Feb. 17, 1948. C. J. WESTLING 2,436,157

METALLURGICAL PROCESS AND APPARATUS

Filed Dec. 15, 1941 3 Sheets-Sheet 1

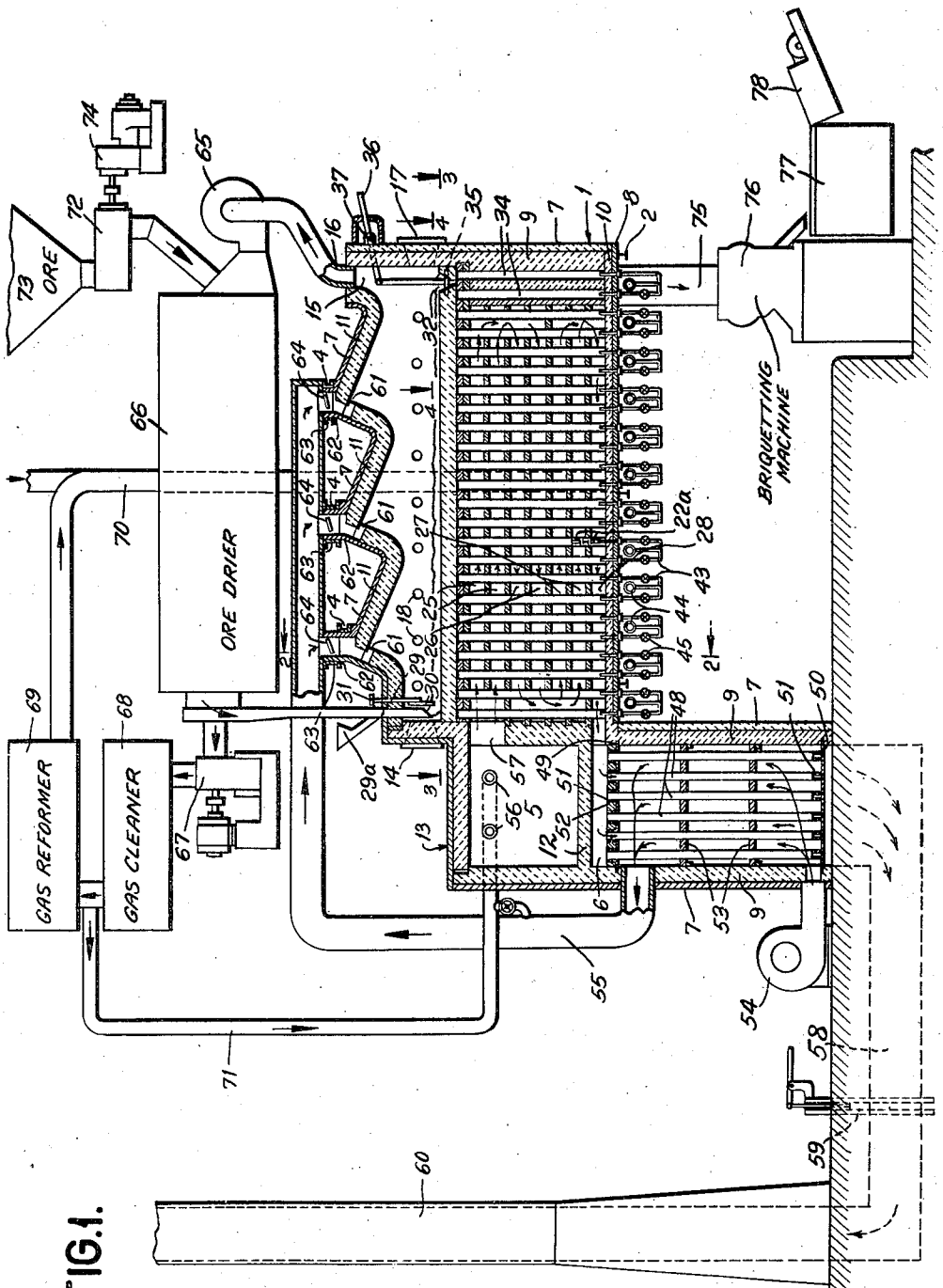


FIG. 1.

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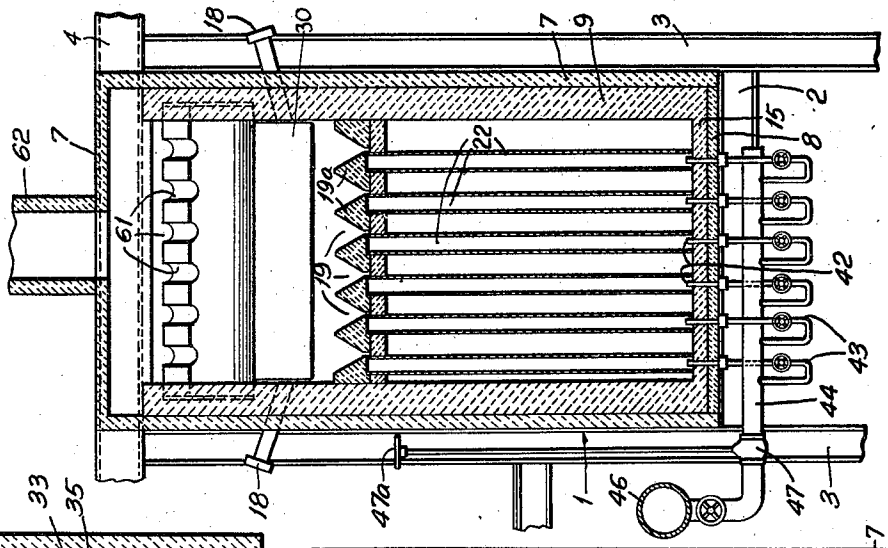
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METALLURGICAL PROCESS AND APPARATUS

Filed Dec. 15, 1941 3 Sheets-Sheet 2

FIG. 2.



