May 30, 1950 S. A. HARDIN 2,509,228

ELECTRIC FURNACE FOR PHOSPHATE REDUCTION

Filed Feb. 26, 1949 2 Sheets-Sheet 1

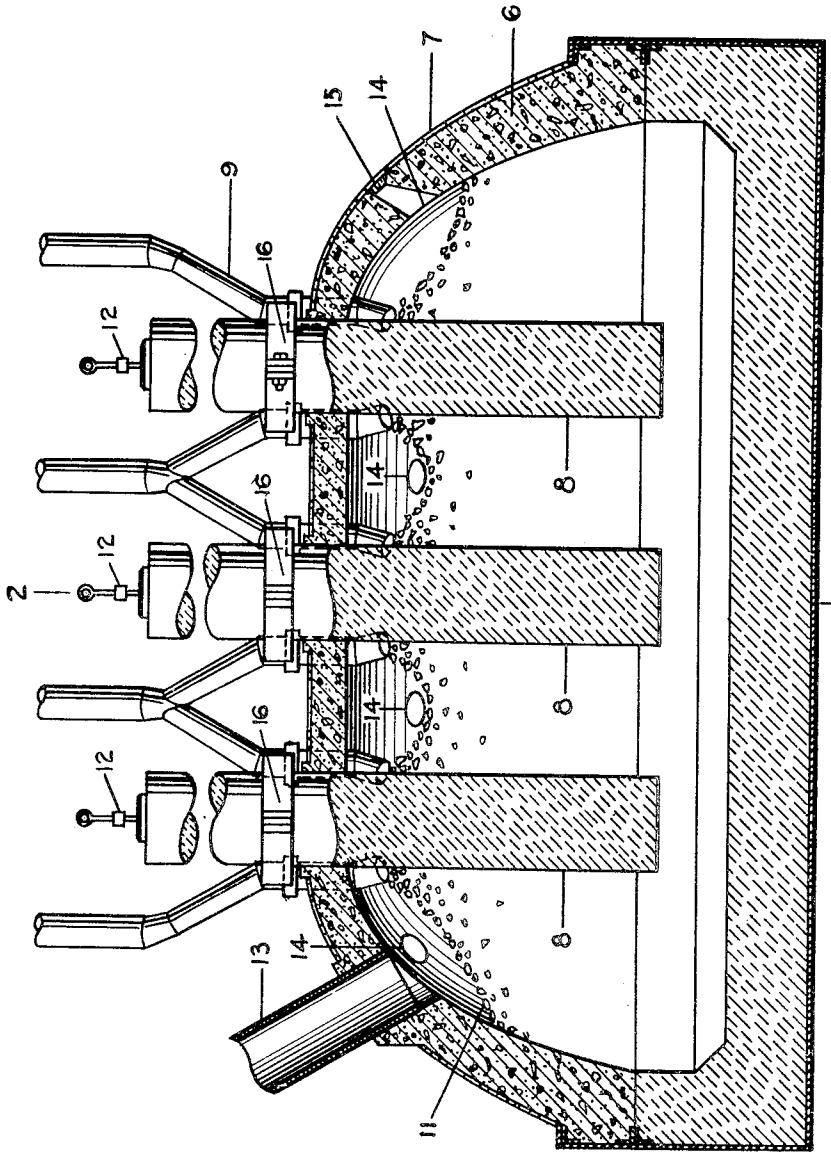


Fig. 1

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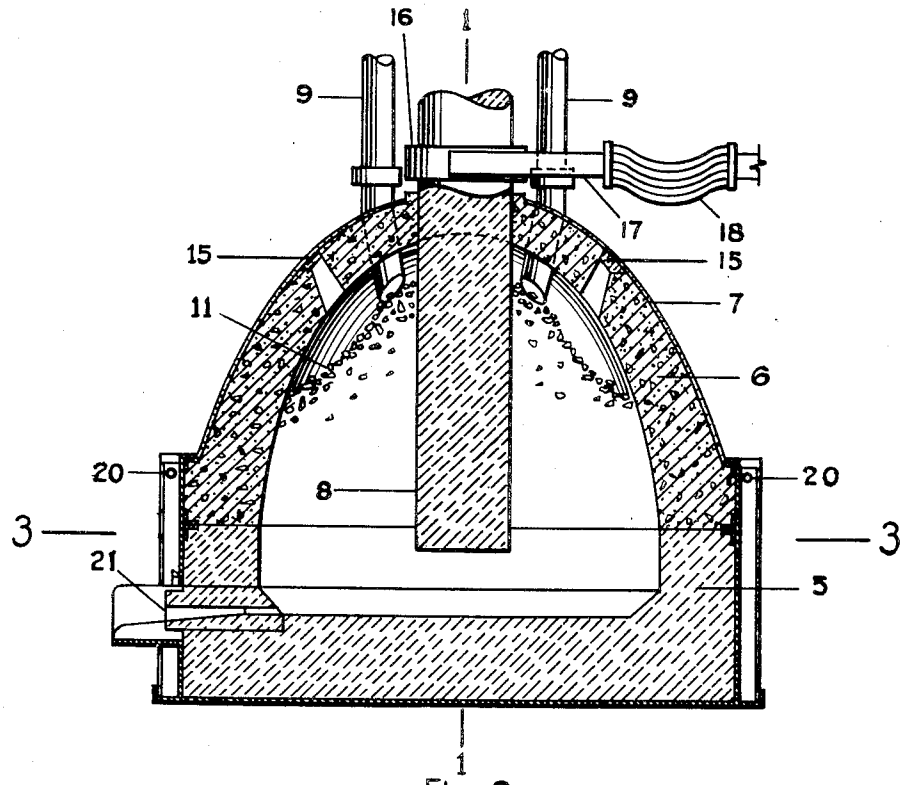


Fig. 2

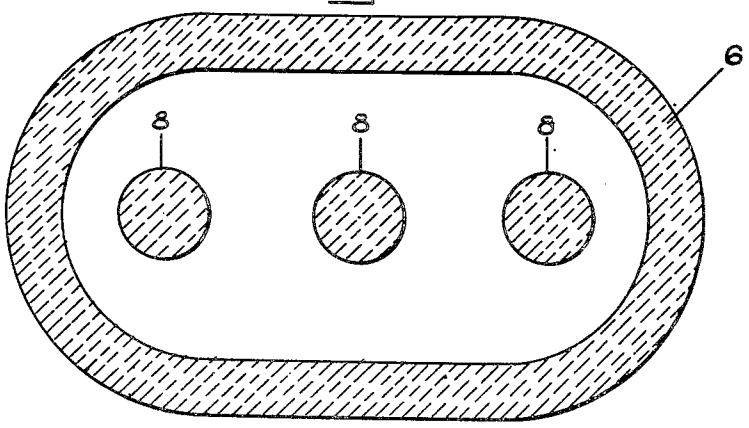


Fig. 3

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2,509,228

ELECTRIC FURNACE FOR PHOSPHATE REDUCTION

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Application February 26, 1949, Serial No. 78,584

3 Claims. (Cl. 13—9)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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The invention herein described may be manufactured and used by or for the Government for governmental purposes without payment to me of any royalty thereon.

This invention relates to the art of smelting ore electrically. It relates particularly to improved electric furnaces adapted for use in smelting phosphate rock and ores having properties similar thereto.

This application is a continuation-in-part of my application Serial No. 633,250, filed December 6, 1945, for Phosphate reduction furnace, now abandoned.

In the production of phosphorus a mixture of phosphate rock, coke, and silica is smelted in an electric furnace. The over-all reaction in smelting phosphate rock is the reduction of the phosphate to elemental phosphorus and the reduction of other components of the rock, such as iron oxide, carbonate, sulfate, etc., by the coke used in the charge. Elemental phosphorus is withdrawn as a gas, preferably from an upper part of the furnace, and a liquid slag is withdrawn from the hearth portion by tapping.

