..	14
2′- 7″	4 5/32″	2′- 7″	5	9	..	14
2′- 8″	4 9/32″	2′- 8″	5	10	..	15
2′- 9″	4 7/16″	2′- 9″	4	11	..	15
2′-10″	4 9/16″	2′-10″	4	11	..	15
2′-11″	4 11/16″	2′-11″	4	12	..	16
3′- 0″	4 13/16″	3′- 0″	3	13	..	16
3′- 1″	4 31/32″	3′- 1″	3	13	..	16
3′- 2″	5 5/32″	3′- 2″	3	14	..	17
3′- 3″	5 7/32″	3′- 3″	2	15	..	17
3′- 4″	5 11/32″	3′- 4″	2	16	..	18
3′- 5″	5 1/2″	3′- 5″	2	16	..	18
3′- 6″	5 5/8″	3′- 6″	1	17	..	18
3′- 7″	5 3/4″	3′- 7″	1	18	..	19
3′- 8″	5 29/32″	3′- 8″	1	18	..	19
3′- 9″	6 1/32″	3′- 9″	..	19	..	19
3′-10″	6 5/32″	3′-10″	..	19	1	20
3′-11″	6 9/32″	3′-11″	..	18	2	20
4′- 0″	6 7/16″	4′- 0″	..	18	2	20
4′- 1″	6 9/16″	4′- 1″	..	18	3	21
4′- 2″	6 11/16″	4′- 2″	..	17	4	21
4′- 3″	6 27/32″	4′- 3″	..	17	4	21
4′- 4″	6 31/32″	4′- 4″	..	17	5	22
4′- 5″	7 3/32″	4′- 5″	..	16	6	22
4′- 6″	7 1/4″	4′- 6″	..	16	6	22
4′- 7″	7 3/4″	4′- 7″	..	16	7	23
4′- 8″	7 1/2″	4′- 8″	..	15	8	23
4′- 9″	7 5/4″	4′- 9″	..	15	8	23
4′-10″	7 25/32″	4′-10″	..	15	9	24
4′-11″	7 29/32″	4′-11″	..	14	10	24
5′- 0″	8 1/32″	5′- 0″	..	14	10	24
5′- 1″	8 3/16″	5′- 1″	..	14	11	25
5′- 2″	8 5/16″	5′- 2″	..	13	12	25
5′- 3″	8 7/16″	5′- 3″	..	13	13	26
5′- 4″	8 9/16″	5′- 4″	..	12	14	26
5′- 5″	8 23/32″	5′- 5″	..	12	14	26

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
5′- 6″	8 27/32″	5′- 6″	12	15	..	27
5′- 7″	8 31/32″	5′- 7″	11	16	..	27
5′- 8″	9 1/8″	5′- 8″	11	16	..	27
5′- 9″	9 1/4″	5′- 9″	11	17	..	28
5′-10″	9 3/8″	5′-10″	10	18	..	28
5′-11″	9 1/2″	5′-11″	10	18	..	28
6′- 0″	9 21/32″	6′- 0″	10	19	..	29
6′- 1″	9 25/32″	6′- 1″	9	20	..	29
6′- 2″	9 29/32″	6′- 2″	9	20	..	29
6′- 3″	10 1/16″	6′- 3″	9	21	..	30
6′- 4″	10 3/16″	6′- 4″	8	22	..	30
6′- 5″	10 5/16″	6′- 5″	8	22	..	30
6′- 6″	10 7/16″	6′- 6″	8	23	..	31
6′- 7″	10 19/32″	6′- 7″	7	24	..	31
6′- 8″	10 23/32″	6′- 8″	7	24	..	31
6′- 9″	10 27/32″	6′- 9″	7	25	..	32
6′-10″	11″	6′-10″	6	26	..	32
6′-11″	11 1/8″	6′-11″	6	27	..	33
7′- 0″	11 1/4″	7′- 0″	6	27	..	33
7′- 1″	11 3/8″	7′- 1″	5	28	..	33
7′- 2″	11 17/32″	7′- 2″	5	29	..	34
7′- 3″	11 21/32″	7′- 3″	4	30	..	34
7′- 4″	11 25/32″	7′- 4″	4	30	..	34
7′- 5″	11 15/16″	7′- 5″	4	31	..	35
7′- 6″	1′- 0 1/16″	7′- 6″	3	32	..	35
7′- 7″	1′- 0 3/16″	7′- 7″	3	32	..	35
7′- 8″	1′- 0 5/16″	7′- 8″	3	33	..	36
7′- 9″	1′- 0 15/32″	7′- 9″	2	34	..	36
7′-10″	1′- 0 19/32″	7′-10″	2	34	..	36
7′-11″	1′- 0 23/32″	7′-11″	2	35	..	37
8′- 0″	1′- 0 7/8″	8′- 0″	1	36	..	37
8′- 1″	1′- 1″	8′- 1″	1	36	..	37
8′- 2″	1′- 1 1/8″	8′- 2″	1	37	..	38
8′- 3″	1′- 1 1/4″	8′- 3″	..	38	..	38
8′- 6″	1′- 1 21/32″	8′- 6″	..	38	1	39
9′- 0″	1′- 2 15/32″	9′- 0″	..	38	3	41
9′- 6″	1′- 3 9/32″	9′- 6″	..	38	5	43
10′- 0″	1′- 4 1/16″	10′- 0″	..	38	7	45
10′- 6″	1′- 4 7/8″	10′- 6″	..	38	10	48
11′- 0″	1′- 5 11/16″	11′- 0″	..	38	12	50
11′- 6″	1′- 6 1/2″	11′- 6″	..	38	14	52
12′- 0″	1′- 7 9/32″	12′- 0″	..	38	16	54
12′- 6″	1′- 8 3/32″	12′- 6″	..	38	18	56
13′- 0″	1′- 8 29/32″	13′- 0″	..	38	20	58
13′- 6″	1′- 9 11/16″	13′- 6″	..	38	22	60
14′- 0″	1′-10 1/2″	14′- 0″	..	38	24	62
14′- 6″	1′-11 5/16″	14′- 6″	..	38	26	64
15′- 0″	2′- 0 1/8″	15′- 0″	..	38	28	66

†More exactly 1.608″

For skewback illustration see page 58.

9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

2″ RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	3″	1′- 3″	11	2	..	13
1′- 7″	3 5/32″	1′- 3 27/32″	10	3	..	13
1′- 7″	3 11/32″	1′- 4 21/32″	9	5	..	14
1′- 8″	3 1/2″	1′- 5 1/2″	8	6	..	14
1′- 9″	3 21/32″	1′- 6 11/32″	7	7	..	14
1′-10″	3 27/32″	1′- 7 5/32″	7	8	..	15
1′-11″	3 27/32″	1′- 7 5/32″	7	8	..	15
2′- 0″	4″	1′- 8″	6	9	..	15
2′- 1″	4 5/32″	1′- 8 27/32″	6	10	..	16
2′- 2″	4 11/32″	1′- 9 21/32″	5	11	..	16
2′- 3″	4 1/2″	1′-10 1/2″	4	13	..	17
2′- 4″	4 21/32″	1′-11 11/32″	3	14	..	17
2′- 5″	4 27/32″	2′- 0 5/32″	2	15	..	17
2′- 6″	5″	2′- 1″	2	16	..	18
2′- 7″	5 5/32″	2′- 1 27/32″	1	17	..	18
2′- 8″	5 11/32″	2′- 2 21/32″	1	18	..	19
2′- 9″	5 1/2″	2′- 3 1/2″	..	18	1	19
2′-10″	5 21/32″	2′- 4 11/32″	..	18	2	20
2′-11″	5 27/32″	2′- 5 5/32″	..	18	2	20
3′- 0″	6″	2′- 6″	..	17	3	20
3′- 1″	6 5/32″	2′- 6 27/32″	..	17	4	21
3′- 2″	6 11/32″	2′- 7 21/32″	..	17	4	21
3′- 3″	6 1/2″	2′- 8 1/2″	..	17	5	22
3′- 4″	6 21/32″	2′- 9 11/32″	..	16	6	22
3′- 5″	6 27/32″	2′-10 5/32″	..	16	7	23
3′- 6″	7″	2′-11″	..	16	7	23
3′- 7″	7 5/32″	2′-11 27/32″	..	15	8	23
3′- 8″	7 11/32″	3′- 0 21/32″	..	15	9	24
3′- 9″	7 1/2″	3′- 1 1/2″	..	15	9	24
3′-10″	7 21/32″	3′- 2 11/32″	..	15	10	25
3′-11″	7 27/32″	3′- 3 5/32″	..	14	11	25
4′- 0″	8″	3′- 4″	..	14	12	26
4′- 1″	8 5/32″	3′- 4 27/32″	..	14	12	26
4′- 2″	8 11/32″	3′- 5 21/32″	..	13	13	26
4′- 3″	8 1/2″	3′- 6 1/2″	..	13	14	27
4′- 4″	8 21/32″	3′- 7 11/32″	..	13	14	27
4′- 5″	8 27/32″	3′- 8 5/32″	..	13	15	28
4′- 6″	9″	3′- 9″	..	12	16	28
4′- 7″	9 5/32″	3′- 9 27/32″	..	12	17	29
4′- 8″	9 11/32″	3′-10 21/32″	..	12	17	29
4′- 9″	9 1/2″	3′-11 1/2″	..	11	18	29
4′-10″	9 21/32″	4′- 0 11/32″	..	11	19	30
4′-11″	9 27/32″	4′- 1 5/32″	..	11	19	30
5′- 0″	10″	4′- 2″	..	11	20	31
5′- 1″	10 5/32″	4′- 2 27/32″	..	10	21	31
5′- 2″	10 11/32″	4′- 3 21/32″	..	10	22	32
5′- 3″	10 1/2″	4′- 4 1/2″	..	10	22	32
5′- 4″	10 21/32″	4′- 5 11/32″	..	9	23	32
5′- 5″	10 27/32″	4′- 6 5/32″	..	9	24	33

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
5′- 6″	11″	4′- 7″	9	24	..	33
5′- 7″	11 5/32″	4′- 7 27/32″	9	25	..	34
5′- 8″	11 11/32″	4′- 8 21/32″	8	26	..	34
5′- 9″	11 1/2″	4′- 9 1/2″	8	27	..	35
5′-10″	11 21/32″	4′-10 11/32″	8	27	..	35
5′-11″	11 27/32″	4′-11 5/32″	7	28	..	35
6′- 0″	1′- 0″	5′- 0″	7	29	..	36
6′- 1″	1′- 0 5/32″	5′- 0 27/32″	7	29	..	36
6′- 2″	1′- 0 11/32″	5′- 1 21/32″	7	30	..	37
6′- 3″	1′- 0 1/2″	5′- 2 1/2″	6	31	..	37
6′- 4″	1′- 0 21/32″	5′- 3 11/32″	6	32	..	38
6′- 5″	1′- 0 27/32″	5′- 4 5/32″	6	32	..	38
6′- 6″	1′- 1″	5′- 5″	5	33	..	38
6′- 7″	1′- 1 5/32″	5′- 5 27/32″	5	34	..	39
6′- 8″	1′- 1 11/32″	5′- 6 21/32″	5	34	..	39
6′- 9″	1′- 1 1/2″	5′- 7 1/2″	5	35	..	40
6′-10″	1′- 1 21/32″	5′- 8 11/32″	4	36	..	40
6′-11″	1′- 1 27/32″	5′- 9 5/32″	4	37	..	41
7′- 0″	1′- 2″	5′-10″	4	37	..	41
7′- 1″	1′- 2 5/32″	5′-10 27/32″	3	38	..	41
7′- 2″	1′- 2 11/32″	5′-11 21/32″	3	39	..	42
7′- 3″	1′- 2 1/2″	6′- 0 1/2″	3	39	..	42
7′- 4″	1′- 2 21/32″	6′- 1 11/32″	3	40	..	43
7′- 5″	1′- 2 27/32″	6′- 2 5/32″	2	41	..	43
7′- 6″	1′- 3″	6′- 3″	2	42	..	44
7′- 7″	1′- 3 5/32″	6′- 3 27/32″	2	42	..	44
7′- 8″	1′- 3 11/32″	6′- 4 21/32″	2	43	..	45
7′- 9″	1′- 3 1/2″	6′- 5 1/2″	1	44	..	45
7′-10″	1′- 3 21/32″	6′- 6 11/32″	1	44	..	45
7′-11″	1′- 3 27/32″	6′- 7 5/32″	1	45	..	46
8′- 0″	1′- 4″	6′- 8″	..	46	..	46
8′- 1″	1′- 4 5/32″	6′- 8 27/32″	..	47	..	47
8′- 2″	1′- 4 11/32″	6′- 9 21/32″	..	47	..	47
8′- 3″	1′- 4 1/2″	6′-10 1/2″	..	47	1	48
8′- 4″	1′- 4 21/32″	6′-11 11/32″	..	47	1	48
8′- 5″	1′- 4 27/32″	7′- 0 5/32″	..	47	1	48
8′- 6″	1′- 5″	7′- 1″	..	47	2	49
9′- 0″	1′- 6″	7′- 6″	..	47	4	51
9′- 6″	1′- 7″	7′-11″	..	47	7	54
10′- 0″	1′- 8″	8′- 4″	..	47	10	57
10′- 6″	1′- 9″	8′- 9″	..	47	12	59
11′- 0″	1′-10″	9′- 2″	..	47	15	62
11′- 6″	1′-11″	9′- 7″	..	47	17	64
12′- 0″	2′- 0″	10′- 0″	..	47	20	67
12′- 6″	2′- 1″	10′- 5″	..	47	22	69
13′- 0″	2′- 2″	10′-10″	..	47	25	72
13′- 6″	2′- 3″	11′- 3″	..	47	28	75
14′- 0″	2′- 4″	11′- 8″	..	47	30	77
14′- 6″	2′- 5″	12′- 1″	..	47	33	80
15′- 0″	2′- 6″	12′- 6″	..	47	35	82

For skewback illustration see page 57.