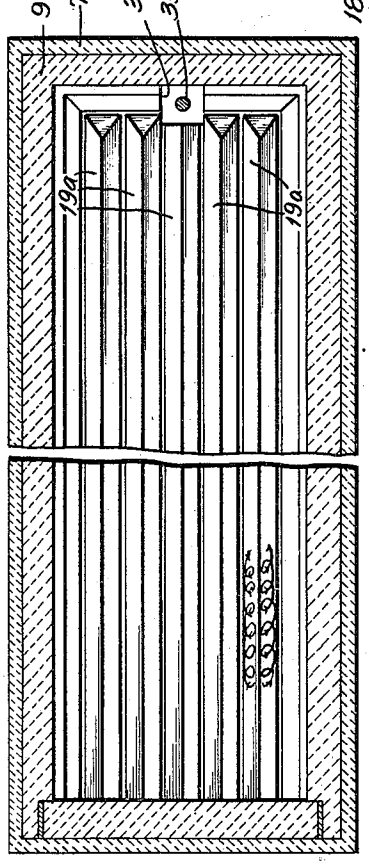


FIG. 3.

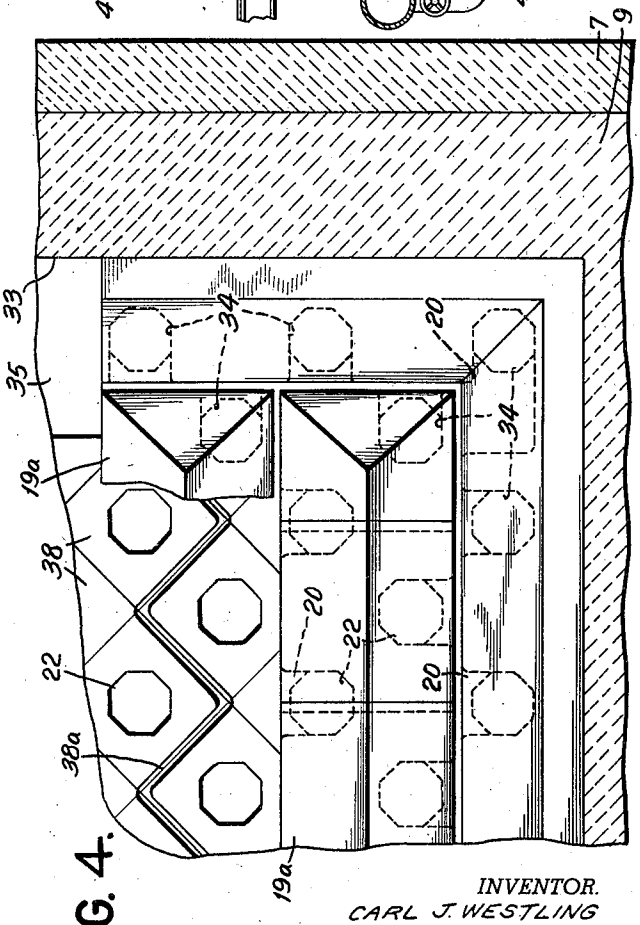


FIG. 4.

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METALLURGICAL PROCESS AND APPARATUS

Filed Dec. 15, 1941 3 Sheets-Sheet 3

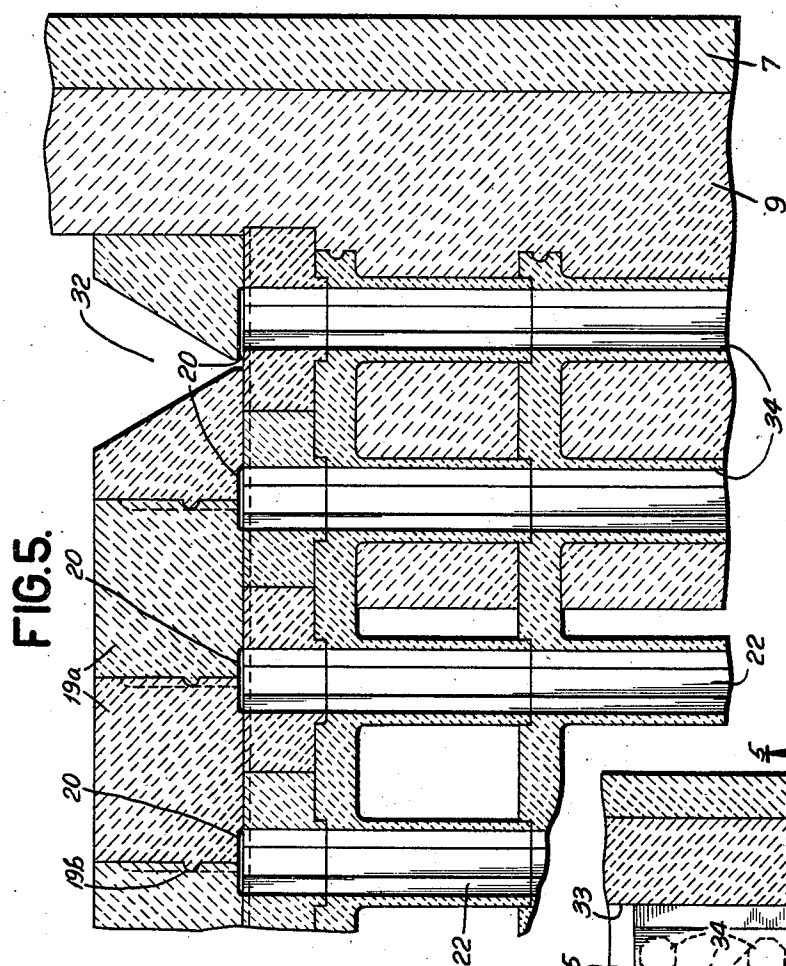


FIG.5.

