

July 30, 1946.

H. A. BRASSERT

2,404,944

APPARATUS FOR REDUCTION OF OXIDES

Filed April 29, 1943

4 Sheets-Sheet 1

FIG. 1.

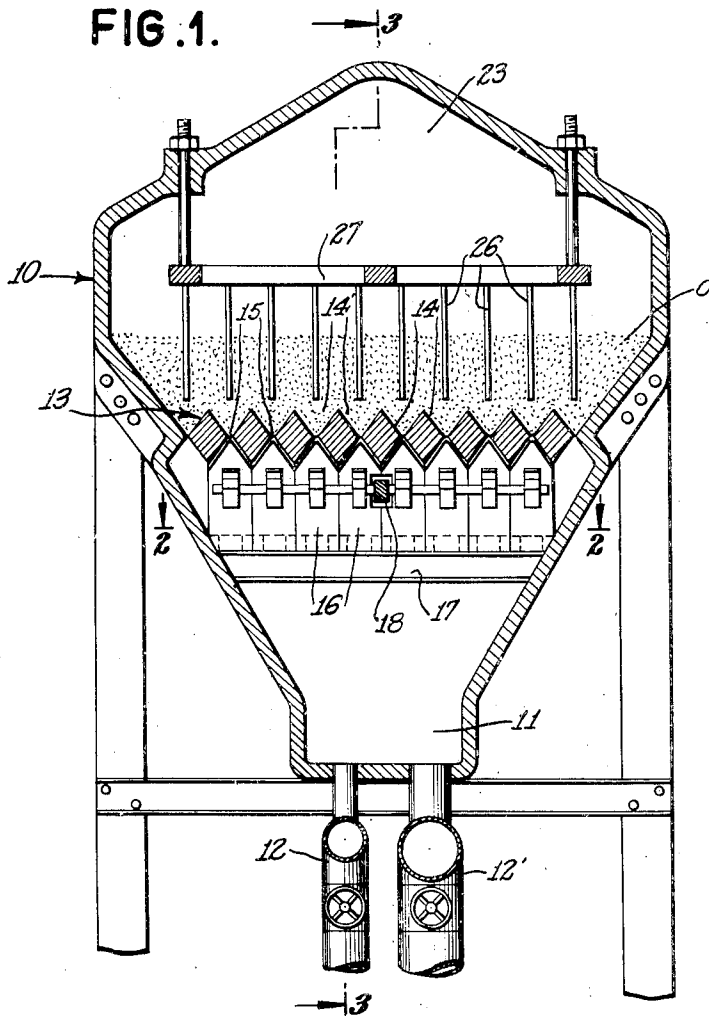


FIG. 4.

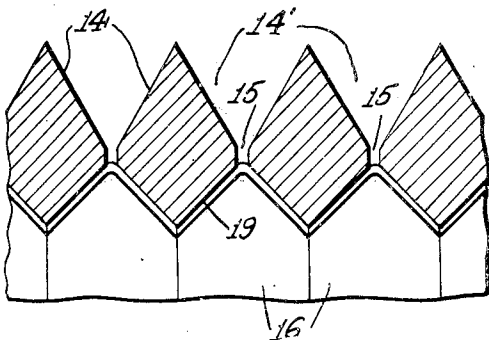
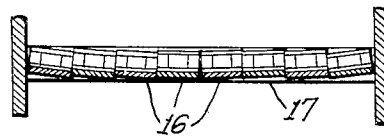


FIG. 2.