9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

2″ RISE PER FOOT OF SPAN

This table can be used also for **13½″ x 9″ x 3″ arch brick,** by substituting No. 1, 2 and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
1′-10″	3 21/32″	1′- 6 11/32″	12	..	..	12
1′-11″	3 27/32″	1′- 7 5/32″	11	1	..	12
2′- 0″	4″	1′- 8″	11	2	..	13
2′- 1″	4 5/32″	1′- 8 27/32″	10	3	..	13
2′- 2″	4 11/32″	1′- 9 21/32″	10	4	..	14
2′- 3″	4 1/2″	1′-10 1/2″	10	4	..	14
2′- 4″	4 21/32″	1′-11 11/32″	9	5	..	14
2′- 5″	4 27/32″	2′- 0 5/32″	9	6	..	15
2′- 6″	5″	2′- 1″	9	6	..	15
2′- 7″	5 5/32″	2′- 1 27/32″	8	7	..	15
2′- 8″	5 11/32″	2′- 2 21/32″	8	8	..	16
2′- 9″	5 1/2″	2′- 3 1/2″	8	8	..	16
2′-10″	5 21/32″	2′- 4 11/32″	7	9	..	16
2′-11″	5 27/32″	2′- 5 5/32″	7	10	..	17
3′- 0″	6″	2′- 6″	7	10	..	17
3′- 1″	6 5/32″	2′- 6 27/32″	6	11	..	17
3′- 2″	6 11/32″	2′- 7 21/32″	6	12	..	18
3′- 3″	6 1/2″	2′- 8 1/2″	5	13	..	18
3′- 4″	6 21/32″	2′- 9 11/32″	5	14	..	19
3′- 5″	6 27/32″	2′-10 5/32″	5	14	..	19
3′- 6″	7″	2′-11″	4	15	..	19
3′- 7″	7 5/32″	2′-11 27/32″	4	16	..	20
3′- 8″	7 11/32″	3′- 0 21/32″	4	16	..	20
3′- 9″	7 1/2″	3′- 1 1/2″	3	17	..	20
3′-10″	7 21/32″	3′- 2 11/32″	3	18	..	21
3′-11″	7 27/32″	3′- 3 5/32″	3	18	..	21
4′- 0″	8″	3′- 4″	2	19	..	21
4′- 1″	8 5/32″	3′- 4 27/32″	2	20	..	22
4′- 2″	8 11/32″	3′- 5 21/32″	2	20	..	22
4′- 3″	8 1/2″	3′- 6 1/2″	1	21	..	22
4′- 4″	8 21/32″	3′- 7 11/32″	1	22	..	23
4′- 5″	8 27/32″	3′- 8 5/32″	1	22	..	23
4′- 6″	9″	3′- 9″	..	24	..	24
4′- 7″	9 5/32″	3′- 9 27/32″	..	23	1	24
4′- 8″	9 11/32″	3′-10 21/32″	..	23	1	24
4′- 9″	9 1/2″	3′-11 1/2″	..	22	3	25
4′-10″	9 21/32″	4′- 0 11/32″	..	22	3	25
4′-11″	9 27/32″	4′- 1 5/32″	..	21	4	25
5′- 0″	10″	4′- 2″	..	21	5	26
5′- 1″	10 5/32″	4′- 2 27/32″	..	21	5	26
5′- 2″	10 11/32″	4′- 3 21/32″	..	20	6	26
5′- 3″	10 1/2″	4′- 4 1/2″	..	20	7	27
5′- 4″	10 21/32″	4′- 5 11/32″	..	20	7	27
5′- 5″	10 27/32″	4′- 6 5/32″	..	19	8	27
5′- 6″	11″	4′- 7″	..	19	9	28
5′- 7″	11 5/32″	4′- 7 27/32″	..	19	9	28
5′- 8″	11 11/32″	4′- 8 21/32″	..	19	10	29
5′- 9″	11 1/2″	4′- 9 1/2″	..	18	11	29
5′-10″	11 21/32″	4′-10 11/32″	..	18	11	29
5′-11″	11 27/32″	4′-11 5/32″	..	17	13	30

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
6′- 0″	1′- 0″	5′- 0″	17	13	..	30
6′- 1″	1′- 0 5/32″	5′- 0 27/32″	16	14	..	30
6′- 2″	1′- 0 11/32″	5′- 1 21/32″	16	15	..	31
6′- 3″	1′- 0 1/2″	5′- 2 1/2″	16	15	..	31
6′- 4″	1′- 0 21/32″	5′- 3 11/32″	15	16	..	31
6′- 5″	1′- 0 27/32″	5′- 4 5/32″	15	17	..	32
6′- 6″	1′- 1″	5′- 5″	15	17	..	32
6′- 7″	1′- 1 5/32″	5′- 5 27/32″	15	18	..	33
6′- 8″	1′- 1 11/32″	5′- 6 21/32″	14	19	..	33
6′- 9″	1′- 1 1/2″	5′- 7 1/2″	14	19	..	33
6′-10″	1′- 1 21/32″	5′- 8 11/32″	14	20	..	34
6′-11″	1′- 1 27/32″	5′- 9 5/32″	13	21	..	34
7′- 0″	1′- 2″	5′-10″	13	21	..	34
7′- 1″	1′- 2 5/32″	5′-10 27/32″	12	23	..	35
7′- 2″	1′- 2 11/32″	5′-11 21/32″	12	23	..	35
7′- 3″	1′- 2 1/2″	6′- 0 1/2″	11	24	..	35
7′- 4″	1′- 2 21/32″	6′- 1 11/32″	11	25	..	36
7′- 5″	1′- 2 27/32″	6′- 2 5/32″	11	25	..	36
7′- 6″	1′- 3″	6′- 3″	10	26	..	36
7′- 7″	1′- 3 5/32″	6′- 3 27/32″	10	27	..	37
7′- 8″	1′- 3 11/32″	6′- 4 21/32″	10	27	..	37
7′- 9″	1′- 3 1/2″	6′- 5 1/2″	10	28	..	38
7′-10″	1′- 3 21/32″	6′- 6 11/32″	9	29	..	38
7′-11″	1′- 3 27/32″	6′- 7 5/32″	9	29	..	38
8′- 0″	1′- 4″	6′- 8″	9	30	..	39
8′- 1″	1′- 4 5/32″	6′- 8 27/32″	8	31	..	39
8′- 2″	1′- 4 11/32″	6′- 9 21/32″	8	31	..	39
8′- 3″	1′- 4 1/2″	6′-10 1/2″	7	33	..	40
8′- 4″	1′- 4 21/32″	6′-11 11/32″	7	33	..	40
8′- 5″	1′- 4 27/32″	7′- 0 5/32″	6	34	..	40
8′- 6″	1′- 5″	7′- 1″	6	35	..	41
8′- 7″	1′- 5 5/32″	7′- 1 27/32″	6	35	..	41
8′- 8″	1′- 5 11/32″	7′- 2 21/32″	5	36	..	41
8′- 9″	1′- 5 1/2″	7′- 3 1/2″	5	37	..	42
8′-10″	1′- 5 21/32″	7′- 4 11/32″	5	37	..	42
8′-11″	1′- 5 27/32″	7′- 5 5/32″	5	38	..	43
9′- 0″	1′- 6″	7′- 6″	4	39	..	43
9′- 2″	1′- 6 11/32″	7′- 7 21/32″	4	40	..	44
9′- 4″	1′- 6 21/32″	7′- 9 11/32″	3	41	..	44
9′- 6″	1′- 7″	7′-11″	2	43	..	45
9′- 8″	1′- 7 11/32″	8′- 0 21/32″	1	45	..	46
9′-10″	1′- 7 21/32″	8′- 2 11/32″	..	46	..	46
10′- 0″	1′- 8″	8′- 4″	..	47	..	47
10′- 6″	1′- 9″	8′- 9″	..	47	2	49
11′- 0″	1′-10″	9′- 2″	..	47	4	51
12′- 0″	2′- 0″	10′- 0″	..	47	9	56
13′- 0″	2′- 2″	10′-10″	..	47	13	60
14′- 0″	2′- 4″	11′- 8″	..	47	17	64
15′- 0″	2′- 6″	12′- 6″	..	47	22	69

For skewback illustration see page 57.

9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 2½″, 9″ x 6¾″ x 2½″ or 9″ x 9″ x 2½″

2 5/16″† RISE PER FOOT OF SPAN

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
1′- 6″	3 15/32″	1′- 1 15/32″	14	..	..	14
1′- 7″	3 21/32″	1′- 2 3/16″	13	1	..	14
1′- 8″	3 27/32″	1′- 2 15/16″	12	2	..	14
1′- 9″	4 1/32″	1′- 3 11/16″	11	4	..	15
1′-10″	4 7/32″	1′- 4 7/16″	10	5	..	15
1′-11″	4 13/32″	1′- 5 3/16″	10	6	..	16
2′- 0″	4 19/32″	1′- 5 15/16″	9	7	..	16
2′- 1″	4 25/32″	1′- 6 11/16″	9	8	..	17
2′- 2″	5″	1′- 7 7/16″	8	9	..	17
2′- 3″	5 5/16″	1′- 8 3/16″	7	11	..	18
2′- 4″	5 3/8″	1′- 8 15/16″	6	12	..	18
2′- 5″	5 9/16″	1′- 9 11/16″	5	13	..	18
2′- 6″	5 3/4″	1′-10 7/16″	5	14	..	19
2′- 7″	5 15/16″	1′-11 5/32″	4	15	..	19
2′- 8″	6 1/8″	1′-11 29/32″	3	17	..	20
2′- 9″	6 11/32″	2′- 0 21/32″	2	18	..	20
2′-10″	6 17/32″	2′- 1 13/32″	2	19	..	21
2′-11″	6 23/32″	2′- 2 5/32″	1	20	..	21
3′- 0″	6 29/32″	2′- 2 29/32″	..	21	..	21
3′- 1″	7 3/32″	2′- 3 21/32″	..	21	1	22
3′- 2″	7 9/32″	2′- 4 13/32″	..	21	1	22
3′- 3″	7 15/32″	2′- 5 5/32″	..	21	2	23
3′- 4″	7 11/16″	2′- 5 29/32″	..	20	3	23
3′- 5″	7 7/8″	2′- 6 21/32″	..	20	4	24
3′- 6″	8 1/16″	2′- 7 13/32″	..	20	4	24
3′- 7″	8 1/4″	2′- 8 1/8″	..	20	5	25
3′- 8″	8 7/16″	2′- 8 7/8″	..	19	6	25
3′- 9″	8 5/8″	2′- 9 5/8″	..	19	6	25
3′-10″	8 13/16″	2′-10 3/8″	..	18	8	26
3′-11″	9 1/32″	2′-11 1/8″	..	18	8	26
4′- 0″	9 7/32″	2′-11 7/8″	..	18	9	27
4′- 1″	9 15/32″	3′- 0 5/8″	..	17	10	27
4′- 2″	9 19/32″	3′- 1 3/8″	..	17	11	28
4′- 3″	9 25/32″	3′- 2 1/8″	..	17	11	28
4′- 4″	9 31/32″	3′- 2 7/8″	..	16	12	28
4′- 5″	10 5/32″	3′- 3 5/8″	..	16	13	29
4′- 6″	10 3/8″	3′- 4 3/8″	..	16	13	29
4′- 7″	10 9/16″	3′- 5 1/8″	..	16	14	30
4′- 8″	10 3/4″	3′- 5 27/32″	..	15	15	30
4′- 9″	10 15/16″	3′- 6 19/32″	..	15	16	31
4′-10″	11 1/8″	3′- 7 11/32″	..	15	16	31
4′-11″	11 5/16″	3′- 8 3/32″	..	15	17	32
5′- 0″	11 1/2″	3′- 8 27/32″	..	14	18	32
5′- 1″	11 23/32″	3′- 9 19/32″	..	14	18	32
5′- 2″	11 29/32″	3′-10 11/32″	..	14	19	33
5′- 3″	1′- 0 3/32″	3′-11 3/32″	..	13	20	33
5′- 4″	1′- 0 9/32″	3′-11 27/32″	..	13	21	34
5′- 5″	1′- 0 15/32″	4′- 0 19/32″	..	13	21	34
5′- 6″	1′- 0 21/32″	4′- 1 11/32″	..	13	22	35
5′- 7″	1′- 0 27/32″	4′- 2 1/16″	..	12	23	35
5′- 8″	1′- 1 1/16″	4′- 2 13/16″	..	12	23	35
5′- 9″	1′- 1 1/4″	4′- 3 9/16″	..	12	24	36
5′-10″	1′- 1 7/16″	4′- 4 5/16″	..	11	25	36
5′-11″	1′- 1 5/8″	4′- 5 1/16″	..	11	26	37