It has been customary to smelt phosphate rock in cylindrical or rectangular electric furnaces having thick walls of refractory masonry enclosed within a steel shell. Cylindrical furnaces require the use of heavy special refractory shapes which are very expensive. In addition it is necessary to crowd electrodes, feed chutes, poke holes, and gas offtake on the roof of cylindrical furnaces, and such crowding gives less favorable working conditions in maintaining electrode seals, adding new lengths of electrodes, poking the burden, etc., than are available with rectangular furnaces. Better power factors are obtained with cylindrical furnaces than with rectangular furnaces, however, the cylindrical furnaces showing characteristic power factors of from 0.88 to 0.90, whereas the rectangular furnaces have power factors of from 0.86 to 0.88.

In cylindrical furnaces three electrodes are ordinarily used, usually disposed in an equilateral triangle. In furnaces of this type the reaction zone of each electrode overlaps, causing an excessive amount of electrical energy to be expended within this area. Consequently, the major portion of the furnace charge has to be fed into this area. This makes it impossible to maintain an even flow of charge throughout the interior of the furnace and, as a result, high offgas temperatures frequently occur which damage auxiliary equipment attached to the furnace. The difference in the rate of flow of the charge on the inside and the outside of this area tends to push the electrodes out of plumb, causing electrode breakage, and makes it difficult to keep electrode seal rings packed effectively. Rectangular furnaces require much more steel and refractories in their construction than the cylindrical type of furnace. Heavy buckstays of nonmagnetic materials are necessary, adding greatly to the cost of construction and making it much more difficult to water-cool the shell of such furnaces. Repair of a section of rectangular furnaces is also much more difficult than in cylindrical furnaces.

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In the operation of furnaces for smelting phosphate rock, it is customary to keep the furnace substantially filled with charge. A principal difficulty encountered results from the fact that such charges are prone to crust in the upper part of the furnace. Much poking of the resulting crusts is necessary, and it is frequently impossible to keep such crusts broken up well enough to obtain smooth operation of the furnace. Pent-up gases beneath this crust build up pressure until the crust is ruptured and the furnace puffs to a very undesirable extent.

Conventional furnaces require much poking of the burden to break up crusts. Such poking admits air and, since phosphorus is autoinflammable in air, combustion in the upper part of the furnace is greatly increased. This often raises the temperature of offgas to so great a degree as to seriously damage electrostatic precipitators or other auxiliary equipment used in processing the offgas. Low temperature of offgas is very desirable in such smelting processes. A review of phosphate reduction furnaces is published in Chemical and Metallurgical Engineering 45, pages 116–20, 193–97, 374–79, and 536–40 (1938).

It is very desirable that a furnace for the production of phosphorus be provided which will have a higher power factor than those hitherto constructed, which does not require extensive refractory shapes, heavy buckstays, or expensive steel shells. Such a furnace preferably should have a design which permits location of electrodes and feed chutes conveniently, so that the charge will be distributed uniformly throughout the interior of the furnace. It is also desir-

able that such a furnace may be constructed at very low initial cost and in very little time as compared to conventional furnaces and be cheap to repair. It is also very desirable to obtain a furnace in which the flow of charge is smooth and even and in which puffs of gas are not obtained.

It is an object of this invention to provide an electric furnace which has a higher power factor than cylindrical or rectangular furnaces previously in use.

Another object of this invention is to provide such a furnace which is very cheap to construct and repair.

Another object is to provide such a furnace in which no expensive refractory shapes are required, and no heavy buckstays or expensive steel shells.

Another object of this invention is to provide an electric furnace for the smelting of phosphate ores in which an even flow of charge is obtained and puffing is substantially eliminated.

Other objects and advantages will become apparent as this disclosure proceeds.