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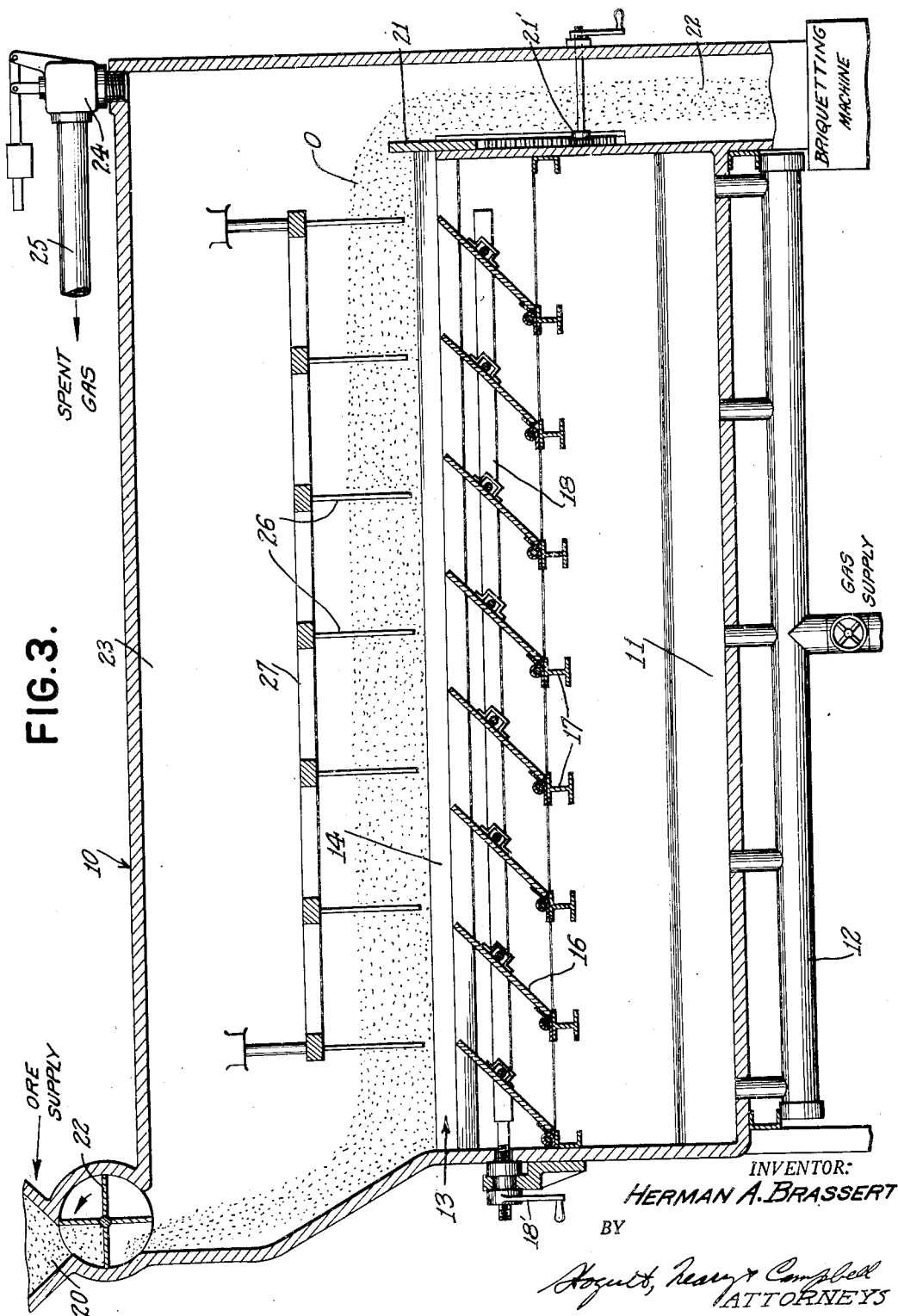
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FIG. 3.