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X Wedge	Straight	Total
6′- 0″	1′- 1 13/16″	4′- 5 13/16″	11	26	..	37
6′- 1″	1′- 2″	4′- 6 9/16″	11	27	..	38
6′- 2″	1′- 2 3/16″	4′- 7 5/16″	10	28	..	38
6′- 3″	1′- 2 3/8″	4′- 8 1/16″	10	29	..	39
6′- 4″	1′- 2 19/32″	4′- 8 13/16″	10	29	..	39
6′- 5″	1′- 2 25/32″	4′- 9 9/16″	9	30	..	39
6′- 6″	1′- 2 31/32″	4′-10 5/16″	9	31	..	40
6′- 7″	1′- 3 5/32″	4′-11 1/32″	9	31	..	40
6′- 8″	1′- 3 11/32″	4′-11 25/32″	9	32	..	41
6′- 9″	1′- 3 17/32″	5′- 0 17/32″	8	33	..	41
6′-10″	1′- 3 23/32″	5′- 1 9/32″	8	34	..	42
6′-11″	1′- 3 15/16″	5′- 2 1/32″	8	34	..	42
7′- 0″	1′- 4 1/8″	5′- 2 25/32″	7	35	..	42
7′- 1″	1′- 4 5/16″	5′- 3 17/32″	7	36	..	43
7′- 2″	1′- 4 1/2″	5′- 4 9/32″	7	36	..	43
7′- 3″	1′- 4 11/16″	5′- 5 1/32″	7	36	..	43
7′- 4″	1′- 4 7/8″	5′- 5 25/32″	6	37	..	43
7′- 5″	1′- 5 1/16″	5′- 6 17/32″	6	38	..	44
7′- 6″	1′- 5 9/32″	5′- 7 9/32″	6	39	..	45
7′- 7″	1′- 5 15/32″	5′- 8 1/32″	5	39	..	44
7′- 8″	1′- 5 21/32″	5′- 8 3/4″	5	41	..	46
7′- 9″	1′- 5 27/32″	5′- 9 1/2″	5	41	..	46
7′-10″	1′- 6 1/32″	5′-10 1/4″	4	41	..	45
7′-11″	1′- 6 7/32″	5′-11″	4	42	..	46
8′- 0″	1′- 6 13/32″	5′-11 3/4″	4	43	..	46
8′- 1″	1′- 6 5/8″	6′- 0 1/2″	4	43	..	46
8′- 2″	1′- 6 13/16″	6′- 1 1/4″	3	44	..	47
8′- 3″	1′- 7″	6′- 2″	3	44	..	47
8′- 4″	1′- 7 3/16″	6′- 2 3/4″	3	45	..	48
8′- 5″	1′- 7 3/8″	6′- 3 1/2″	2	45	..	47
8′- 6″	1′- 7 9/16″	6′- 4 1/4″	2	46	..	48
8′- 7″	1′- 7 3/4″	6′- 5″	2	46	..	48
8′- 8″	1′- 7 31/32″	6′- 5 23/32″	2	47	..	49
8′- 9″	1′- 8 5/32″	6′- 6 15/32″	2	47	..	49
8′-10″	1′- 8 11/32″	6′- 7 7/32″	2	48	..	50
8′-11″	1′- 8 17/32″	6′- 7 31/32″	2	48	..	50
9′- 0″	1′- 8 23/32″	6′- 8 23/32″	2	49	..	51
9′- 6″	1′- 9 7/8″	7′- 1 7/32″	1	50	..	51
10′- 0″	1′-11 1/32″	7′- 5 11/16″	1	52	..	53
10′- 6″	2′- 0 3/16″	7′-10 3/16″	1	53	..	54
11′- 0″	2′- 1 5/16″	8′- 2 21/32″	1	54	..	55
11′- 6″	2′- 2 15/32″	8′- 7 5/32″	1	55	..	56
12′- 0″	2′- 3 5/8″	8′-11 5/8″	1	56	..	57
12′- 6″	2′- 4 25/32″	9′- 4 1/8″	1	57	..	58
13′- 0″	2′- 5 15/16″	9′- 8 19/32″	1	58	..	59
13′- 6″	2′- 7 3/32″	10′- 1 3/32″	1	59	..	60
14′- 0″	2′- 8 1/4″	10′- 5 9/16″	1	60	..	61
14′- 6″	2′- 9 3/8″	10′-10 1/16″	1	61	..	62
15′- 0″	2′-10 17/32″	11′- 2 17/32″	..	62	..	62

†More exactly, 2.302″

For skewback illustration see page 57.

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asbestosclaims.law/library/25269/222

9″ ARCH THICKNESS—WEDGE BRICK

9″ x 4½″ x 3″, 9″ x 6¾″ x 3″ or 9″ x 9″ x 3″

2 5⁄16″† RISE PER FOOT OF SPAN

This table can be used also for **13½″ x 9″ x 3″ arch brick** by substituting No. 1, 2 and 3 arch brick for the corresponding wedge brick.

Span	Rise	Inside Radius	Number Required Per Course: No. 3 Wedge	No. 2 Wedge	No. 1 Wedge	Total
2′- 0″	4 19⁄32″	1′- 5 15⁄16″	14	..	..	14
2′- 1″	4 25⁄32″	1′- 6 11⁄16″	13	1	..	14
2′- 2″	5″	1′- 7 7⁄16″	13	1	..	14
2′- 3″	5 3⁄16″	1′- 8 3⁄16″	12	3	..	15
2′- 4″	5 3⁄8″	1′- 8 15⁄16″	12	3	..	15
2′- 5″	5 9⁄16″	1′- 9 11⁄16″	11	4	..	15
2′- 6″	5 3⁄4″	1′-10 7⁄16″	11	5	..	16
2′- 7″	5 15⁄16″	1′-11 5⁄32″	11	5	..	16
2′- 8″	6 1⁄8″	1′-11 29⁄32″	10	6	..	16
2′- 9″	6 11⁄32″	2′- 0 21⁄32″	10	7	..	17
2′-10″	6 17⁄32″	2′- 1 13⁄32″	10	7	..	17
2′-11″	6 23⁄32″	2′- 2 5⁄32″	10	8	..	18
3′- 0″	6 29⁄32″	2′- 2 29⁄32″	9	9	..	18
3′- 1″	7 3⁄32″	2′- 3 21⁄32″	9	9	..	18
3′- 2″	7 9⁄32″	2′- 4 13⁄32″	8	11	..	19
3′- 3″	7 15⁄32″	2′- 5 5⁄32″	8	11	..	19
3′- 4″	7 11⁄16″	2′- 5 29⁄32″	7	12	..	19
3′- 5″	7 7⁄8″	2′- 6 21⁄32″	7	13	..	20
3′- 6″	8 1⁄16″	2′- 7 13⁄32″	7	13	..	20
3′- 7″	8 1⁄4″	2′- 8 1⁄32″	6	14	..	20
3′- 8″	8 7⁄16″	2′- 8 7⁄8″	6	15	..	21
3′- 9″	8 5⁄8″	2′- 9 5⁄8″	6	15	..	21
3′-10″	8 13⁄16″	2′-10 3⁄8″	6	16	..	22
3′-11″	9 1⁄32″	2′-11 1⁄8″	5	17	..	22
4′- 0″	9 7⁄32″	2′-11 7⁄8″	4	18	..	22
4′- 1″	9 13⁄32″	3′- 0 5⁄8″	4	19	..	23
4′- 2″	9 19⁄32″	3′- 1 3⁄8″	4	19	..	23
4′- 3″	9 25⁄32″	3′- 2 1⁄8″	3	20	..	23
4′- 4″	9 31⁄32″	3′- 2 7⁄8″	3	21	..	24
4′- 5″	10 5⁄32″	3′- 3 5⁄8″	3	21	..	24
4′- 6″	10 3⁄8″	3′- 4 3⁄8″	3	22	..	25
4′- 7″	10 9⁄16″	3′- 5 3⁄32″	2	23	..	25
4′- 8″	10 3⁄4″	3′- 5 27⁄32″	2	23	..	25
4′- 9″	10 15⁄16″	3′- 6 19⁄32″	2	24	..	26
4′-10″	11 1⁄8″	3′- 7 11⁄32″	1	25	..	26
4′-11″	11 5⁄16″	3′- 8 3⁄32″	..	26	..	26
5′- 0″	11 1⁄2″	3′- 8 27⁄32″	..	27	..	27
5′- 1″	11 23⁄32″	3′- 9 19⁄32″	..	26	1	27
5′- 2″	11 29⁄32″	3′-10 11⁄32″	..	26	1	27
5′- 3″	1′- 0 3⁄32″	3′-1 3⁄32″	..	26	2	28
5′- 4″	1′- 0 9⁄32″	3′-11 27⁄32″	..	25	3	28
5′- 5″	1′- 0 15⁄32″	4′- 0 19⁄32″	..	25	4	29
5′- 6″	1′- 0 21⁄32″	4′- 1 11⁄32″	..	25	4	29
5′- 7″	1′- 0 27⁄32″	4′- 2 1⁄16″	..	24	5	29
5′- 8″	1′- 1 1⁄16″	4′- 2 13⁄16″	..	24	6	30
5′- 9″	1′- 1 1⁄4″	4′- 3 9⁄16″	..	23	7	30
5′-10″	1′- 1 7⁄16″	4′- 4 5⁄16″	..	23	7	30
5′-11″	1′- 1 5⁄8″	4′- 5 1⁄16″	..	23	8	31

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	Straight	Total
6′- 0″	1′- 1 13⁄16″	4′- 5 13⁄16″	22	9	..	31
6′- 1″	1′- 2″	4′- 6 9⁄16″	22	9	..	31
6′- 2″	1′- 2 3⁄16″	4′- 7 5⁄16″	22	10	..	32
6′- 3″	1′- 2 3⁄8″	4′- 8 1⁄16″	21	11	..	32
6′- 4″	1′- 2 19⁄32″	4′- 8 13⁄16″	21	12	..	33
6′- 5″	1′- 2 25⁄32″	4′- 9 9⁄16″	20	13	..	33
6′- 6″	1′- 2 31⁄32″	4′-10 5⁄16″	20	13	..	33
6′- 7″	1′- 3 5⁄32″	4′-11 1⁄32″	20	14	..	34
6′- 8″	1′- 3 11⁄32″	4′-11 25⁄32″	19	15	..	34
6′- 9″	1′- 3 17⁄32″	5′- 0 17⁄32″	19	15	..	34
6′-10″	1′- 3 23⁄32″	5′- 1 9⁄32″	19	16	..	35
6′-11″	1′- 3 15⁄16″	5′- 2 1⁄32″	18	17	..	35
7′- 0″	1′- 4 1⁄8″	5′- 2 25⁄32″	18	17	..	35
7′- 1″	1′- 4 5⁄16″	5′- 3 17⁄32″	18	18	..	36
7′- 2″	1′- 4 1⁄2″	5′- 4 9⁄32″	17	19	..	36
7′- 3″	1′- 4 11⁄16″	5′- 5 1⁄32″	17	20	..	37
7′- 4″	1′- 4 7⁄8″	5′- 5 25⁄32″	16	21	..	37
7′- 5″	1′- 5 1⁄16″	5′- 6 17⁄32″	16	21	..	37
7′- 6″	1′- 5 9⁄32″	5′- 7 9⁄32″	16	22	..	38
7′- 7″	1′- 5 15⁄32″	5′- 8 1⁄32″	15	23	..	38
7′- 8″	1′- 5 21⁄32″	5′- 8 3⁄4″	15	23	..	38
7′- 9″	1′- 5 27⁄32″	5′- 9 1⁄2″	15	24	..	39
7′-10″	1′- 6 1⁄32″	5′-10 1⁄4″	14	25	..	39
7′-11″	1′- 6 7⁄32″	5′-11″	14	25	..	39
8′- 0″	1′- 6 13⁄32″	5′-11 3⁄4″	14	26	..	40
8′- 2″	1′- 6 13⁄16″	6′- 1 1⁄4″	13	28	..	41
8′- 4″	1′- 7 3⁄16″	6′- 2 3⁄4″	12	29	..	41
8′- 6″	1′- 7 9⁄16″	6′- 4 1⁄4″	11	31	..	42
8′- 8″	1′- 7 31⁄32″	6′- 5 23⁄32″	11	32	..	43
8′-10″	1′- 8 11⁄32″	6′- 7 7⁄32″	10	34	..	44
9′- 0″	1′- 8 23⁄32″	6′- 8 23⁄32″	9	35	..	44
9′- 2″	1′- 9 3⁄32″	6′-10 7⁄32″	8	37	..	45
9′- 4″	1′- 9 1⁄2″	6′-11 23⁄32″	8	38	..	46
9′- 6″	1′- 9 7⁄8″	7′- 1 7⁄32″	7	39	..	46
9′- 8″	1′-10 1⁄4″	7′- 2 11⁄16″	6	41	..	47
9′-10″	1′-10 5⁄8″	7′- 4 3⁄16″	6	42	..	48
10′- 0″	1′-11 1⁄32″	7′- 5 11⁄16″	5	44	..	49
10′- 2″	1′-11 13⁄32″	7′- 7 3⁄16″	4	45	..	49
10′- 4″	1′-11 25⁄32″	7′- 8 11⁄16″	3	47	..	50
10′- 6″	2′- 0 3⁄16″	7′-10 3⁄16″	3	48	..	51
10′- 8″	2′- 0 9⁄16″	7′-11 21⁄32″	2	50	..	52
10′-10″	2′- 0 15⁄16″	8′- 1 5⁄32″	1	51	..	52
11′- 0″	2′- 1 5⁄16″	8′- 2 21⁄32″	..	53	..	53
11′- 6″	2′- 2 15⁄32″	8′- 7 5⁄32″	..	53	2	55
12′- 0″	2′- 3 5⁄8″	8′-11 5⁄8″	..	53	4	57
13′- 0″	2′- 5 15⁄16″	9′- 8 19⁄32″	..	53	9	62
14′- 0″	2′- 8 1⁄4″	10′- 5 9⁄16″	..	53	13	66
15′- 0″	2′-10 17⁄32″	11′- 2 17⁄32″	..	53	18	71

†More exactly, 2.302″

For skewback illustration see page 57.