I have now found that all these advantages may be obtained in a furnace having the novel features of design and materials of construction described below. In my novel furnace I provide a carbon hearth section, preferably having semicircular end portions in plan view and carbon walls extending upward to a slightly higher level than that to which slag fills the hearth in operation. Monolithic walls and roof of refractory concrete having inner surfaces of a curvature substantially that of an inverted catenary having a ratio of width to height preferably in the range from about 1.4 to about 1.6 rise from the hearth to the apex of the catenary. One or more electrodes project vertically through suitable openings in this monolithic roof to a location adjacent to the hearth section and are disposed in the longitudinal center line of the furnace. A plurality of feed chutes project into the furnace through suitable openings near the electrode and are adapted to pile up charge introduced thereby around said electrodes. Conventional means for withdrawing gases from the upper part of the furnace, for energizing the electrodes and withdrawing molten material from the hearth section are provided.

I have found that in a furnace of this design the vertical travel of charge in the upper part of the furnace occurs at a rate which is several times faster than the vertical travel of charge in the lower part of the furnace. This is due to the constant increase in cross section of the furnace from apex to hearth section as the catenary arch increases in width. I have found that this rate of constant increase in cross section with consequent decrease in rate of vertical travel results in breaking up crusts as fast as they are formed and effectively prevents puffing of the furnace and substantially eliminates the necessity for poking the charge.

The attached drawings illustrate diagrammatically one type of furnace embodying my invention. Figure 1 is a longitudinal vertical section through the furnace on a line 1—1 of Figure 2, Figure 2 is a cross section through the furnace, and Figure 3 is a plan of the same furnace.

In these figures the reference numeral 5 indicates a carbon hearth having walls rising to a level slightly above the level of slag or liquid product attained in operation of the furnace.

Monolithic walls and roof 6 of refractory concrete rest upon the hearth section 5. The interior surfaces of this monolithic section 6 rise from section 5 in a curve which is substantially that of an inverted catenary having a ratio of width to height preferably in the range of from about 1:4:1 to about 1:6:1 when determined along a vertical section through the furnace perpendicular to the longitudinal center line of the furnace between the centers of curvature of the semicircular end portions of hearth section 5, and when determined along vertical sections coinciding with radii of a curved end portion of section 5 which form acute angles with that portion of the longitudinal center line lying between such centers of curvature and an adjacent end of the furnace, and extending from the apex of the furnace to the hearth section. The ratio of height to width of this catenary curve may vary slightly outside the preferred range, but a substantial variation therefrom is undesirable. The curve also may vary somewhat from that of a true catenary, either in the direction of an elipse or in the direction of a parabola, but substantial variation from the catenary type of curve is undesirable, as the monolithic walls and roof are thereby greatly weakened. The refractory cement used in preparing the refractory concrete is a high calcium aluminate cement. One representative cement of this type is sold in America under the trade name "Lumnite" cement. The composition of two representative samples of this cement is shown in the following table.

	Composition, per cent	
	Sample A	Sample B
SiO_2	3.84	3.75
TiO_2	2.86	2.20
FeO	9.88	3.50
Fe_2O_3	8.52	7.50
Al_2O_3	35.38	36.50
CaO	34.20	36.00
MgO	2.77	.70
S		.10
Mn_3O_4		.50

Other cements of European origin have even higher calcium aluminate content. Such cements have very low coefficients of expansion. The aggregates used with such cement are preferably flint clay grog, fireclay grog, or grog prepared from firebrick scrap. The grog used should have a coefficient of expansion as near that of the cement as is obtainable. So far as I know, no other type of refractory cement possesses sufficient strength, sufficiently low coefficient of expansion, resistance to chemical action, and refractory properties to make a furnace of this type practical for use in smelting phosphate rock.