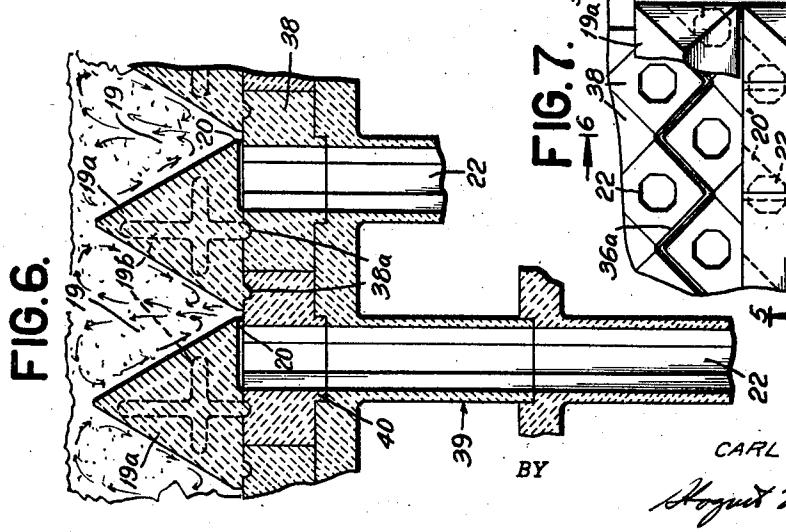


FIG.6.

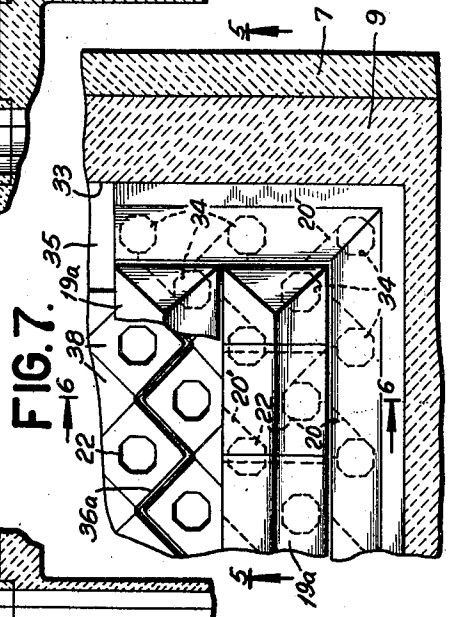


FIG.7.

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Patented Feb. 17, 1948

2,436,157

UNITED STATES PATENT OFFICE

2,436,157

METALLURGICAL PROCESS AND APPARATUS

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Application December 15, 1941, Serial No. 422,930

4 Claims. (Cl. 23—1)

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This invention relates to the treatment of finely-divided metallic materials by reduction, roasting, or other metallurgical or chemical process, and has particular reference to methods and apparatus for reducing metallic compounds, and is so described herein as illustrative of the invention, but it is to be understood that the invention is not limited to that use.

In general the invention relates to treatment of the finely-divided charge on a hearth, preferably horizontal, by means of gases while the charge is caused to move over the hearth. Moving charge hearths of this general nature have been known heretofore and may be classified according to the mode of advancement of the charge. According to one method, the hearth is vibrated in such a way that the finely-divided charge advances thereover during reduction, and Hardy Patent No. 2,236,474 and/or Brassert Patent No. 2,296,498, disclose examples of the application of this method. Another method involves propulsion of the charge along the hearth by directional jets of gas under pressure and may be effected by reducing gas impulses as in Simonds Patent No. 1,802,959, or by constant reducing gas flow imparting directional movement to the finely-divided charge, and Brassert Patent No. 2,296,498 and/or Brassert and Hartley Patent No. 2,316,664 disclose examples of the application of this method.

These prior arrangements are satisfactory for certain purposes but are not usable under all conditions and are expensive to manufacture, maintain and operate. Thus, the vibrating hearth is expensive, because it requires costly temperature-resistant alloys and refractories, while in the gas propulsion hearth the metallic particles are likely to flow back into and thus clog the gas jet openings during interruptions in operation, unless the jet openings are made smaller than the smallest particles of the charge, again requiring expensive heat-resisting alloys and refractories in order to obtain the accurately-sized jet openings required. Also, where very fine materials are treated, which means 100 to 200 mesh, the number of apertures required for the necessary gas volume would be excessive. Furthermore, even if jet openings of sufficiently small size could be economically practicable, it would be difficult to keep them open because of the tendency toward carbon deposit and corrosion under the rigorous operating conditions to which the hearth would be subjected. Also, it is difficult to supply sufficient heat by means of the preheated reducing gases without liability of fritting or sintering in the charge itself or in the jet openings or on the walls of the hearth.

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Nevertheless, the general charge propulsion method has many advantages and the gas agitation method in particular is simple and superior to the method of charge propulsion by vibration of the hearth, providing that the hearth is properly constructed and operated. Thus, an important consideration in proper construction and operation of the hearth is the relation between volume of gas and weight of the superimposed column of materials. I have found this relation to be a definite ratio that must be substantially adhered to in order to preclude channeling of the bed through a few holes, thus destroying uniform distribution of the gases through the ore bed and precluding its progressive advancement along the hearth in the nature of a desirable flowing action. For example, I have found that for many ores and fine particle sizes, the ore bed should have a thickness between four and twelve inches, depending upon particle size and weight, inasmuch as the finer and lighter the ore the smaller may be the volume of gas which can be blown through the ore bed. However, if the ore bed is too thin in relation to the gas pressure, the dust losses may become too great with fine ores. On the other hand, if the ore bed is too thick, a disproportionately high gas pressure is required to permeate the bed with resultant gas conduit leakages, and dust losses also result when the gas breaks through the heavy charge.