12″ ARCH THICKNESS—WEDGE BRICK

12″ x 4½″ x 3″, 12″ x 6″ x 3″ or 12″ x 9″ x 3″

1 19⁄32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X* Wedge	Total
6′- 0″	9 21⁄32″	6′- 0″	21	9	..	30
6′- 3″	10 1⁄16″	6′- 3″	20	11	..	31
6′- 6″	10 7⁄16″	6′- 6″	19	13	..	32
6′- 9″	10 27⁄32″	6′- 9″	18	15	..	33
7′- 0″	11 1⁄4″	7′- 0″	17	17	..	34
7′- 3″	11 21⁄32″	7′- 3″	16	19	..	35
7′- 6″	1′- 0 1⁄16″	7′- 6″	15	21	..	36
7′- 9″	1′- 0 15⁄32″	7′- 9″	14	23	..	37
8′- 0″	1′- 0 7⁄8″	8′- 0″	13	25	..	38
8′- 3″	1′- 1 1⁄4″	8′- 3″	12	27	..	39
8′- 6″	1′- 1 21⁄32″	8′- 6″	11	29	..	40
8′- 9″	1′- 2 1⁄16″	8′- 9″	10	31	..	41
9′- 0″	1′- 2 15⁄32″	9′- 0″	8	34	..	42
9′- 3″	1′- 2 7⁄8″	9′- 3″	7	36	..	43
9′- 6″	1′- 3 9⁄32″	9′- 6″	6	38	..	44
9′- 9″	1′- 3 11⁄16″	9′- 9″	5	40	..	45
10′- 0″	1′- 4 1⁄16″	10′- 0″	4	42	..	46
10′- 3″	1′- 4 15⁄32″	10′- 3″	4	44	..	48
10′- 6″	1′- 4 7⁄8″	10′- 6″	3	46	..	49
10′- 9″	1′- 5 9⁄32″	10′- 9″	1	49	..	50
11′- 0″	1′- 5 11⁄16″	11′- 0″	..	51	..	51
11′- 3″	1′- 6 3⁄32″	11′- 3″	..	50	2	52
11′- 6″	1′- 6 1⁄2″	11′- 6″	..	48	5	53
11′- 9″	1′- 6 7⁄8″	11′- 9″	..	47	7	54
12′- 0″	1′- 7 9⁄32″	12′- 0″	..	46	9	55
12′- 3″	1′- 7 11⁄16″	12′- 3″	..	45	11	56
12′- 6″	1′- 8 3⁄32″	12′- 6″	..	44	13	57
12′- 9″	1′- 8 1⁄2″	12′- 9″	..	43	15	58
13′- 0″	1′- 8 29⁄32″	13′- 0″	..	42	17	59
13′- 3″	1′- 9 5⁄16″	13′- 3″	..	41	19	60
13′- 6″	1′- 9 11⁄16″	13′- 6″	..	40	21	61
13′- 9″	1′-10 3⁄32″	13′- 9″	..	39	23	62
14′- 0″	1′-10 1⁄2″	14′- 0″	..	38	25	63
14′- 3″	1′-10 29⁄32″	14′- 3″	..	37	27	64
14′- 6″	1′-11 5⁄16″	14′- 6″	..	36	29	65
14′- 9″	1′-11 23⁄32″	14′- 9″	..	35	31	66
15′- 0″	2′- 0 1⁄8″	15′- 0″	..	34	33	67
15′- 3″	2′- 0 17⁄32″	15′- 3″	..	32	36	68
15′- 6″	2′- 0 29⁄32″	15′- 6″	..	32	38	70
15′- 9″	2′- 1 5⁄16″	15′- 9″	..	31	40	71
16′- 0″	2′- 1 23⁄32″	16′- 0″	..	30	42	72
16′- 3″	2′- 2 1⁄8″	16′- 3″	..	29	44	73
16′- 6″	2′- 2 17⁄32″	16′- 6″	..	28	46	74
16′- 9″	2′- 2 15⁄16″	16′- 9″	..	27	48	75
17′- 0″	2′- 3 11⁄32″	17′- 0″	..	25	51	76
17′- 3″	2′- 3 23⁄32″	17′- 3″	..	24	53	77
17′- 6″	2′- 4 1⁄8″	17′- 6″	..	23	55	78
17′- 9″	2′- 4 17⁄32″	17′- 9″	..	22	57	79

Span	Rise	Inside Radius	Number Required Per Course: No. 1 Wedge	No. 1-X* Wedge	Straight	Total
18′- 0″	2′- 4 15⁄16″	18′- 0″	21	59	..	80
18′- 3″	2′- 5 11⁄32″	18′- 3″	20	61	..	81
18′- 6″	2′- 5 3⁄4″	18′- 6″	19	63	..	82
18′- 9″	2′- 6 5⁄32″	18′- 9″	18	65	..	83
19′- 0″	2′- 6 17⁄32″	19′- 0″	17	67	..	84
19′- 3″	2′- 6 15⁄16″	19′- 3″	16	69	..	85
19′- 6″	2′- 7 11⁄32″	19′- 6″	15	71	..	86
19′- 9″	2′- 7 3⁄4″	19′- 9″	14	73	..	87
20′- 0″	2′- 8 5⁄32″	20′- 0″	13	75	..	88
20′- 3″	2′- 8 9⁄16″	20′- 3″	12	77	..	89
20′- 6″	2′- 8 31⁄32″	20′- 6″	10	80	..	90
20′- 9″	2′- 9 11⁄32″	20′- 9″	10	82	..	92
21′- 0″	2′- 9 3⁄4″	21′- 0″	9	84	..	93
21′- 3″	2′-10 5⁄32″	21′- 3″	8	86	..	94
21′- 6″	2′-10 9⁄16″	21′- 6″	7	88	..	95
21′- 9″	2′-10 31⁄32″	21′- 9″	6	90	..	96
22′- 0″	2′-11 3⁄8″	22′- 0″	5	92	..	97
22′- 3″	2′-11 25⁄32″	22′- 3″	3	95	..	98
22′- 6″	3′- 0 3⁄16″	22′- 6″	2	97	..	99
22′- 9″	3′- 0 9⁄16″	22′- 9″	1	99	..	100
23′- 0″	3′- 0 31⁄32″	23′- 0″	..	101	..	101
23′- 3″	3′- 1 3⁄8″	23′- 3″	..	101	1	102
23′- 6″	3′- 1 25⁄32″	23′- 6″	..	101	2	103
23′- 9″	3′- 2 3⁄16″	23′- 9″	..	101	3	104
24′- 0″	3′- 2 19⁄32″	24′- 0″	..	101	4	105
24′- 3″	3′- 3″	24′- 3″	..	101	5	106
24′- 6″	3′- 3 3⁄8″	24′- 6″	..	101	6	107
24′- 9″	3′- 3 25⁄32″	24′- 9″	..	101	7	108
25′- 0″	3′- 4 3⁄16″	25′- 0″	..	101	8	109
25′- 3″	3′- 4 19⁄32″	25′- 3″	..	101	9	110
25′- 6″	3′- 5″	25′- 6″	..	101	10	111
25′- 9″	3′- 5 13⁄32″	25′- 9″	..	101	11	112
26′- 0″	3′- 5 13⁄16″	26′- 0″	..	101	12	113
26′- 3″	3′- 6 3⁄16″	26′- 3″	..	101	14	115
26′- 6″	3′- 6 19⁄32″	26′- 6″	..	101	15	116
26′- 9″	3′- 7″	26′- 9″	..	101	16	117
27′- 0″	3′- 7 13⁄32″	27′- 0″	..	101	17	118
27′- 3″	3′- 7 13⁄16″	27′- 3″	..	101	18	119
27′- 6″	3′- 8 7⁄32″	27′- 6″	..	101	19	120
27′- 9″	3′- 8 5⁄8″	27′- 9″	..	101	20	121
28′- 0″	3′- 9″	28′- 0″	..	101	21	122
28′- 3″	3′- 9 13⁄32″	28′- 3″	..	101	22	123
28′- 6″	3′- 9 13⁄16″	28′- 6″	..	101	23	124
28′- 9″	3′-10 7⁄32″	28′- 9″	..	101	24	125
29′- 0″	3′-10 5⁄8″	29′- 0″	..	101	25	126
29′- 3″	3′-11 1⁄32″	29′- 3″	..	101	26	127
29′- 6″	3′-11 7⁄16″	29′- 6″	..	101	27	128
29′- 9″	3′-11 13⁄16″	29′- 9″	..	101	28	129
30′- 0″	4′- 0 7⁄32″	30′- 0″	..	101	29	130

*NOTE: The No. 1-X Wedge is standard in Silica Material only. For Fireclay Material in the case of arches with spans over 11′-0″, use combinations of No. 1 Wedge and Straight brick. The quantity of No. 1 Wedge brick remains constant at 51. The quantity of Straight brick is determined by subtracting 51 from the quantity given in the column "Total".

†More exactly 1.608″

For skewback illustration see page 58.

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asbestosclaims.law/library/25269/223

13½″ ARCH THICKNESS—WEDGE BRICK

13½″ x 4½″ x 3″, 13½″ x 6″ x 3″ or 13½″ x 9″ x 3″

1 19/32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X* Wedge	Total
6′- 0″	9 21/32″	6′- 0″	27	3	..	30
6′- 3″	10 1/16″	6′- 3″	26	5	..	31
6′- 6″	10 7/16″	6′- 6″	25	7	..	32
6′- 9″	10 27/32″	6′- 9″	24	9	..	33
7′- 0″	11 1/4″	7′- 0″	22	12	..	34
7′- 3″	11 21/32″	7′- 3″	21	14	..	35
7′- 6″	1′- 0 1/16″	7′- 6″	21	16	..	37
7′- 9″	1′- 0 15/32″	7′- 9″	20	18	..	38
8′- 0″	1′- 0 7/8″	8′- 0″	19	20	.	39
8′- 3″	1′- 1 1/4″	8′- 3″	18	22	.	40
8′- 6″	1′- 1 21/32″	8′- 6″	17	24	.	41
8′- 9″	1′- 2 1/16″	8′- 9″	16	26	..	42
9′- 0″	1′- 2 15/32″	9′- 0″	14	29	..	43
9′- 3″	1′- 2 7/8″	9′- 3″	13	31	..	44
9′- 6″	1′- 3 9/32″	9′- 6″	12	33	..	45
9′- 9″	1′- 3 11/16″	9′- 9″	11	35	..	46
10′- 0″	1′- 4 1/16″	10′- 0″	10	37	..	47
10′- 3″	1′- 4 15/32″	10′- 3″	9	39	..	48
10′- 6″	1′- 4 7/8″	10′- 6″	8	41	..	49
10′- 9″	1′- 5 9/32″	10′- 9″	7	43	..	50
11′- 0″	1′- 5 11/16″	11′- 0″	6	45	..	51
11′- 3″	1′- 6 3/32″	11′- 3″	5	47	..	52
11′- 6″	1′- 6 1/2″	11′- 6″	4	49	..	53
11′- 9″	1′- 6 7/8″	11′- 9″	3	51	..	54
12′- 0″	1′- 7 9/32″	12′- 0″	2	53	..	55
12′- 3″	1′- 7 11/16″	12′- 3″	1	55	..	56
12′-4 1/2″	1′- 7 29/32″	12′- 4 1/2″	..	57	..	57
12′- 6″	1′- 8 3/32″	12′- 6″	..	56	1	57
12′- 9″	1′- 8 1/2″	12′- 9″	..	55	4	59
13′- 0″	1′- 8 29/32″	13′- 0″	..	54	6	60
13′- 3″	1′- 9 5/16″	13′- 3″	..	53	8	61
13′- 6″	1′- 9 11/16″	13′- 6″	..	52	10	62
13′- 9″	1′-10 3/32″	13′- 9″	..	51	12	63
14′- 0″	1′-10 1/2″	14′- 0″	..	50	14	64
14′- 3″	1′-10 29/32″	14′- 3″	..	49	16	65
14′- 6″	1′-11 5/16″	14′- 6″	..	48	18	66
14′- 9″	1′-11 23/32″	14′- 9″	..	47	20	67
15′- 0″	2′- 0 1/8″	15′- 0″	..	46	22	68
15′- 3″	2′- 0 17/32″	15′- 3″	..	45	24	69
15′- 6″	2′- 0 29/32″	15′- 6″	..	44	26	70
15′- 9″	2′- 1 5/16″	15′- 9″	..	43	28	71
16′- 0″	2′- 1 23/32″	16′- 0″	..	41	31	72
16′- 3″	2′- 2 1/8″	16′- 3″	..	40	33	73
16′- 6″	2′- 2 17/32″	16′- 6″	..	39	35	74
16′- 9″	2′- 2 15/16″	16′- 9″	..	38	37	75
17′- 0″	2′- 3 11/32″	17′- 0″	..	37	39	76
17′- 3″	2′- 3 23/32″	17′- 3″	..	36	41	77
17′- 6″	2′- 4 1/8″	17′- 6″	..	35	43	78
17′- 9″	2′- 4 17/32″	17′- 9″	..	34	45	79
18′- 0″	2′- 4 15/16″	18′- 0″	33	48	..	81
18′- 3″	2′- 5 11/32″	18′- 3″	32	50	..	82
18′- 6″	2′- 5 3/4″	18′- 6″	31	52	..	83
18′- 9″	2′- 6 5/32″	18′- 9″	30	54	..	84
19′- 0″	2′- 6 17/32″	19′- 0″	29	56	..	85
19′- 3″	2′- 6 15/16″	19′- 3″	28	58	..	86
19′- 6″	2′- 7 11/32″	19′- 6″	27	60	..	87
19′- 9″	2′- 7 3/4″	19′- 9″	26	62	..	88
20′- 0″	2′- 8 5/32″	20′- 0″	25	64	..	89
20′- 3″	2′- 8 9/16″	20′- 3″	24	66	..	90
20′- 6″	2′- 8 31/32″	20′- 6″	23	68	..	91
20′- 9″	2′- 9 11/32″	20′- 9″	22	70	..	92
21′- 0″	2′- 9 3/4″	21′- 0″	21	72	..	93
21′- 3″	2′-10 5/32″	21′- 3″	19	75	..	94
21′- 6″	2′-10 9/16″	21′- 6″	18	77	..	95
21′- 9″	2′-10 31/32″	21′- 9″	17	79	..	96
22′- 0″	2′-11 3/8″	22′- 0″	16	81	..	97
22′- 3″	2′-11 25/32″	22′- 3″	15	83	..	98
22′- 6″	3′- 0 3/16″	22′- 6″	14	85	..	99
22′- 9″	3′- 0 9/16″	22′- 9″	13	87	..	100
23′- 0″	3′- 0 31/32″	23′- 0″	12	89	..	101
23′- 3″	3′- 1 3/8″	23′- 3″	12	91	..	103
23′- 6″	3′- 1 25/32″	23′- 6″	10	94	..	104
23′- 9″	3′- 2 3/16″	23′- 9″	9	96	..	105
24′- 0″	3′- 2 19/32″	24′- 0″	8	98	..	106
24′- 3″	3′- 3″	24′- 3″	7	100	..	107
24′- 6″	3′- 3 3/8″	24′- 6″	6	102	..	108
24′- 9″	3′- 3 25/32″	24′- 9″	5	104	..	109
25′- 0″	3′- 4 3/16″	25′- 0″	4	106	..	110
25′- 6″	3′- 5″	25′- 6″	2	110	..	112
26′- 0″	3′- 5 13/16″	26′- 0″	..	113	1	114
26′- 6″	3′- 6 19/32″	26′- 6″	..	113	3	116
27′- 0″	3′- 7 13/32″	27′- 0″	..	113	5	118
27′- 6″	3′- 8 7/32″	27′- 6″	..	113	7	120
28′- 0″	3′- 9″	28′- 0″	..	113	9	122
28′- 6″	3′- 9 13/16″	28′- 6″	..	113	11	124
29′- 0″	3′-10 5/8″	29′- 0″	..	113	14	127
29′- 6″	3′-11 7/16″	29′- 6″	..	113	16	129
30′- 0″	4′- 0 7/32″	30′- 0″	..	113	18	131
30′- 6″	4′- 1 1/32″	30′- 6″	..	113	20	133
31′- 0″	4′- 1 27/32″	31′- 0″	..	113	22	135
32′- 0″	4′- 3 7/16″	32′- 0″	..	113	26	139
33′- 0″	4′- 5 1/16″	33′- 0″	..	113	30	143
34′- 0″	4′- 6 21/32″	34′- 0″	..	113	35	148
35′- 0″	4′- 8 9/32″	35′- 0″	..	113	39	152

*NOTE: The No. 1-X Wedge is standard in Silica Material only. For Fireclay Material in the case of arches with spans over 12′-4½″, use combinations of No. 1 Wedge and Straight brick. The quantity of No. 1 Wedge brick remains constant at 57. The quantity of Straight brick is determined by subtracting 57 from the quantity given in the column "Total".