A sealing coat 7, preferably an asphaltic asbestos compound, may be applied to the exterior of monolithic refractory section 6. A suitable number of electrodes 8 are disposed along the longitudinal center line of the furnace and project vertically downward to the vicinity of the hearth portion through suitable openings in the apex of monolithic section 6. The number of electrodes used is the nearest integer to the result calculated

$$\frac{L-D}{D}$$

in which L is the inside length of the furnace in the plane of greatest length and D is the

distance from the center of an electrode nearest the end of the furnace to the inside of the nearest end wall in the plane of greatest furnace length. A plurality of feed chutes 9 are disposed adjacent to each electrode 8 and project into the interior of the furnace through suitable openings in the catenary roof and are adapted to pile up burden introduced therethrough around the electrodes to fill the furnace to the line indicated by numeral 11. Each electrode is equipped with a suitable attachment 12 for connecting to hoisting apparatus (not shown) for raising and lowering electrodes as desired. A gas offtake line 13 projects through an upper part of the monolithic section 6 and is adapted to withdraw gases from the furnace. A plurality of access holes 14 may also be formed in monolithic section 6 as desired. These are adapted to be closed by plugs 15. Each electrode is held by an electrode holder 16 and is in electrical conductance relationship with electrode holder 16 and bus bar 17, the latter being shown only in Figure 2. Suitable conductors 18 connect each bus bar with a source of electric current. A water cooling means 20 is disposed at the sides of hearth section 5. A suitable taphole and spout 21 are provided for withdrawing molten material from the furnace hearth.

In operation the furnace is filled with a charge of phosphate rock, silica, and coke to a level substantially that indicated by the numeral 11. As elemental phosphorus is produced and slag accumulates in the hearth section, gaseous products are withdrawn by line 13 to further processing or use as desired, and fresh charge is introduced by feed chutes 9. The level of charge within the furnace is maintained at approximately the level shown numeral 11. As the charge travels downward from 11 to the hearth of the furnace its cross sectional area constantly increases and its vertical rate of travel decreases. I have found that this method of operation results in the crust being broken up by the rapid flow of charge in the upper part of the furnace and results in very smooth, steady rate of operation. Puffing of the furnace is substantially eliminated. Fine material blown out of the furnace with the gaseous product is greatly reduced and the necessity of poking the charge is eliminated. From time to time the slag and ferrophosphorus are withdrawn by tapping the hearth in conventional manner.

Example I

A furnace of full commercial size was constructed according to the principles of my invention described above. This furnace was operated substantially constantly for six months and operating data from this furnace are compared in the following table with operating data for a rectangular furnace of similar capacity operated in the same plant.

	Rectangular Furnace	Catenary Furnace
Electrode consumption per ton P_2O_5 charged	23.3	20
Power consumption per ton P_2O_5 charged—kwh.	5,023	4,700
Offgas temperature—degrees	700 to 1,600	600 to 1,100
Average offgas temperature—° F.	1,150	850
Power factor	88-89	95-96
Time on full load—per cent		99.8

It will be noticed that the electrode consumption per ton of P_2O_5 charged was greatly reduced in my novel furnace, the power consumption was reduced, and the offgas temperature was reduced some 300 degrees. The power factor was also substantially increased. In addition to these advantages, puffing was substantially eliminated and the amount of fine material blown out of the furnace with offgas was greatly reduced. Very smooth operation of the furnace was obtained, and the necessity for poking the charge was eliminated.

Example II

Comparison between the time of construction of the furnace described in Example I with the construction time of walls and roof of a conventional furnace was made. The time spent in constructing monolithic portion 6 of this furnace was only 8 hours as compared to from 14 days to 3 weeks required for the construction of equivalent sections of masonry furnaces of similar capacity. The cost of material and labor used in constructing this furnace was found to be only a small fraction of the cost of constructing a masonry furnace of similar capacity.

Example III

Damage to a side wall of the furnace described in the above example necessitated reconstruction of a portion approximately one square yard in area. Repair of this furnace required only the insertion of a patch. Reconstruction of this portion required only 3½ hours' labor time using the materials of construction referred to above. Damage to side walls of conventional masonry type furnaces requires substantially complete rebuilding of the wall affected.