A primary object of the present invention, therefore, is to provide a method by which finely-divided ores and other metallic compounds can be reduced with pre-heated gases in a horizontal hearth type furnace through which the charge is caused to flow by inducing in it a state similar to fluidity by means of permeating reducing gases, while heating the same to reducing temperature but without the disadvantages inherent in the previous types of furnaces described above.

Another object of the invention is to provide a reducing furnace having a hearth over which the charge of finely-divided ore, or other materials to be reduced, with or without the addition of carbon, is caused to maintain the aforementioned state of fluidity by regulating the thickness of the charge at the inlet and outlets of the furnace, and also by regulating the volume of reducing gas admitted to the hearth, particularly near the point of discharge therefrom.

Another object of this invention is to provide a reducing furnace hearth structure which, although having relatively few and wide gas inlet

orifices, can nevertheless maintain uniform agitation throughout the whole area of a relatively deep charge on the hearth without the necessity of using excessive pressure and volume of gas.

Another object is the provision of a hearth structure capable of being blown from relatively few gas orifice openings, and which at the same time will eliminate depressions that trap the ore and interfere with its continuous forward travel, and which, when the ore feed is shut off, may be emptied and cleaned by continuing the flow of gas through the hearth.

Another object is the provision of a hearth structure wherein gas openings of desirable width may be sealed against back leakage of a finely-divided charge, but without an attendant formation of pockets wherein the charge may frit or obstruct flow or prevent any cleaning.

Another object is the provision of a hearth structure in which gas slots and preheat passages may be laid open and made accessible for periodic inspection and cleaning, if desired, by a simple removal of the hearth surface structure.

Another object is the provision of a furnace structure in which the above objectives may be completely attained, not only in metal construction but with equal safety and facility in refractory materials.

Another object is to provide a furnace hearth primary heating means and substructure whereby the hearth and the reducing gas for individual slot connections may at the same time be efficiently preheated between the inlet at which the cold gas volume is controlled and its exit to the individual slot sections.

Another object is to provide a reducing furnace in which speed of reduction is made possible by the use of a reducing gas high in H_2 and CO and very low in N_2, together with satisfying a peak portion of the heat demand throughout the length of the charge, by a secondary heating means, supplying radiant heat from direct partial combustion of spent reducing gases blowing up from and protecting the charge against reoxidation.

Another object is to provide a safe method of supplying secondary heat by direct partial combustion, preferably of spent reducing gases, above the charge whereby the radiant heat created is transferred directly into the charge in the furnace while the sensible heat of the gases is exchanged to the ore ahead of the furnace, thereby obtaining high overall efficiency.

Another object is to provide a controllable secondary heat source by which heat input can be varied throughout the length of the furnace to suit the demands of the reducing charge, or as may be desired to modify or control the rate of reaction throughout the charge.

Another object is to provide a method and means whereby part of the dust loss in the dirty exit reducing gas from the furnace is trapped in the ore drying operation by these gases and thus also to make one set of gas cleaning apparatus take care of both reducing furnace and ore drying apparatus requirements.

These and other objects of the invention are obtained in a furnace of the horizontal hearth type, as distinguished from vertical shaft or rotary kiln type furnaces, and in which the hearth contains a series of adjacent parallel, preferably V-shaped longitudinal troughs through which the material flows from the charging to the discharging end of the furnace, and from the bottom of each of which the permeating reducing gas issues with sufficient volume and under sufficient pressure, correlated to the particle size and weight of the charge, so that a state of fluency is imparted thereto resembling fluidity, with the result that the entire charge will progress with a flowing motion at predetermined speed from one end of the hearth to the other while the particles thereof are being reduced to metal. The gas openings are relatively wide and horizontally-directed and are not necessarily designed to impart directional propulsion to the charge, the permeation of the charge and the construction and arrangement of the hearth causing the natural flow of the fine materials without the provision of positive or directional means urging the charge in the desired direction. With this arrangement, preheated reducing gas may be employed without liability of fritting or sintering of the charge in or near the gas openings, and the horizontal disposition of the latter precludes back flow and clogging of the gas passages for any reason. Also, since the gas is not employed for direct or positive propulsion of the charge, the pressures need not be great, no greater than is necessary to obtain the fluid simulation of the charge which is a concomitant of the desired thorough permeation of the charge by the reducing gas. In conjunction with the hearth, primary indirect heating means and secondary heating means for the charge are provided, as well as means for transferring the sensible heat in the spent gases to the cold charge, including a gas cleaning system for the spent gases, which are recovered and regenerated for reuse.

It will be seen that the present invention provides a very simple and effective method of procuring continuous and economical reduction of finely-divided ores or other reducible metallic compounds of a wide range of particle sizes, since the pressures and volume of gas can be adjusted to suit reducing and charge permeation requirements without regard to forcible directional propulsion requirements of the moving charge methods heretofore known, the gas pressure and volume being merely correlated to the weight of the column of charge above the gas openings. The apparatus in which this method is practiced has no moving parts and is extremely simple in construction, and may be made of inexpensive materials. Its construction enables compact arrangement over a heat exchanger structure whereby minimum heat losses and maximum heat recovery are provided. The hearth may be readily removed, section by section, for repair inspection and replacement, and remains clean at all times. It may be cleared of the charge for inspection without manual effort and when cleared will be clean and ready for reuse in a short time.