†More exactly 1.608″

For skewback illustration see page 58.

15″ ARCH THICKNESS—WEDGE BRICK

15″ x 6″ x 3″ or 15″ x 9″ x 3″

1 19/32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1 X Wedge	Total
6′- 3″	10 1/16″	6′- 3″	32	..	..	32
6′- 6″	10 7/16″	6′- 6″	31	2	..	33
6′- 9″	10 27/32″	6′- 9″	30	4	..	34
7′- 0″	11 1/4″	7′- 0″	28	7	..	35
7′- 3″	11 21/32″	7′- 3″	27	9	..	36
7′- 6″	1′- 0 1/16″	7′- 6″	26	11	..	37
7′- 9″	1′- 0 15/32″	7′- 9″	25	13	..	38
8′- 0″	1′- 0 7/8″	8′- 0″	24	15	..	39
8′- 3″	1′- 1 1/4″	8′- 3″	23	17	..	40
8′- 6″	1′- 1 21/32″	8′- 6″	22	19	..	41
8′- 9″	1′- 2 1/16″	8′- 9″	21	21	..	42
9′- 0″	1′- 2 15/32″	9′- 0″	20	23	..	43
9′- 3″	1′- 2 7/8″	9′- 3″	19	25	..	44
9′- 6″	1′- 3 9/32″	9′- 6″	18	27	..	45
9′- 9″	1′- 3 11/16″	9′- 9″	17	29	..	46
10′- 0″	1′- 4 1/16″	10′- 0″	16	32	..	48
10′- 3″	1′- 4 15/32″	10′- 3″	15	34	..	49
10′- 6″	1′- 4 7/8″	10′- 6″	14	36	..	50
10′- 9″	1′- 5 9/32″	10′- 9″	13	38	..	51
11′- 0″	1′- 5 11/16″	11′- 0″	12	40	..	52
11′- 3″	1′- 6 3/32″	11′- 3″	11	42	..	53
11′- 6″	1′- 6 1/2″	11′- 6″	10	44	..	54
11′- 9″	1′- 6 7/8″	11′- 9″	9	46	..	55
12′- 0″	1′- 7 9/32″	12′- 0″	8	48	..	56
12′- 3″	1′- 7 11/16″	12′- 3″	7	50	..	57
12′- 6″	1′- 8 3/32″	12′- 6″	5	53	..	58
12′- 9″	1′- 8 1/2″	12′- 9″	4	55	..	59
13′- 0″	1′- 8 29/32″	13′- 0″	3	57	..	60
13′- 3″	1′- 9 5/16″	13′- 3″	2	59	..	61
13′- 6″	1′- 9 11/16″	13′- 6″	1	61	..	62
13′- 9″	1′-10 3/32″	13′- 9″	..	63	..	63
14′- 0″	1′-10 1/2″	14′- 0″	..	62	2	64
14′- 3″	1′-10 29/32″	14′- 3″	..	61	4	65
14′- 6″	1′-11 5/16″	14′- 6″	..	60	6	66
14′- 9″	1′-11 23/32″	14′- 9″	..	59	8	67
15′- 0″	2′- 0 1/8″	15′- 0″	..	58	10	68
15′- 3″	2′- 0 17/32″	15′- 3″	..	57	13	70
15′- 6″	2′- 0 29/32″	15′- 6″	..	56	15	71
15′- 9″	2′- 1 5/16″	15′- 9″	..	55	17	72
16′- 0″	2′- 1 23/32″	16′- 0″	..	54	19	73
16′- 3″	2′- 2 1/8″	16′- 3″	..	53	21	74
16′- 6″	2′- 2 17/32″	16′- 6″	..	52	23	75
16′- 9″	2′- 2 15/16″	16′- 9″	..	51	25	76
17′- 0″	2′- 3 11/32″	17′- 0″	..	49	28	77
17′- 3″	2′- 3 23/32″	17′- 3″	..	48	30	78
17′- 6″	2′- 4 1/8″	17′- 6″	..	47	32	79
17′- 9″	2′- 4 17/32″	17′- 9″	..	46	34	80
18′- 0″	2′- 4 15/16″	18′- 0″	45	36	..	81
18′- 3″	2′- 5 11/32″	18′- 3″	44	38	..	82
18′- 6″	2′- 5 3/4″	18′- 6″	43	40	..	83
18′- 9″	2′- 6 5/32″	18′- 9″	42	42	..	84
19′- 0″	2′- 6 17/32″	19′- 0″	41	44	..	85
19′- 3″	2′- 6 15/16″	19′- 3″	40	46	..	86
19′- 6″	2′- 7 11/32″	19′- 6″	39	48	..	87
19′- 9″	2′- 7 3/4″	19′- 9″	38	50	..	88
20′- 0″	2′- 8 5/32″	20′- 0″	37	52	..	89
20′- 3″	2′- 8 9/16″	20′- 3″	36	54	..	90
20′- 6″	2′- 8 31/32″	20′- 6″	35	57	..	92
20′- 9″	2′- 9 11/32″	20′- 9″	34	59	..	93
21′- 0″	2′- 9 3/4″	21′- 0″	33	61	..	94
21′- 3″	2′-10 5/32″	21′- 3″	32	63	..	95
21′- 6″	2′-10 9/16″	21′- 6″	31	65	..	96
21′- 9″	2′-10 31/32″	21′- 9″	30	67	..	97
22′- 0″	2′-11 3/8″	22′- 0″	29	69	..	98
22′- 3″	2′-11 25/32″	22′- 3″	28	71	..	99
22′- 6″	3′- 0 3/16″	22′- 6″	26	74	..	100
22′- 9″	3′- 0 9/16″	22′- 9″	25	76	..	101
23′- 0″	3′- 0 31/32″	23′- 0″	24	78	..	102
23′- 3″	3′- 1 3/8″	23′- 3″	23	80	..	103
23′- 6″	3′- 1 25/32″	23′- 6″	22	82	..	104
23′- 9″	3′- 2 3/16″	23′- 9″	21	84	..	105
24′- 0″	3′- 2 19/32″	24′- 0″	20	86	..	106
24′- 3″	3′- 3″	24′- 3″	19	88	..	107
24′- 6″	3′- 3 3/8″	24′- 6″	18	90	..	108
24′- 9″	3′- 3 25/32″	24′- 9″	17	92	..	109
25′- 0″	3′- 4 3/16″	25′- 0″	16	94	..	110
25′- 3″	3′- 4 19/32″	25′- 3″	15	96	..	111
25′- 6″	3′- 5″	25′- 6″	14	98	..	112
25′- 9″	3′- 5 13/32″	25′- 9″	13	100	..	113
26′- 0″	3′- 5 13/16″	26′- 0″	12	103	..	115
26′- 3″	3′- 6 3/16″	26′- 3″	11	105	..	116
26′- 6″	3′- 6 19/32″	26′- 6″	10	107	..	117
26′- 9″	3′- 7″	26′- 9″	9	109	..	118
27′- 0″	3′- 7 13/32″	27′- 0″	8	111	..	119
27′- 3″	3′- 7 13/16″	27′- 3″	7	113	..	120
27′- 6″	3′- 8 7/32″	27′- 6″	6	115	..	121
27′- 9″	3′- 8 5/8″	27′- 9″	4	118	..	122
28′- 0″	3′- 9″	28′- 0″	3	120	..	123
28′- 3″	3′- 9 13/32″	28′- 3″	2	122	..	124
28′- 6″	3′- 9 13/16″	28′- 6″	1	124	..	125
28′- 9″	3′-10 7/32″	28′- 9″	..	126	..	126
29′- 0″	3′-10 5/8″	29′- 0″	..	126	1	127
29′- 6″	3′-11 7/16″	29′- 6″	..	126	3	129
30′- 0″	4′- 0 7/32″	30′- 0″	..	126	5	131
31′- 0″	4′- 1 27/32″	31′- 0″	..	126	9	135
32′- 0″	4′- 3 7/16″	32′- 0″	..	126	14	140

†More exactly 1.608″

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18″ ARCH THICKNESS—WEDGE BRICK

18″ x 6″ x 3″ or 18″ x 9″ x 3″

1 19/32″† RISE PER FOOT OF SPAN (60° CENTRAL ANGLE)

Span	Rise	Inside Radius	Number Required Per Course: No. 2 Wedge	No. 1 Wedge	No. 1-X Wedge	Total
8′-0″	1′- 0 7/8″	8′-0″	36	4	..	40
8′-3″	1′- 1 1/4″	8′-3″	35	6	..	41
8′-6″	1′- 1 21/32″	8′-6″	34	8	..	42
8′-9″	1′- 2 1/16″	8′-9″	32	11	..	43
9′-0″	1′- 2 15/32″	9′-0″	31	13	..	44
9′-3″	1′- 2 7/8″	9′-3″	30	15	..	45
9′-6″	1′- 3 9/32″	9′-6″	29	17	..	46
9′-9″	1′- 3 11/16″	9′-9″	29	19	..	48
10′-0″	1′- 4 1/16″	10′-0″	28	21	..	49
10′-3″	1′- 4 15/32″	10′-3″	27	23	..	50
10′-6″	1′- 4 7/8″	10′-6″	25	26	..	51
10′-9″	1′- 5 9/32″	10′-9″	24	28	..	52
11′-0″	1′- 5 11/16″	11′-0″	23	30	..	53
11′-3″	1′- 6 3/32″	11′-3″	22	32	..	54
11′-6″	1′- 6 1/2″	11′-6″	21	34	..	55
11′-9″	1′- 6 7/8″	11′-9″	20	36	..	56
12′-0″	1′- 7 9/32″	12′-0″	19	38	..	57
12′-3″	1′- 7 11/16″	12′-3″	18	40	..	58
12′-6″	1′- 8 3/32″	12′-6″	17	42	..	59
12′-9″	1′- 8 1/2″	12′-9″	16	44	..	60
13′-0″	1′- 8 29/32″	13′-0″	15	46	..	61
13′-3″	1′- 9 5/16″	13′-3″	14	48	..	62
13′-6″	1′- 9 11/16″	13′-6″	13	50	..	63
13′-9″	1′-10 3/32″	13′-9″	12	52	..	64
14′-0″	1′-10 1/2″	14′-0″	11	54	..	65
14′-3″	1′-10 29/32″	14′-3″	9	57	..	66
14′-6″	1′-11 5/16″	14′-6″	8	59	..	67
14′-9″	1′-11 23/32″	14′-9″	7	61	..	68
15′-0″	2′- 0 1/8″	15′-0″	7	63	..	70
15′-3″	2′- 0 17/32″	15′-3″	6	65	..	71
15′-6″	2′- 0 29/32″	15′-6″	5	67	..	72
15′-9″	2′- 1 5/16″	15′-9″	4	69	..	73
16′-0″	2′- 1 23/32″	16′-0″	2	72	..	74
16′-3″	2′- 2 1/8″	16′-3″	1	74	..	75
16′-6″	2′- 2 17/32″	16′-6″	..	76	..	76
16′-9″	2′- 2 15/16″	16′-9″	..	75	2	77
17′-0″	2′- 3 11/32″	17′-0″	..	74	4	78
17′-3″	2′- 3 23/32″	17′-3″	..	72	7	79
17′-6″	2′- 4 1/8″	17′-6″	..	71	9	80
17′-9″	2′- 4 17/32″	17′-9″	..	70	11	81
18′-0″	2′- 4 15/16″	18′-0″	..	69	13	82
18′-3″	2′- 5 11/32″	18′-3″	..	68	15	83
18′-6″	2′- 5 3/4″	18′-6″	..	67	17	84
18′-9″	2′- 6 5/32″	18′-9″	..	66	19	85
19′-0″	2′- 6 17/32″	19′-0″	..	65	21	86
19′-3″	2′- 6 15/16″	19′-3″	..	64	23	87
19′-6″	2′- 7 11/32″	19′-6″	..	63	25	88
19′-9″	2′- 7 3/4″	19′-9″	..	62	27	89
20′-0″	2′- 8 5/32″	20′-0″	..	61	29	90
20′-3″	2′- 8 9/16″	20′-3″	..	60	32	92
20′-6″	2′- 8 31/32″	20′-6″	..	59	34	93
20′-9″	2′- 9 11/32″	20′-9″	..	58	36	94
21′-0″	2′- 9 3/4″	21′-0″	..	57	38	95
21′-3″	2′-10 5/32″	21′-3″	..	56	40	96
21′-6″	2′-10 9/16″	21′-6″	..	55	42	97
21′-9″	2′-10 31/32″	21′-9″	..	54	44	98
22′-0″	2′-11 3/8″	22′-0″	..	53	46	99
22′-3″	2′-11 25/32″	22′-3″	..	52	48	100
22′-6″	3′- 0 3/16″	22′-6″	..	50	51	101
22′-9″	3′- 0 9/16″	22′-9″	..	49	53	102
23′-0″	3′- 0 31/32″	23′-0″	..	48	55	103
23′-3″	3′- 1 3/8″	23′-3″	..	47	57	104
23′-6″	3′- 1 25/32″	23′-6″	..	46	59	105
23′-9″	3′- 2 3/16″	23′-9″	..	45	61	106
24′-0″	3′- 2 19/32″	24′-0″	..	44	63	107
24′-3″	3′- 3″	24′-3″	..	43	65	108
24′-6″	3′- 3 3/8″	24′-6″	..	42	67	109
24′-9″	3′- 3 25/32″	24′-9″	..	41	69	110
25′-0″	3′- 4 3/16″	25′-0″	..	40	71	111
25′-3″	3′- 4 19/32″	25′-3″	..	39	73	112
25′-6″	3′- 5″	25′-6″	..	38	75	113
25′-9″	3′- 5 13/32″	25′-9″	..	37	78	115
26′-0″	3′- 5 13/16″	26′-0″	..	36	80	116
26′-3″	3′- 6 7/16″	26′-3″	..	35	82	117
26′-6″	3′- 6 29/32″	26′-6″	..	34	84	118
26′-9″	3′- 7″	26′-9″	..	33	86	119
27′-0″	3′- 7 13/32″	27′-0″	..	32	88	120
27′-3″	3′- 7 13/16″	27′-3″	..	31	90	121
27′-6″	3′- 8 7/32″	27′-6″	..	30	92	122
27′-9″	3′- 8 5/8″	27′-9″	..	29	94	123
28′-0″	3′- 9″	28′-0″	..	27	97	124
28′-3″	3′- 9 13/32″	28′-3″	..	26	99	125
28′-6″	3′- 9 13/16″	28′-6″	..	25	101	126
28′-9″	3′-10 7/32″	28′-9″	..	24	103	127
29′-0″	3′-10 5/8″	29′-0″	..	23	105	128
29′-3″	3′-11 1/32″	29′-3″	..	22	107	129
29′-6″	3′-11 7/16″	29′-6″	..	21	109	130
29′-9″	3′-11 13/16″	29′-9″	..	20	111	131
30′-0″	4′- 0 7/32″	30′-0″	..	19	113	132
30′-3″	4′- 0 5/8″	30′-3″	..	18	115	133
30′-6″	4′- 1 1/32″	30′-6″	..	17	117	134
30′-9″	4′- 1 7/16″	30′-9″	..	16	119	135
31′-0″	4′- 1 27/32″	31′-0″	..	15	122	137
31′-3″	4′- 2 1/4″	31′-3″	..	14	124	138
31′-6″	4′- 2 21/32″	31′-6″	..	13	126	139
31′-9″	4′- 3 1/32″	31′-9″	..	12	128	140
32′-0″	4′- 3 7/16″	32′-0″	..	11	130	141