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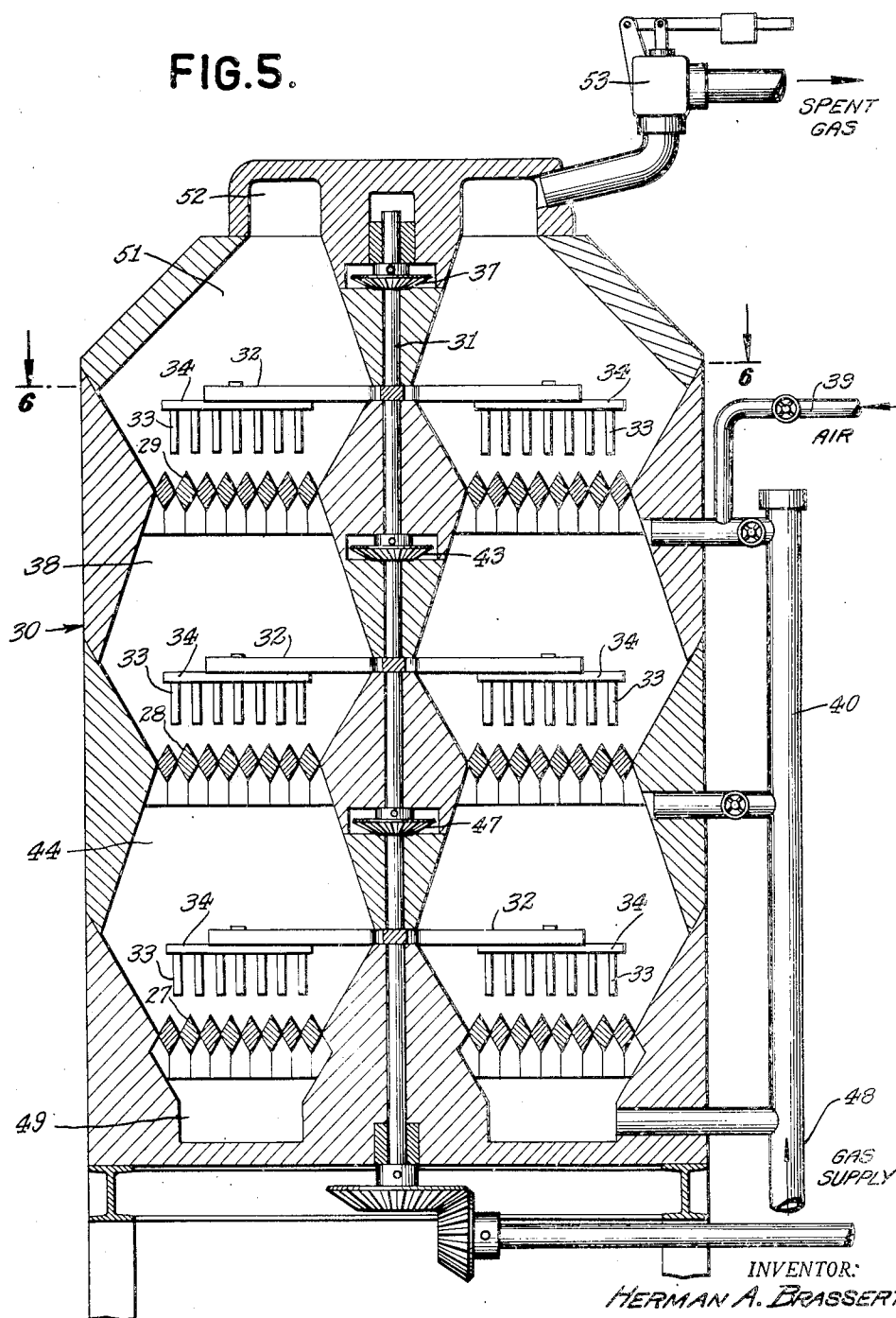
2,404,944

APPARATUS FOR REDUCTION OF OXIDES

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FIG. 5.



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APPARATUS FOR REDUCTION OF OXIDES

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Application April 29, 1943, Serial No. 484,960

6 Claims. (Cl. 266—21)

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This invention relates to apparatus for facilitating and controlling chemical reactions between finely-divided solids and fluids, and has particular reference to apparatus for the reduction of finely-divided metallic ores or other oxides by reducing gases, or to the desulphurization or beneficiation of such ores or oxides by gases, although the invention is not limited to such uses.