For a more complete understanding of the invention, reference may be had to the accompanying drawings, in which:

Figure 1 is a vertical longitudinal section through the reducing apparatus of this invention for operation in accordance with the method thereof, certain of the items being shown schematically;

Fig. 2 is a vertical section through the furnace including the reducing gas preheater, as seen along the line 2—2 of Fig. 1;

Fig. 3 is a plan view of the hearth as seen along the line 3—3 of Fig. 1;

Fig. 4 is an enlarged plan view of the hearth, as seen along the line 4—4 of Fig. 1, with certain of the hearth rib sections removed to show the arrangement of the gas discharge slots and gas preheating flues;

Fig. 5 is an enlarged vertical transverse section through the hearth floor and the upper portion of the reducing gas preheater, as seen along the line 5—5 of Fig. 7;

Fig. 6 is an enlarged longitudinal section through the discharge end of the hearth, as seen along the line 6—6 of Fig. 7; and

Fig. 7 is a plan view of a modified form of hearth providing means for rapid removal of the entire charge.

In its preferred embodiment, the reducing furnace of this invention is contained in a suitable casing 1 supported by bottom beams 2, buckstay beams 3, and top tie beams 4. The casing 1 contains the combustion chamber 5 and air preheating recuperator 6, and is preferably made pressure-tight to permit the combustion chamber 5 and the gas preheating structure under the hearth, as described later, to be put under an equalizing pressure if desired. Any variation required in the pressure of the reducing gas supplied to the hearth may thus be offset by varying the waste gas pressure so as to reduce the differential pressure across the gas preheating structure practically to zero, whereby the danger of leakage losses or pressure damage can be eliminated.

The furnace casing is provided with an insulation lining 7 and refractory walls 9 disposed interiorly of the insulation. The bottom of the furnace consists of a suitable refractory base 10, resting on an insulating concrete slab 8, and the top of the furnace comprises a series of arches 11, preferably of the suspended type of construction. The roof arches 11 are also preferably finished with the insulation 7 but do not necessarily need a pressure tight casing cover, since the reducing gas above the charge on the hearth may be maintained substantially at atmospheric pressure.

A refractory arch 12 forms the bottom of the combustion chamber 5 and the top of the air preheater chamber 6. The top of the combustion chamber preferably consists of a suspended arch 13 placed at or below the level of the furnace hearth, thereby permitting the use of access doors 14 at the feed end of the furnace hearth. Similar access doors 17 are provided at the discharge end of the furnace. Near the discharge end of the furnace, the roof structure is arranged to form an outlet 15 for the spent reducing gas which is removed from the furnace as later described, through the insulated duct 16. Peep-sight connections 18 are provided along the sides of the furnace to enable the operator to observe the action of the charge on the hearth.

In its preferred form the refractory hearth consists of a series of parallel ribs 19*a* of triangular section forming V-shaped longitudinal channels 19, although they may have any other suitable contour, disposed side by side across the width of the furnace hearth, as shown in Figs. 2 and 3. Horizontal slot openings 20 at the bottom of each hearth channel introduce preheated reducing gas into the charge on the hearth. The gas slots 20, narrow vertically and wide horizontally, are suitably spaced longitudinally of the hearth and are staggered with respect to the slots in the adjacent row, as indicated in Fig. 4. Each slot is supplied with preheated gas from a corresponding flue passage 22 to insure uniform gas distribution with resultant complete agitation in the charge from end to end of the hearth channels 19.

The channel-forming ribs 19*a* rest on a cap

structure 38 above preheat flue tiles forming the reducing gas preheating flue passages 22. The ribs 19*a* are preferably made in sections corresponding to the spacing of flues 22 or multiples thereof. The ends of the rib sections 19*a* have tongue and groove joints 19*b* which may be sealed to prevent short-circuiting of reducing gas. The bottom of the rib sections 19*a* and top of cap structure 38 are provided with tongue and groove joints 38*a* for the same reason.

The spacing of the hearth channels 19 is dependent on the spacing of gas supply flues 22, or vice versa. Preferably the hearth channel spacing will be made to suit the flue spacing of standard heat exchange structures, but in any event will be made the minimum dimension consistent with gas manifold piping space requirements under the furnace. The minimum width and spacing provides a maximum charge volume and the least dead space, as represented by the area of rib sections 19*a*, for any given total width hearth with a given depth of charge.

The ore, or other metallic compound to be reduced, with or without admixed carbon, is supplied to the furnace at the feed end of the hearth through a feed chute 29, which is adapted to spread the ore to all the channels 19 across the width of the furnace. An adjustable gate means 30, operated by suitable adjusting means 31, is provided for the regulation of the depth of the charge at the feed end of the hearth. Near the discharge end of the hearth the reduced ore is preferably collected in transverse troughs 32 delivering to the discharge drop chute 33. Reducing gas admitted to flues 34 under transverse troughs 32 is used primarily to control the discharge flow of reduced product. A discharge regulating gate 35 may be provided for additional regulation of the product discharge. This gate may be operated by suitable regulating means 36 extending through a gas tight connection 37 to cooperate with the gate 35 on the inside of the furnace.

The supply of gas to the individual sets of slots 20 is admitted by individual connections 43 below the furnace through inlet pipes 42 to the preheating flues 22. The gas is supplied to each pair of transverse rows of flues 22 through a manifold 44 and is metered to inlet pipes 42 through a fixed or variable orifice 45 set to a desired maximum rate of gas flow. Each of the several manifolds 44 extends across the width of the furnace and is supplied from a longitudinal-supply manifold 46 extending along the entire length of the furnace. Each transverse manifold 44 is equipped with a regulating valve 47 for control of total gas flow to corresponding length sections of the hearth. The sectional regulating valves 47 are preferably all disposed out beyond one side of the furnace to permit key manipulation by means of handles 47*a* by an operator standing on a platform above and alongside the furnace, where he may at the same time observe the effect of the volume regulation through the peep-sights 18.