It will be noticed in the above examples that a furnace of this design constructed of the materials described has a number of distinct advantages over conventional type furnaces. Among these are the reduction in electrode consumption obtained, reduction in power consumption per ton of phosphorus pentoxide charged, reduction of offgas temperature, and increase in the power factor, smooth feeding of stock within the furnace, reduction in dust removed with the gaseous product, substantial elimination of puffing of the furnace, complete elimination of the necessity of poking the burden within the furnace, very great reduction of furnace cost, time of construction, and cost and time required for repairs, complete elimination of heavy buck stays of nonmagnetic materials, and complete elimination of the necessity for a steel shell in the upper part of the furnace. Substantially all dead space within the furnace is eliminated and the crusting of the burden in a manner to wall off inactive sections is eliminated, thus preventing localization of the heating in small zones which in turn results in superheating and may burn holes in the walls of the furnace. These advantages are all due to the novel features of my furnace.

Having described my invention and explained its operation, I claim:

1. In an electric furnace for smelting ores, that combination which comprises a carbon hearth section having end portions substantially semicircular in plan view; and a monolithic walls-and-roof section of refractory concrete superimposed on the hearth section and supported only in a region adjacent to said hearth section, said monolithic walls and roof having inner surfaces of a curvature substantially that of an inverted catenary having a ratio of width to height in the range from about 1.4:1 to about 1.6:1 when determined along a vertical section through

said furnace extending from the apex of said furnace to said hearth section perpendicular to the longitudinal center line of the furnace between the centers of the semicircular end portions of the hearth section, and when determined along vertical sections coinciding with radii of a curved end portion of said hearth section which form acute angles with that portion of the longitudinal center line lying between such centers of curvature and an adjacent end of the furnace.

2. In an electric furnace for smelting ores, that combination which comprises a carbon hearth section having end portions substantially semicircular in plan view; and a monolithic walls-and-roof section of refractory concrete consisting of a cement high in calcium aluminate and a refractory grog having substantially the same coefficient of expansion as said refractory cement superimposed thereon and supported only in a region adjacent to said hearth section, said monolithic walls and roof having inner surfaces of a curvature substantially that of an inverted catenary having a ratio of width to height in the range from about 1.4:1 to about 1.6:1 when determined along a vertical section through said furnace extending from the apex of said furnace to said hearth section perpendicular to the longitudinal center line of the furnace between the centers of the semicircular end portions of the hearth section, and when determined along vertical sections coinciding with radii of a curved end portion of the hearth section which form acute angles with that portion of the longitudinal center line lying between such centers of curvature and an adjacent end of the furnace.

3. In an electric furnace for smelting ores, that combination which comprises a carbon hearth section having end portions substantially semicircular in plan view; a monolithic walls-and-roof section of refractory concrete, having openings therethrough suitable for the introduction of electrodes and feed chutes, superimposed thereon and supported only in a region adjacent to said hearth section, said monolithic walls and roof having inner surfaces of a curvature substantially that of an inverted catenary having a ratio of width to height in the range from about 1.4:1 to about 1.6:1 when determined along a vertical section through said furnace extending from the apex of said furnace to said hearth section perpendicular to the longitudinal center line of the furnace between the centers of the semicircular end portions of the hearth section, and when determined along vertical sections coinciding with radii of a curved end portion of the hearth section which form acute angles with that portion of the longitudinal center line lying between such centers of curvature and an adjacent end of the furnace; a number of electrodes equal to the integer corresponding most closely to the value of the fraction

$$\frac{L-D}{D}$$

in which L is the inside length of the furnace and D is the distance from the center of an electrode nearest the end of the furnace to the inside of the furnace end wall, said electrodes being disposed substantially vertically to project through suitable openings in said monolithic walls-and-roof section to a location adjacent to the hearth section; means for energizing said electrodes; a plurality of feed chutes, disposed adjacent to each electrode, projecting into the interior of the furnace through suitable openings therein and adapted to introduce burden into the furnace and to pile up the same around said electrodes to substantially fill the furnace; means for withdrawing gas from an upper part of the furnace; and means for withdrawing molten material from the hearth section.

STANFORD A. HARDIN.

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