†More exactly 1.608″

GLOSSARY AND INDEX



HARBISON-WALKER REFRACTORIES COMPANY, PITTSBURGH, PENNA.

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asbestosclaims.law/library/25269/225

GLOSSARY

Abrasion of Refractories: Wearing away of the surfaces of refractory bodies in service by the scouring action of moving solids.

Absorption: As applied to ceramic products, the ratio between the weight of water which can be absorbed by the ware, and the weight of the dry ware. It is expressed as a percentage.

Abutment: In furnace construction, the structural member which withstands the thrust of an arch. In general, an abutment consists of a brick skewback, and a steel supporting member.

Acid-Proof Brick: Brick having low porosity and permeability, and a high resistance to chemical attack or penetration by most commercial acids.

Acid Refractories: Refractories such as silica brick, which contain an appreciable amount of uncombined silica.

Air Ramming: A method of forming refractory shapes, furnace hearths or other furnace parts by means of pneumatic hammers.

Air-Setting Refractory Mortar: A finely ground refractory mortar material which develops a strong bond upon drying.

Alumina: Al_2O_3, the oxide of aluminum; in combination with H_2O, alumina forms the minerals diaspore, bauxite and gibbsite; in combination with SiO_2 and H_2O, alumina forms kaolinite and other clay minerals.

Alumina-Diaspore Fireclay Brick: Brick made essentially of diaspore or nodule clay, and having an alumina content of 50, 60 or 70% plus or minus 2½%.

Alumina-Silica Refractories: Refractories consisting essentially of alumina and silica, and including high-alumina, fireclay, kaolin and mullite refractories.

Amorphous: Lacking crystalline structure or definite molecular arrangement; without definite external form.

Andalusite: A mineral having the theoretical composition $Al_2O_3 \cdot SiO_2$, corresponding to Al_2O_3 62.9%, SiO_2 37.1%. Specific gravity 3.1 – 3.2. Decomposes on heating, beginning at about 2460° F. (1350° C.) to form mullite ($3Al_2O_3 \cdot 2SiO_2$) and free silica.

Anorthite: A feldspar mineral having the theoretical composition $CaO \cdot Al_2O_3 \cdot 2SiO_2$, corresponding to CaO 20.1%, Al_2O_3 36.7%, SiO_2 43.2%. Specific gravity 2.75. Melting point 2824° F. (1551° C.).

Arc: As applied to circles, any portion of a circumference.

Arch: In furnace construction, a structural member supported at its ends only, and formed of a number of tapered brick shapes or of such shapes and straights, all of which are held in place by the keying effect of the tapered brick.

Arch, Flat: An arch in which both outer and inner surfaces are horizontal. (See page 280.)

Arch, Sprung: An arch which is supported by abutments at the sides or ends only. A cross section of a sprung arch, taken at right angles to its axis, usually consists of a segment of a circular ring, in which the inner and outer arch surfaces are represented by arcs of concentric circles. (See page 272.)

Arch, Suspended: A furnace roof consisting of brick shapes suspended from overhead supporting members.

Arch Brick: A brick shape having six plane faces (two sides, two edges, and two ends), in which two faces (the sides) are inclined toward each other and one edge face is narrower than the other, as illustrated on page 31.

Asbestos: Commercially, any mineral which can be separated into flexible fibers. Several of the amphibole minerals and one serpentine mineral are regarded as asbestos. The most common form of commercial asbestos is chrysotile, a serpentine; theoretical composition, $3MgO \cdot 2SiO_2 \cdot 2H_2O$, corresponding to MgO 43.5%, SiO_2 43.5%, combined water 13.0%.

Auger Machine: A machine for extruding ground clays in moist and stiffly plastic form, through a die by means of a revolving screw or auger.

Baddeleyite: A mineral composed of zirconia (ZrO_2). Specific gravity 5.8. Melting point 4890° F. (2700° C.).

Bagasse: The fibrous material remaining after the extraction of the juice from sugar cane.

Ball Clay: A highly plastic refractory bond clay of very fine grain, which burns to a light color; often high in carbonaceous matter.

Basic Refractories: Refractories whose major constituent is lime, magnesia, chrome spinel or forsterite.

Batter: A slope of the face of a wall, usually causing a decrease in thickness as the wall ascends; the angle at which a face of a wall slopes from the vertical.

Bauxite: A high-alumina rock, usually consisting of rounded concretionary grains embedded in a clay-like mass, and believed to consist essentially of alumina trihydrate ($Al_2O_3 \cdot 3H_2O$) and alumina hydrate ($Al_2O_3 \cdot H_2O$), in varying proportions.

Bentonite: A kind of clay derived from volcanic ash, and characterized by extreme fineness of grain. Its main constituent is the clay mineral montmorillonite. It is somewhat variable in composition and usually contains 5 to 10% of alkalies or alkaline earth oxides. One type has the capacity for absorption of large amounts of water, with enormous increase in volume. Another type has about the same capacity to absorb water as an ordinary plastic clay.

Body: (1) A ceramic shape; (2) The blend of raw materials used for the production of a ceramic shape; (3) More specifically, the most important mineral constituent of a ceramic shape.

Breunerite: A variety of magnesite containing several per cent of siderite ($FeCO_3$) in solid solution.

Brucite: A mineral having the composition $MgO \cdot H_2O$ corresponding to MgO 69.0%, H_2O 31.0%. Specific gravity 2.38 – 2.40. A soft, waxy, translucent mineral; dissociates at moderate temperatures with the formation of MgO.

British Thermal Unit: (B.t.u.) The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit at standard barometric pressure, and at a standard temperature.

Bunker Oil: A heavy fuel oil formed by stabilization of the residual oil remaining after the cracking of crude petroleum.

Burn: The degree of heat treatment to which refractory brick are subjected in the firing process.

Burning (Firing) of Refractories: The final heat treatment in a kiln to which refractory brick are subjected in the process of manufacture, for the purpose of developing strength and other necessary physical and chemical properties.

Calcination: A heat treatment to which many ceramic raw materials are subjected, during which a chemically combined constituent is driven off in the form of a gas.

Calcite: A mineral having the theoretical composition $CaCO_3$, which corresponds to a composition of CaO 56.0%, CO_2 44.0%. Specific gravity 2.71 for pure calcite crystals. Calcite is the essential constituent of limestone, chalk, and marble, and a minor constituent of many other rocks.

Calliau Blocks: 9 x 4½ x 9-inch cupola blocks. (See illustration on page 37.)

Calorie (small): The amount of heat required to raise the temperature of one gram of water one degree Centigrade at standard barometric pressure and at a standard temperature.

Calorie (large): One thousand small calories.

Castable Refractory: A mixture of a heat-resistant aggregate and a heat-resistant hydraulic cement; for use, it is mixed with water and rammed or poured into place.

Cement: Finely divided mineral substances which harden as a result of chemical reaction or crystallization.

Ceramic Bond: In a ceramic body, the mechanical strength developed by a heat treatment which causes the cohesion of adjacent particles.

Ceramics: Originally, the term ceramics referred only to ware formed from clay and hardened by the action of heat, and to the art of making such ware. However, its significance has gradually been extended by usage, and it is now understood to include all refractory materials, cement, lime, plaster, pottery, glass, enamels, glazes, abrasives, electrical insulating products, and thermal insulating products made from clay or from other inorganic non-metallic mineral substances.

Cermet: A product consisting of a mixture of ceramic material and finely divided metal; also referred to as ceramals.

Chemically Bonded Brick: Brick manufactured by processes in which mechanical strength is imparted by chemical bonding agents instead of by firing.

Chord: As applied to circles, a straight line joining any two points on a circumference.

Chrome Brick: A refractory brick manufactured substantially or entirely of chrome ore.

Chrome-Magnesite Brick: A refractory brick which may be either fired or chemically bonded, manufactured substantially of a mixture of chrome ore and dead-burned magnesite, in which the chrome ore predominates by weight.

Chrome Ore: A rock having as its essential constituent the mineral known as chromite or chrome spinel, which is a combination of FeO and MgO with Cr_2O_3, Al_2O_3 and usually a small proportion of Fe_2O_3. The composition, which is represented by the formula $(Fe, Mg)O \cdot (Cr, Al, Fe)_2O_3$, is extremely variable.

Cold Set: The hardening or "setting" of a mortar material which takes place at room temperature. Bonding mortars containing agents which give them greater strength after drying than is obtainable with a clay or other refractory base alone are said to be air-setting or cold-setting.

Colloid: "A condition of the dispersion of a substance in a medium, the peculiar characters of the substance depending upon the size of the particles." — Friend.

Colloidal particles are so small that they are invisible under the microscope. Their diameters are believed to lie roughly between one tenth and one thousandth of a micron. Particles of smaller diameter are of molecular dimensions. Glue, starch, and gelatin are typical colloids, and many clays are colloidal at least in part.

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Congruent Melting: The change of a substance, when heated, from the solid form to a liquid of the same composition. The melting of ice is an example of congruent melting.

Corbel: An arrangement of brick in a wall in which each course projects beyond the one immediately below it to form a support.

Cordierite: A double silicate of magnesium and aluminum, having the theoretical composition $2MgO{\cdot}2Al_2O_3{\cdot}5SiO_2$. The natural mineral contains ferrous oxide replacing part of the magnesium oxide. Specific gravity 2.60 – 2.66.

Corrosion of Refractories: Deterioration or wearing away of refractory bodies at their surfaces through chemical attack.

Corundum: A natural or synthetic mineral theoretically consisting solely of alumina (Al_2O_3). Specific gravity 4.00 – 4.02. Melting point 3720° F. (2050° C.). Hardness 8.8.

Course: A horizontal layer or row of brick in a structure.

Cristobalite: A mineral form of silica; stable from 2678° F. (1470° C.) to the melting point, 3135° F. (1724° C.). Specific gravity 2.32. Cristobalite is an important constituent of silica brick.

Crown: A furnace roof, especially one which is dome-shaped; the highest point of an arch.

Cryptocrystalline: A crystalline structure in which the individual crystals are so small that they cannot be made visible by means of the petrographic microscope. Various so-called amorphous minerals are actually cryptocrystalline.

Crystal: A chemically homogeneous solid body having a definite internal molecular structure and, if developed under favorable conditions, having a characteristic external form, bounded by plane surfaces.

Crystalline: Composed of crystals.

Dead-Burned Magnesite: A sintered product consisting mainly of magnesia in the form of dense weather-stable refractory granules.

De-Airing: Removal of air from fire brick mixes in an auger machine before extrusion, by means of a partial vacuum.

Density: The mass of a unit volume of a substance. It is usually expressed either in grams per cubic centimeter, or in pounds per cubic foot.

Devitrification: The change from a glassy to a crystalline condition.

Diaspore: A mineral having the theoretical composition $Al_2O_3{\cdot}H_2O$, corresponding to 85% alumina and 15% water of combination. Decomposes when heated and forms corundum. Specific gravity 3.45.

Diaspore Brick: Refractory brick made essentially from diaspore clay.

Diaspore Clay: A rock consisting essentially of diaspore bonded by fire clay. Commercial diaspore clay of the purest grade usually contains between 70 and 80% alumina after calcination.

Diatomaceous Earth: A hydrous form of silica which is soft, light in weight, and consists mainly of microscopic shells of diatoms or other marine organisms. It is widely used for furnace insulation.

Dickite: A clay mineral having the theoretical composition $Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$, the same as that of kaolinite.

Diopside: One of the pyroxene minerals; chemical formula $CaO{\cdot}MgO{\cdot}2SiO_2$, composition CaO 25.9%, MgO 18.5%, SiO_2 55.6%. Specific gravity 3.2 – 3.4. Melting point 2536° F. (1391° C.).

Dobie: A molded block of ground clay or other refractory material usually crudely formed and either raw or fired.

Dolomite: The mineral calcium-magnesium carbonate, having the theoretical composition. $CaO{\cdot}MgO{\cdot}2CO_2$ which corresponds to CaO 30.4%, MgO 21.9%, CO_2 47.7%. Specific gravity 2.85 – 2.95. The rock called dolomite consists mainly of the mineral of that name and may also contain a large amount of the mineral calcite ($CaO{\cdot}CO_2$).

Dunite: A basic rock consisting of Mg-Fe olivine, with minor amounts of accessory minerals.