The flues 22 may be filled with a series of suitably shaped refractory fillers 22*a* to increase the velocity and create turbulence in the rising gases and thereby improve the rate of heat transfer to them, similar to the practice in modern blast furnace stoves.

The reducing gas in flues 22 is preheated by hot gases flowing around them from the combustion chamber 5 through a series of horizontal passes, 25, 26, 27, and 28. The cap structure 38 for the gas preheater on which the hearth rib sections 19*a* rest is of refractory material and is

of such thickness that the rate of heat transmission through the hearth to the ribs 19a and channels 19 supporting the charge can be held at substantially the same temperature as that of the reducing gas entering the charge. This is for the reason that in order to effect rapid heat transfer, a temperature differential of several hundred degrees may be necessary between the waste gases surrounding the upper ends of the preheating flues, and the temperature of the reducing gas leaving the flues. It would be a disadvantage to allow the top of the hearth structure to reach a temperature very much higher than that of the reducing gas or the desired temperature in the charge, since there is danger of sticking or fritting to the hot surfaces.

The heating gases flowing around reducing gas flues 22 are supplied by combustion chamber 5 which is preferably fired by cleaned spent reducing gas from the furnace. Air and gas are introduced under controlled pressure through suitable burners 56. The hot products of combustion pass from the combustion chamber 5 through the opening 57 directly into the waste gas passages 25 circulating back and forth through the preheater courses around flues 22 as described previously, whereby the column of reducing gas rising in flues 22 is first heated by the cooler combustion products and finally by the hottest gases immediately before it is projected into the charge, meanwhile increasing its pressure as it is heated. From the last course 28 the combustion gases pass down into the air preheater 6 after which they exhaust to a stack flue 58. The stack flue 58 is preferably equipped with a regulating damper 59 for the purpose of maintaining the required back pressure of waste gases all the way back to the furnace combustion chamber 5. Waste gases are discharged to the atmosphere through a suitable stack 60.

The air preheater 6 is preferably built as an integral part of the reducing furnace to simplify the construction requirements necessary for holding the unit at a controlled pressure above atmospheric to minimize leakage losses, as previously mentioned. In the preferred form shown, air preheater 6 consists of suitable vertical metal tubes 48 supported between upper and lower deck plates 49 and 50. The deck plates 49 and 50 are provided with vertical thimbles 51, and the top of the tubes with sealing collars 52 so that by filling the deck plates with a layer of sand or other suitable material, the connections may be sealed against leakage.

The furnace waste gas passes down through the air preheater tubes 48, and the space around the tubes is preferably divided into a number of passes for the air by means of horizontal baffles 53. Air is supplied to the bottom pass from a blower 54 and leaves the preheater from the top pass to enter an insulated air duct 55, which extends along the length of the furnace to supply air for supporting gas combustion at the burners 56 of the preliminary combustion chamber 5 and for the secondary partial combustion under the furnace roof arches 11, as will be described later.

The furnace top or roof construction consists of a series of flat sloping arches 11 each so inclined as to reflect heat diagonally downwardly toward the charging end of the hearth. Preheated air from preheater 6 may be introduced under each arch 11 from manifold duct 55 through supply ducts 63 and 62 to multiple ports or openings 61. A series of these openings 61 extends across the width of the furnace under the arch to obtain proper air distribution. The port openings 61 are supplied from the ducts 62 which are insulated manifolds, preferably formed as an integral part of the furnace support structure by extending the function of the top tie beams 4 which, by proper disposition will serve to provide framing for the manifolds 62, as shown. Each connection 63 is equipped with regulating means 64 which may consist of a butterfly or other suitable type of valve, by which the volume of air admitted to the manifold and consequently the degree of combustion of the combustible excess reducing gas and gaseous reduction products can be controlled. The furnace roof arches 11 are so arranged that the low point of each succeeding arch is higher than that of the previous arch, thereby preventing undue increase in the velocity of the gas flowing toward the gas outlet 15 near the discharge end of the furnace.

The spent gases from the furnace leave at the outlet 15, thence out through a duct 16 and through a blower 65 exhausting to the rotary ore dryer 66. The gases are exhausted from the dryer 66 through the fan 67 and pass on to the gas cleaning equipment 68 for removal of entrained dust and to cool the gas and condense moisture from the reaction and partial combustion. Part of the gas from the cleaning equipment 68 is supplied by pipe 71 to the burners 56 of the combustion chamber 5 as previously described, and the remainder to meet the heat requirements of the gas reforming apparatus 69. A portion of the cleaned gas may also be recirculated back to the furnace through the reducing gas main 70 to supply the manifolds 46 and 44. The spent gas main 70 will preferably be connected to, and supply, about the first third of the length of the hearth, where it may be desired to use clean spent gas or an admixture of spent gas to fresh reducing gas.

The ore for the reduction process may be fed in finely-divided state to the dryer 66 through a feeder 72 from a storage bin 73. If desired, a small percentage of finely-divided carbon to aid in the reduction of the metal may be admixed with the ore in the bin 73. The feeder 72 is preferably arranged to provide a seal against ingress of air or the escape of spent reducing gases from the dryer 66, and may be driven by a variable speed gear and motor unit 74, which may be controlled to hold the rate of the ore feed at a volume in accordance with the rate of reduction taking place in the furnace. The dried ore discharges from dryer 66 through the distributing chute 29 to feed all the channels 19 across the width of the furnace. A small percentage of carbon may also be added at 29a if desirable, in addition to or instead of at the bin 73.

The product from the furnace hearth falls through the discharge opening or duct 33 as previously described, thence out through the bottom of the furnace, and through a connecting chute 75 to suitable briquetting machine or other compacting means 76, wherein the substantially reduced powdered product is compacted into a form suitable for further processing. The briquetting machine 76 is equipped with a sealed discharge 77 to prevent the escape of reducing gases and to permit pressing or working the powder in a hot reducing atmosphere. The compacted product is preferably quenched and discharged through a conveyor 78.

In operation of the apparatus of this invention

in accordance with the method of this invention, the reducing gas at approximately the reducing temperature of the charge particles flows through the horizontal slots 20 and percolates upwardly in contact with the particles of the charge in the V-shaped channel troughs 19. The gas issues at a number of exit points along the hearth, which precludes channeling, and the gas exits are staggered so that they do not oppose each other. The gas is supplied in volume and pressure correlated to the charge weight and particle size so that as the gas flows through the interstices between the particles they are buoyed up in a state of suspension imparting a state of fluency to the charge resembling fluidity. As this hot gas emerges from slots 20 it expands and imparts a current to the fluent bed which may be described as moving upwardly at the center, diverging into two streams near the surface of the bed to travel laterally in opposite directions for a short distance and then downwardly to meet at the center of the channel 19 for repetition of the cycle, as is indicated by the arrows in Fig. 6.

The level of the bed at the charging end is maintained higher than at the discharge end, as indicated in an exaggerated way in Fig. 1, so that a pressure head is produced. In view of the fluency of the material, the entire bed flows longitudinally of the hearth under this pressure head. The rate of longitudinal flow of the fluent bed is controllable by means of the gas pressure and volume at the discharge end of the hearth, as will be described.

In view of this longitudinal flow of the bed, there is superimposed on the general transverse particle movement shown in Fig. 6 a gradual longitudinal movement toward the discharge end of the furnace, whereby the particles in each channel 19 described paths generally resembling double inverse spirals as they advance from the feed to the discharge end of the hearth, as indicated generally by the arrows in Fig. 3. This movement may be likened to that of two oppositely rotating parallel screws.

Another result of this rotating, double helical current effect, causing the general rise and fall of all particles throughout the depth of the charge, is to progressively and repeatedly expose all of the charge to the radiant heat directed down upon it from the roof arches 11. Thus, the radiant heat is more effective than if it had to penetrate a relatively static bed.

This radiant heat is the reflected heat produced by the partial combustion of, or combustion of a part of, the reducing gases at the top of the furnace, air from duct 55 being supplied thereto for this purpose. The reducing gas burns under the ceiling of the furnace and its heat is reflected downwardly on the charge in the manner described. By regulating valves 64 the supply of air to the several arches 11 may be altered to suit the heat requirement of the various sections of the hearth. Thus if more heat is required at the center of the hearth, more air supplied to the center arch through corresponding valves 64, results in combustion of a greater volume of gas at that point, with consequent intensified reflected heat for the center arch 11.

This method of supplying additional heat to the charge from without the charge is important for, by means of it, adequate heat is supplied to the whole or any part of the charge to completely reduce it, but without the danger of fritting and sintering with consequent clogging and sticking of the particles to each other and to the apparatus. Thus, even where the ore and gas are preheated, the heat input may be insufficient to complete reduction in many cases and in other cases, if sufficient heat is supplied in this way, the aforementioned fritting and sintering result. With the auxiliary radiant heating arrangement of this invention, excessive preheating and large gas volume for carrying heat into the charge may be avoided. Obviously, an ideal economical operation involves preheating the gas and charge and use of a minimum volume of gas, and such operation is obtainable with the present invention with the radiant heat augmentation described.

The control of reducing gas flow is effected ahead of the furnace while the gas is cold and of relatively constant pressure and volume. Control of the speed of charge travel may be obtained by regulating the gas flow with valves 47 near the discharge ends of the channels 19 to the volume which will maintain a charge travel speed in accordance with the desired throughput capacity of the furnace as based on the time required for the percent of complete reduction to be maintained in the product.

It will be observed that the arrangement of the gas orifices in the hearth is such that if gas flow at the discharge end were stopped, the charge at this point would come to rest, preventing exit charge flow from the furnace. This follows even if the balance of the charge is held in a state of agitation equal to fluidity. As a further aid in the control of charge flow, provision may be made, as previously described, for varying the difference in head between the ore feed inlet and reduced product outlet ends of the hearth by means of the adjustable inlet gate 31 and outlet gate 35.

The control of charge flow may also be aided by building the furnace and hearth at a slight inclination from the horizontal, as determined by experience, or the entire furnace unit may be mounted on adjustable supports to obtain the effect desired. These latter means, however, would at best provide for relatively fixed conditions and would be cumbersome to adjust, and hence are not as desirable as the preferred embodiment described herein.

In order that the charge may be removed quickly from the hearth to permit inspection and repair thereof, the slots 20' may be given a slight forward inclination as shown in Fig. 7, whereby the charge may be caused to progress even when the supply from 29 is stopped and the "head" between the charging and the discharging ends is lost. This inclination of slots 20' is solely for that purpose, as it has no effect on the fluent condition of the charge, any directional component force due to the inclination of the slot 20' being lost in the charge.