Dusting: Conversion of a refractory material either wholly or in part, into fine powder or dust. Dusting usually results from (1) chemical reactions such as hydration; or (2) from mineral inversion accompanied by large and abrupt change in volume, such as the inversion of beta to gamma dicalcium silicate upon cooling.

Dutch Oven: A combustion chamber built outside and connected with a furnace.

Enstatite: A mineral belonging to the pyroxene group. Formula $MgO{\cdot}SiO_2$; corresponding composition, MgO 40.0%, SiO_2 60.0%. Specific gravity 3.1 – 3.3; melts incongruently at 2838° F. (1559° C.) to form forsterite and a siliceous liquid.

Erosion of Refractories: Mechanical wearing away of the surfaces of refractory bodies in service by the washing action of moving liquids, such as molten slags or metals.

Eutectic Temperature: The lowest melting temperature in a series of mixtures of two or more components.

Extrusion: A process in which plastic material is forced through a die by the application of pressure.

Fayalite: A mineral having the composition $2FeO{\cdot}SiO_2$, corresponding to FeO 70.6%, SiO_2 29.4%. Specific gravity 4.0 – 4.1. Melting point 2201° F. (1205° C.).

Feldspar: A group of aluminum silicate minerals. The most important feldspars are : (a) the potash group, of which orthoclase and microcline ($K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$) are the most common, and (b) the soda-lime group, of which albite ($Na_2O{\cdot}Al_2O_3{\cdot}6SiO_2$) and anorthite ($CaO{\cdot}Al_2O_3{\cdot}2SiO_2$) form the end members of a continuous series of solid solutions. Specific gravity 2.55 – 2.76. Melting points 2050° to 2820° F. (1120° to 1550° C.).

Fillet: The concave curved junction of two surfaces which would otherwise meet at an angle. Fillets are used at reentrant angles in the design of brick shapes, to lessen the danger of cracking.

Fire Brick: Refractory brick of any type.

Fire Clay: An earthy or stony mineral aggregate which has as the essential constituent hydrous silicates of aluminum with or without free silica, plastic when sufficiently pulverized and wetted and rigid when subsequently dried.

Fireclay Brick: A refractory brick manufactured substantially or entirely from fire clay.

Flat Arch: An arch in which both outer and inner surfaces are horizontal planes. (See sketch on page 280.)

Flint: A hard fine-grained cryptocrystalline rock, composed essentially of silica.

Flint Fire Clay: A hard or flint-like fire clay which has very low plasticity and which usually breaks with a smooth or shell-like fracture.

Floe Rock: Rock in or taken from a body of talus on a mountain side; a term used especially in connection with deposits of Tuscarora quartzite in central Pennsylvania.

Flux: A substance or mixture which promotes fusion of a solid material by chemical action.

Forsterite: A mineral with the theoretical composition $2MgO{\cdot}SiO_2$, corresponding to MgO 57.3%, SiO_2 42.7%. Specific gravity 3.21. Melting point 3461° F. (1905° C.).

Furnace Chrome: A mortar material prepared from finely ground chrome ore, suitable for laying brick or for patching or daubing in furnaces.

Furnace Magnesite: A mortar material prepared from finely ground dead-burned magnesite, suitable for use as a joint material in laying magnesite brick, and for patching or daubing furnace masonry.

Fusion: A state of fluidity or flowing, in consequence of heat; the softening of a solid body, either through heat alone or through heat and the action of a flux, to such a degree that it will no longer support its own weight, but will slump or flow. Also the union or blending of materials, such as metals, upon melting, with the formation of alloys.

Fusion Point: The temperature at which fusion takes place. Most refractory materials have no definite fusion points, but soften gradually over a range of temperatures.

Ganister: A dense, high-silica rock (quartzite), suitable for the manufacture of silica brick. Confusion sometimes results from the use of this term, because it is also applied in some parts of the United States to crushed fire brick or to mixtures of either crushed fire brick or silica rock with clay, for use in tamped linings.

Gibbsite: The mineral $Al_2O_3{\cdot}3H_2O$. Theoretical composition: Al_2O_3 65.4%, H_2O 34.6%. Specific gravity 2.3 – 2.4.

Grain Magnesite: Dead-burned magnesite in the form of granules, ranging from about $\frac{5}{8}$ inch in diameter to very fine sizes.

Grain Size: As applied to ground refractory materials, the relative proportions of particles of different sizes; usually determined by separation into a series of fractions by screening.

Grog: Burned refractory material, usually calcined clay or crushed brick, added to a brick or mortar mix to reduce shrinkage in drying and firing.

Grout: A suspension of mortar material in water, of such consistency that when it is poured upon horizontal courses of brick masonry, it will flow into vertical open joints.

Header: A brick laid on flat with its longest dimension perpendicular to the face of a wall.

Hematite: The mineral Fe_2O_3. (red iron ore). Theoretical composition: iron 70%, oxygen 30%. Specific gravity 4.9–5.3.

High-Alumina Refractories: Alumina-silica refractories containing 47.5% or more alumina. The materials used in their production include diaspore, bauxite, gibbsite, kyanite, sillimanite, andalusite, and fused alumina (artificial corundum). See also Alumina-Diaspore Fireclay Brick.

High Duty Fireclay Brick: As defined in the standard A.S.T.M. classification C27-41, fireclay brick which have a P.C.E. not lower than Cone 31-32, *or* which deform not more than 1.5% at 2460° F. (1350° C.) in the standard load test.

Hot-Setting Bonding Mortar: A refractory mortar material which requires relatively high temperatures for the development of a bond.

Incongruent Melting: Dissociation of a compound upon heating, with the formation of another compound and a liquid of different composition from the original compound. For example, mullite ($3Al_2O_3{\cdot}2SiO_2$) melts incongruently to form corundum (Al_2O_3), and a siliceous liquid.

Insulating Fire Brick: A fire brick having a low thermal conductivity and suitable for use in the insulation of industrial furnaces.

Intermediate Duty Fireclay Brick: As defined in the standard A.S.T.M. classification C27-41, fireclay brick which have a P.C.E. not lower than Cone 29, *or* which deform not more than 3% at 2460° F. (1350° C.) in the standard load test.

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Inversion: A change in crystal form without change in chemical composition; as for example, the change from low-quartz to high-quartz, or the change from quartz to cristobalite.

Isomorphous Mixture: A type of solid solution, in which mineral compounds of analogous chemical composition and closely related crystal habit crystallize together in various proportions. Each "mixture" is a homogeneous crystalline phase.

Jamb: (1) A vertical structural member forming the side of an opening in a furnace wall. (2) A type of brick shapes, intended for use in the sides of wall openings, as illustrated on page 31.

Kaolin: A white-burning clay having kaolinite as its chief constituent. Specific gravity 2.4 – 2.6. The P.C.E. of most commercial kaolins ranges from Cone 33 to Cone 35.

Kaolinite: A mineral consisting theoretically of $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, corresponding to 39.5% alumina, 46.5% silica, and 14.0% combined water. Kaolinite is the principal constituent of most kaolins and fire clays. Specific gravity 2.59. The P.C.E. of pure Kaolin is Cone 35.

Key: In furnace construction, the uppermost or the closing brick of a curved arch.

Key Brick: A brick shape having six plane faces (two sides, two edges and two ends), in which two faces (the edges) are inclined toward each other and one of the end faces is narrower than the other, as illustrated on page 31.

K-factor: The thermal conductivity of a material, expressed in standard units.

Kyanite: Also spelled cyanite. A mineral having the theoretical formula $Al_2O_3 \cdot SiO_2$, and the chemical composition: Al_2O_3 62.9%, SiO_2 37.1%. Specific gravity 3.56 – 3.67. Decomposition begins at about 2415° F. (1325° C.) with the formation of mullite and free silica.

Lime: Calcium oxide, formula CaO; commercially produced by calcination of limestone.

Limestone: A sedimentary rock composed essentially of the mineral calcite ($CaCO_3$) or of calcite mixed with dolomite ($CaCO_3 \cdot MgCO_3$). Specific gravity 2.6 – 2.8.

Limonite: Brown iron ore, $Fe_2O_3 \cdot nH_2O$. Approximately Fe_2O_3 85%, H_2O 15%. Specific gravity 3.6 – 4.0.

Loss on Ignition: As applied to chemical analyses, the loss in weight which results from heating a sample of material to a high temperature, after preliminary drying at a temperature just above the boiling point of water. The loss in weight upon drying is called "free moisture"; that which occurs above the boiling point, "loss on ignition".

Low Duty Fireclay Brick: As defined in the standard A.S.T.M. classification C27-41, fireclay brick which have a P.C.E. not lower than Cone 19.

Magnesioferrite: One of the spinel group of minerals; theoretical composition $MgO \cdot Fe_2O_3$, which corresponds to MgO 20.15%, Fe_2O_3 79.85%. Rarely found in nature; usually constitutes the brown coloring material in magnesite brick. Specific gravity 4.57 – 4.65.

Magnesite: A mineral consisting of magnesium carbonate $MgCO_3$, and theoretically containing 47.8% magnesia and 52.2% carbon dioxide; also a rock containing the mineral magnesite as its essential constituent. Specific gravity 2.9–3.1.

Magnesite Brick: A refractory brick manufactured mainly or entirely of dead-burned magnesite.

Magnesite-Chrome Brick: A refractory brick which may be either fired or chemically bonded, manufactured substantially of a mixture of dead-burned magnesite and refractory chrome ore, in which the magnesite predominates by weight.

Magnetite: Fe_3O_4 (Magnetic Iron Ore). Composition: Iron 72.4%, oxygen 27.6%. Specific gravity 5.17 – 5.18. Strongly magnetic.

Melting Point: The temperature at which crystalline and liquid phases having the same composition coexist in equilibrium. Metals and most pure crystalline materials have sharp melting points, i.e., they change abruptly from solid to liquid at definite temperatures. However, most refractory materials have no true melting points, but melt progressively over a relatively wide range of temperatures.

Metalkase Brick: Magnesite or magnesite-chrome brick provided with thin steel casings.

Mica: A group of rock minerals having nearly perfect cleavage in one direction and consisting of thin elastic plates. The most common varieties are muscovite and biotite.

Micron: The one-thousandth part of a millimeter (0.001 mm.); a unit of measurement used in microscopy.

Mineral: "A mineral species is a natural inorganic substance which is either definite in chemical composition and physical characteristics or varies in these respects between definite natural limits." — Winchell.

Modulus of Rupture: A measure of the transverse or "cross-breaking" strength of a solid body.

Monolithic Lining: A furnace lining without joints, formed of material which is rammed, cast, or sintered into place.

Monticellite: A mineral having the theoretical composition $CaO \cdot MgO \cdot 2SiO_2$, corresponding to CaO 34.9%, MgO 25.6%, SiO_2 39.5%. Specific gravity 3.1 to 3.25; melts incongruently at 2730° F. (1499° C.) to form MgO and a liquid.

Mullite: A mineral having the theoretical composition $3Al_2O_3 \cdot 2SiO_2$, corresponding to Al_2O_3 71.8%, SiO_2 28.2%. Specific gravity 3.15. Dissociates at 3317° F. (1825° C.) to form corundum and a siliceous melt. An important constituent of fireclay and high-alumina brick.

Muscovite: One of the mica group of minerals; composition approximately $K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$, corresponding to K_2O 11.8%, Al_2O_3 38.5%, SiO_2 45.2%, H_2O 4.5%.

Nacrite: A clay mineral having the theoretical composition $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, the same as that of kaolinite.

Nephelite: A mineral having the theoretical composition $Na_2O \cdot Al_2O_3 \cdot 2SiO_2$. A common reaction product in furnaces wherein slags or vapors of high soda content come into contact with fireclay or high-alumina brick. Stable to 2278° F. (1248° C.) at which temperature it inverts to the mineral carnegieite, which has the same composition, but a different crystalline form. Natural nephelite contains a small amount of potash. Specific gravity 2.67.

Neutral Refractory: A refractory material which is neither strongly acid nor strongly basic, such as chrome spinel and mullite.

Nine-Inch Equivalent: A brick volume equal to that of a standard 9" x 4½" x 2½" straight brick; the unit of measurement of brick quantities in the refractories industry.

Nodule Clay: A rock containing aluminous or ferruginous nodules, or both, bonded by fire clay; called "burley" clay in Missouri.

Olivine: A series of minerals having the general formula $2RO \cdot SiO_2$, in which RO is MgO, CaO, FeO, and sometimes MnO. More specifically, chrysolite, a continuous mineral series consisting of forsterite ($2MgO \cdot SiO_2$) and fayalite ($2FeO \cdot SiO_2$) in varying proportions. Specific gravity 3.27 – 3.37, increasing with the amount of iron present.

Overfiring: A heat treatment which causes deformation or bloating of clay or clay ware.

Periclase: The mineral or crystalline form of magnesium oxide. Specific gravity 3.58. Melting point 5070° F. (2800° C.).

Permeability: The property of porous materials which permits the passage of gases and liquids under pressure. The permeability of a body is largely dependent upon the number, size and shape of the open connecting pores, and is measured by the rate of flow of a standard fluid under definite pressure.

Plastic Fire Brick: A blend of ground fireclay materials in plastic form, suitable for ramming into place to form monolithic linings.

Plastic Fire Clay: A fire clay which has sufficient natural plasticity to bond together other materials which have little or no plasticity.

Plasticity: That property of a material that enables it to be molded into desired forms, which are retained after the pressure of molding has been released.

Polymorphism: The property by virtue of which some elements and compounds form two or more minerals of different crystal structures and physical properties. For example, silica crystallizes as quartz, as cristobalite and as tridymite — three minerals having distinctive crystal forms and physical properties.

Pores: As applied to refractories, the small voids between solid particles. Pores are described as "open" if permeable to fluids; "sealed" if impermeable.

Porosity of Refractories: The ratio of the volume of the pores or voids in a body to the total volume, usually expressed as a percentage.

Power Pressing: The forming of refractory brick shapes by means of high pressure applied vertically, from ground refractory material containing an optimum amount of added water.

Pug Mill: A machine used for blending and tempering clays in a moist or stiffly plastic condition.

Pyrite: The most common sulphide mineral; composition FeS_2, corresponding to Fe 46.6%, S 53.4%. Specific gravity 4.9 – 5.2. Color, brass-yellow. Used mainly for making sulphuric acid and sulphates.