The spent hot reducing gases leaving the furnace are passed as described through duct 16 direcly up to the ore dryer 66, which is preferably of a type wherein the hot spent reducing gases pass through the ore, whereby the sensible heat is used to preheat and drive off moisture from the ore. If chemical water and/or CO_2 are present, these may also be driven off, and a small percentage of reduction may also be accomplished, particularly if the temperature is raised by partial combustion of the spent reducing gases. If sulphur is present in the ore and is to be eliminated in the same drying apparatus used for drying and calcining the spent gases used for this purpose must be completely burnt, preferably with an excess of air (roasting) because the elimina-

tion of sulphur to SO_2 occurs in an oxidizing atmosphere. In any case, only part of the spent gases may be used for one preparation, the balance may be taken directly to the cleaning apparatus for use in preheating the fresh reducing gas and air. The ore feed to the dryer **66** is maintained by the feeder **72** at a rate which can be set or varied in accordance with the furnace capacity as affected by the raw materials used and the product to be made. The hot ore from the dryer drops down through the shortest possible chute **29** directly into the furnace. Thus, the length of hot gas and of hot ore paths is reduced to the minimum by the flow circuits made possible with the furnace and drying-reduction gas cycle according to the present invention, resulting in proportionately decreased heat losses.

In the present invention there is thus provided a permeable hearth, which permits controllable charge movement induced by reducing gas agitation producing a state equal to fluidity; which is not restricted as to width of gas slot opening; which can use a varying depth of charge; which will allow rabbling if desired; which will not permit charge backflow; which is cleanable and may with reasonable ease be opened for inspection; which is not restricted to metallic construction; and wherein the method of heating eliminates excessively hot surfaces in contact with the reducing charge and excessive preheat in reducing gases.

The present invention, by taking advantage of the continuous stream of reducing gas blowing up from the charge and creating a protective blanket above it, making use of indirect partial combustion of this gas under radiant arches, thus provides an efficient direct secondary heat source to supply any deficiency from an indirect primary heating means, whereby the total heat requirement of the reducing operation can be met with good economy, especially as the gas cycle preferably also includes a subsequent means for transfer of the exit spent gas sensible heat to raw ore.

It will be evident that by the cycle of gases provided only one gas cleaning system is required, whereas if the ore were preheated by hot gases from some other source, it would be necessary to provide separate sets of cleaning apparatus for both furnace and dryer with proportionately higher installation, maintenance and operating costs. At the same time a certain portion of the entrained dirt in the exit spent gas from the furnace will be trapped by the charge in the dryer and thus be recycled directly to the furnace with the net dust loss lowered accordingly.

The invention by its combination heating method eliminates as far as possible the losses connected with indirect firing where the gas must first be cleaned, cooled and rehandled. At the same time it avoids the retarding effect associated with contacting the charge by high nitrogen gas or by excess CO_2 and H_2O products of combustion, such as much slower operation, lower output and proportionately higher heat consumption.

It will also be evident that the heat input throughout the length of the furnace may in the present invention be adjusted by regulating the admission of combustion air to the different arches so as to release radiant heat into the charge as desired to meet or modify the requirements of the reaction zones throughout the length of the hearth. By thus using a responsive secondary heating means, a degree of control

throughout the process is attained which has not heretofore been possible in furnaces employing gaseous reductants.

While a preferred embodiment of the invention has been illustrated and described herein, it is to be understood that the invention is not limited to structural details of apparatus or to the reduction of ores, but is applicable to the treatment of finely-divided materials while aerated in the manner described. For example, the process is equally applicable to, and the apparatus may be used for other metallurgical or chemical treatments, such as roasting fine ores, the various steps involved in nickel carbonyl treatment, and the like.

I claim:

1. The method of treating finely-divided material, which comprises feeding a layer of the material upon a horizontally placed hearth provided with V-shaped troughs extending from the feed end to the discharge end of the hearth, so injecting a stream of fluidizing gas into and transversely of the bottom of the trough at spaced points along the length of the trough and into the layer from below the same that the interstices between the particles on the hearth are permeated by the gas and the particles in the layer are suspended therein and by so injecting the gas, causing said particles so suspended therein to describe a circular path beginning approximately at the bottom of the layer, progressing upwardly toward the top thereof, there dividing into two streams moving oppositely in a direction transverse to the hearth, and then descending independently toward the gas stream for merging near the source of gas injection to repeat the cycle, and simultaneously causing the bed to progress longitudinally of the hearth, whereby the particles describe a generally double inverse helical movement.

2. In an apparatus for treating finely divided material with a reagent gas, the combination of an elongated substantially horizontally extending hearth, comprising a plurality of troughs, orifices in the bottom portion of said troughs, a hood over said hearth comprising a plurality of reversed arches extending transversely of the troughs, inlets for the admission of a combustion supporting gas between the arches at high points in the hood, and an outlet for gases in the hood in the end portion of the furnace.

3. In apparatus for treating finely divided material with heated gases, the combination of a chamber, a substantially horizontal hearth comprising a trough, gas inlet nozzles in the bottom of said trough horizontally directed into said trough so as to direct the gases against the walls thereof and then upwardly through the finely divided material in said trough, feeding means in one portion of said chamber and discharge means in another portion of said chamber, said hearth feeding means, and discharge means being so constructed that said finely divided material will flow through said chamber by gravity.

4. In apparatus for treating finely divided material with heated gases, the combination of a chamber with a substantially horizontal hearth comprising a trough, gas inlet nozzles in the bottom of said trough and horizontally directed into said trough, some of said nozzles being directed in one direction and others being directed in substantially the opposite direction, so as to direct the gas in generally opposite directions and then upwardly through the material in the trough, feeding means in one portion of said

chamber and discharge means in another portion of said chamber, said hearth feeding means, and discharge means being so constructed that said finely divided material will flow through said chamber by gravity.

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