Pyrometric Cone: One of a series of pyramidal-shaped pieces consisting of mineral mixtures, and used for measuring time-temperature effect. A standard pyrometric cone is a three-sided truncated pyramid; and, approximately, is either 2⅜ inches high by ⅜ inch wide at base, or 1⅛ inches high by ⅜ inch wide at base. Each cone is of a definite mineral composition, and has a number stamped upon one face; and when heated under standard conditions, it bends at a definite temperature.

Pyrometric Cone Equivalent (P.C.E.): The refractoriness of a material, expressed in terms of standard pyrometric cones. More precisely, "the number of that Standard Pyrometric Cone whose tip would touch the supporting plaque simultaneously with a cone of the refractory material being investigated, when tested in accordance with the Standard Method of Test for Pyrometric Cone Equivalent of Refractory Materials" (A.S.T.M. Designation C-24) of the American Society for Testing Materials.

Pyrophyllite: A mineral consisting of hydrated silicate of aluminum, having the theoretical formula $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$, corresponding to 28.3% alumina, 66.7% silica, 5.0% combined water.

Quartz: A common mineral, consisting of silica (SiO_2). Sandstones and quartzites are composed largely of quartz, which occurs also in numerous other rocks. Specific gravity 2.65.

Quartzite: A rock consisting essentially of quartz grains united by a cement of secondary quartz. When a quartzite rock is broken, the fracture passes through both grains and bonding material, while in sandstone, the fracture occurs entirely in the bonding material.

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Ramming Mix: A ground refractory material which is mixed with water and rammed into place to form monolithic furnace linings.

Raschig Rings: Small hollow ceramic or metal cylinders used for packing acid or other chemical towers; the length of the cylinders is usually equal to the outer diameter.

Refractories: Non-metallic materials suitable for use at high temperatures in furnace construction. While their primary function is resistance to high temperature, they are usually called upon to resist one or more of the following destructive influences: abrasion, pressure, chemical attack and rapid changes in temperature.

Refractoriness: In ceramics, the property of resistance to melting, softening or deformation at high temperatures. For fireclay and high-alumina materials the most commonly used index of refractoriness is that known as the Pyrometric Cone Equivalent.

Rise: The vertical distance between the level of the spring lines and the highest point of the under surface of an arch.

Rock: A naturally occurring mineral aggregate consisting of one or more minerals. For example, quartzite rock is an aggregate consisting essentially of crystals of the mineral quartz; granite is an aggregate consisting essentially of crystals of feldspar and quartz.

Rock Floe: A body of talus occurring on the steep slope of a mountain side; generally refers to ganister of the Tuscarora quartzite formation in central Pennsylvania.

Rowlock Course: A course of brick laid on edge with their longest dimensions perpendicular to the face of a wall.

Rutile: A mineral consisting of titanium dioxide (TiO_2). Specific gravity 4.18 – 4.25. Occurs in most fire clays in small amounts.

Screen Analysis: The size distribution of non-cohering particles as determined by screening through a series of standard screens.

Secondary Expansion: The property exhibited by some fireclay refractories of developing permanent expansion at temperatures within their useful range; not the same as overfiring.

Sericite: A flaky form of muscovite mica.

Serpentine: A group of hydrous magnesium silicate minerals. Chrysotile and antigorite, $3MgO{\cdot}2SiO_2{\cdot}2H_2O$, are the most common. Specific gravity 2.5 – 2.7. Also, a common rock consisting essentially of serpentine minerals.

Siderite: A mineral having the theoretical composition $FeCO_3$, corresponding to FeO 62.0%, CO_2 38.0%.

Silica: SiO_2, the oxide of silicon. Quartz and chalcedony are common silica materials; quartzite, sandstone and sand are composed largely of free silica in the form of quartz.

Silica Brick: A fired refractory consisting essentially of silica, and usually made from quartzite bonded with about 1.8 to 3.5% of added lime.

Silica Cement: Finely ground silica material with a plasticizing and bonding agent, suitable for use as mortar in laying silica brick.

Siliceous Fireclay Brick: Fireclay brick containing appreciable quantities of free silica; the total silica content lies within the range of 65 to 80%.

Sillimanite: A mineral having the formula $Al_2O_3{\cdot}SiO_2$; composition: Al_2O_3 62.9%, SiO_2 37.1%. Specific gravity 3.24. At about 2785° F. (1530° C.) it begins to decompose into mullite and free silica.

Sintering: A heat treatment which causes adjacent particles of material to cohere, at a temperature below that of complete melting.

Skewback: The course of brick, having an inclined face, from which an arch is sprung.

Slag: A substance formed in any one of several ways by chemical action and fusion at furnace operating temperatures:

1. In smelting operations, through the combination of a flux, such as limestone, with the gangue or waste portion of the ore.
2. In the refining of metals, by substances (such as lime) added for the purpose of effecting or aiding the refining.
3. By chemical reaction between refractories and fluxing agents such as coal ash, or between two different types of refractories.

Slagging of Refractories: Destructive chemical action upon refractories at high temperatures, resulting in the formation of a liquid.

Slurry: A suspension of finely pulverized solid material in water, of creamy consistency.

Soapstone: A soft magnesium silicate rock consisting mainly of talc.

Soldier Course: A course of brick set on end; little used in the case of refractories except in the bottoms of some types of furnaces.

Solid Solution: A homogeneous crystalline phase with a variable composition. The term "solid solution" usually refers to isomorphous mixtures, but sometimes refers to the solution of small proportions of a material in a seemingly unrelated substance.

Spalling of Refractories: The loss of fragments ("spalls") from the face of a refractory structure, through cracking and rupture, with exposure of inner portions of the original refractory mass.

Span: The horizontal distance between the supports of an arch.

Specific Gravity: The ratio between the weight of a unit volume of a substance and that of a unit volume of some other standard substance, under standard conditions of temperature and pressure. For solids and liquids, the specific gravity is based upon water as the standard.

The "true specific gravity" of a body is based on the volume of solid material, excluding all pores. The bulk or volume specific gravity is based upon the volume as a whole; i.e., the solid material with all included pores. The apparent specific gravity is based upon the volume of the solid material plus the volume of the sealed pores.

Specific Heat: The ratio between the thermal capacity of a substance and the thermal capacity of water at a standard temperature.

Spinel: A group of minerals which crystallize in the cubic system, and which have the formula $RO{\cdot}R_2O_3$; the RO may consist of one or more of the bivalent oxides MgO, FeO, MnO, or ZnO, and the R_2O_3 of one or more of the trivalent oxides Al_2O_3, Cr_2O_3 or Fe_2O_3. Magnesium aluminate spinel ($MgO{\cdot}Al_2O_3$) theoretically is composed of 28.2% MgO, 71.8% Al_2O_3. Its specific gravity is 3.6 and its melting point 3875° F. (2135° C.). Spinel containing substantial proportions of Cr_2O_3 is the essential constituent of chrome ores.

Spring Line: The line of contact between the under surface of an arch and the skewback.

Sprung Arch: An arch which is supported by abutments at the sides or ends only. A cross section of a sprung arch, taken at right angles to its axis, usually consists of a segment of a circular ring, in which the inner and outer arch surfaces are represented by arcs of concentric circles. (See page 272.)

Steatite: A hydrated silicate of magnesium, having the theoretical composition $3MgO{\cdot}4SiO_2{\cdot}H_2O$, corresponding to 31.7% MgO, 63.5% SiO_2, 4.8 H_2O.

Stretcher: A brick laid on flat with its length parallel to the face of the wall.

Super-Duty Fireclay Brick: As defined in the standard A.S.T.M. classification C27-41, fireclay brick which have a P.C.E. not lower than Cone 33, a linear shrinkage not over 1% when reheated for 5 hours at 2910° F. (1600° C.), and a spalling loss not more than 4% in the panel spalling test.

Suspended Arch: An arch in which the brick shapes are suspended from overhead supporting members.

Taconite: Ferruginous chert, often containing 25 to 35% iron oxide.

Talc: A hydrous magnesium silicate mineral having the theoretical composition $3MgO{\cdot}4SiO_2{\cdot}H_2O$, corresponding to MgO 31.7%, SiO_2 63.5%, H_2O 4.8%. Specific gravity 2.7 – 2.8.

Talus: Broken rock which has collected on a mountain side or slope, or at the base of a mountain, slope or cliff.

Thermal Conductivity: The property of matter by virtue of which heat energy is transmitted through particles in contact. For engineering purposes, the amount of heat conducted through refractories is usually given in B.t.u. per hour for one square foot of area, for a temperature difference of one degree Fahrenheit, and for a thickness of one inch.

Thermal Expansion: The increase in linear dimensions and volume which occurs when materials are heated and which is counterbalanced by contraction of equal amount when the materials are cooled. Thermal expansion is not to be confused with volume changes of a permanent character which many materials undergo when heated.

Tolerance: The permissible deviation in a dimension or property of a material from an established standard, or from an average value.

Tridymite: A mineral form of silica; stable from 1598° F. to 2678° F. (870° C. to 1470° C.). Specific gravity 2.26. An important constitutent of silica brick.

Vacuum Pressing: A method of forming brick shapes by which they are subjected to a partial vacuum during pressing in a power press.

Vitrification: A process of permanent chemical and physical change at high temperatures in a ceramic body, such as a fire clay, with the development of a substantial proportion of glass.

Vermiculite: A group of micaceous minerals, all hydrated silicates, varying widely in composition. When heated, vermiculite exfoliates and increases greatly in volume.

Vesicular: Having a cellular structure; applied to fire clays which have become bloated by overfiring.

Warpage: The deviation of the surface of a refractory shape from that intended, caused by bending or bowing during manufacture.

Wedge Brick: A brick shape having six plane faces (two sides, two edges and two ends), in which two faces (the sides) are inclined toward each other, and one end face is narrower than the other, as illustrated on page 31.

Wollastonite: A mineral having the theoretical formula $CaO{\cdot}SiO_2$, equivalent to CaO 48.3%, SiO_2 51.7%. Specific gravity 2.9. Inverts at 2192° F. (1200° C.) to pseudo-wollastonite. Melting point 2806° F. (1541° C.).

Zircon: The mineral $ZrSiO_4$. Composition: ZrO_2 67.1%, SiO_2 32.9%. The specific gravity is 4.7 and the melting point is 4405° F. (2430° C.).

Zirconia: Zirconium oxide, ZrO_2. Specific gravity 5.8. Melting point 4890° F. (2700° C.). Its chief source is the mineral baddeleyite.

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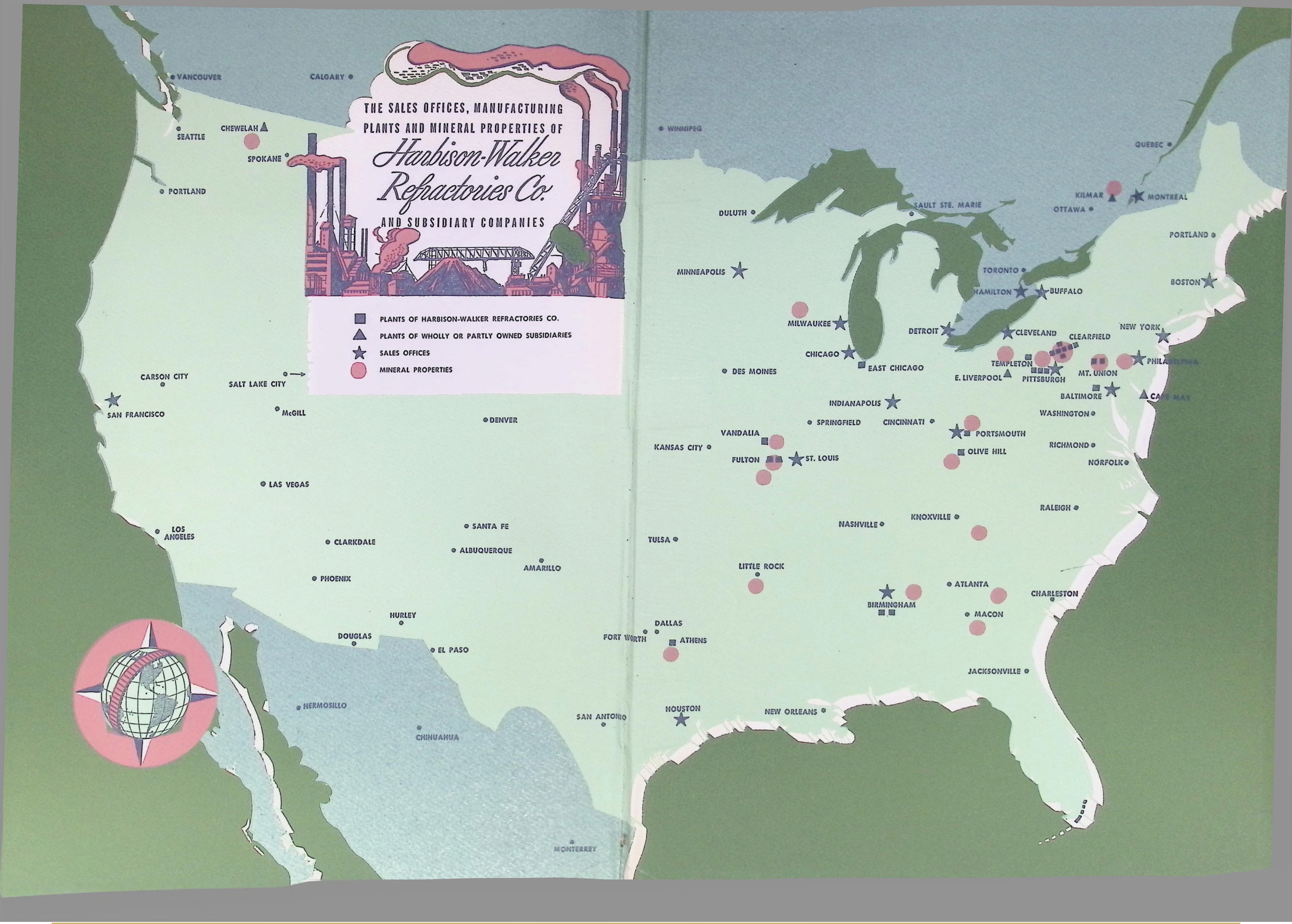
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