One apparatus of effecting such reactions is disclosed in application Serial No. 338,560, filed June 3, 1940, by J. C. Hartley, in which preheated reducing gases are caused to flow through a bed of finely-divided ore under such conditions that the bed assumes a state equivalent to fluidity, and hence flows along the hearth from the charging to the discharging point while the ore is reduced. The preheated reducing gases pass into the ore bed through a perforate hearth, the particular form of hearth shown in said application being provided with directional slots, although other operative forms of perforate hearth give the same effects, as for example that disclosed in application Serial No. 422,930, filed December 15, 1941, by C. J. Westling. That application discloses a V-shaped trough hearth, into the bottom of which the preheated reducing gases are non-directionally introduced for percolation through the ore bed to reduce the ore and to impart the fluid-like condition thereto, so that the bed flows along the hearth while the ore is reduced.

The described forms of hearth are efficiently effective under certain conditions but are not as effective when the conditions change. After investigation to ascertain the reasons for such lack of flexibility, it has been found to be generally due to the velocity and volume of the gas, which is required to perform both functions of adequately reducing the ore and maintaining the desirable fluid-like state of the ore bed. For example, if the gas velocity across the ore bed is too great, as when the ore bed lies in one or two V-channels but into which all the gas is introduced at the bottom, the gas may pass through the ore too rapidly, and cause the very fine particles of the ore to be projected high above the bed and be entrained with the out-flowing spent gases, causing undesirable dust losses. Although such fines can be recovered from the exit gases after they leave the reducing unit, such recovery is expensive. Furthermore, high gas velocities augment the channeling tendency of the gases which, by reason of their high kinetic energy, open up passages through the ore and continually enlarge them while carrying ore fines with them,

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in a cumulative effect, which makes uniform distribution of gas in the ore bed impossible.

It has been found that these difficulties may be avoided by maintaining a definite relation between the volume of the gas that is necessary to reduce the ore, the nozzle velocity at which the gas enters the ore bed, and the velocity at which it traverses the ore bed, and the present invention is primarily directed to the provision of such definite relation for the various conditions that are encountered in the operation of reduction apparatus of the general type described.

In accordance with the invention, the hearth is constructed so that the area of the total gas opening in the hearth is increased in such proportion to the hearth area by providing multiple channels each independently supplied with gas, that not only is the proper volume of gas supplied but a given velocity of gas bears a favorable relation to the physical character of the ore bed, its depth, and the specific gravity of the ore fines. By way of illustration, but not limitation, the invention may be a V-shaped hearth type of reduction apparatus in which the number of V-shaped troughs and the area of the gas openings thereof may be varied to give the desired area relationship necessary for the realization of the advantages of the invention, typical embodiments of which are illustrated in the accompanying drawings, in which:

Figure 1 is a vertical cross-section through the reduction apparatus, as seen along the line 1—1 of Fig. 3, embodying the invention;

Fig. 2 is a horizontal section through the hearth-supporting spacers as seen along the line 2—2 of Fig. 1 and shows their inclination whereby variation in the gas volume may be effected;

Fig. 3 is a longitudinal section through the apparatus as seen along the line 3—3 of Fig. 1;

Fig. 4 is an enlarged cross-section through a modified form of hearth bar, embodying the advantages of the venturi effect.

Fig. 5 is a vertical section through a circular type of multiple furnace as seen along the line 5—5 of Fig. 6, and embodying the features of the furnace of Figs. 1 and 2 and the principles of this invention;

Fig. 6 is a transverse section therethrough as seen along the line 6—6 of Fig. 5; and,

Fig. 7 is a fragmentary section through three of the material transferring pressure locks between the stages of the furnace, as seen along the line 7—7 of Fig. 6.

Referring to Figs. 1 and 3 of the drawings, numeral 10 designates the elongated casing for an

iron ore or other oxide reduction apparatus, which is preferably constructed of metal, although it may be wholly or partly constructed of ceramic material, such as fire brick. At the bottom of the casing 10 is the reducing gas supply box 11, into which the gas is brought through one or more pipes 12, from a suitable manifold or other supply system. Additional gas volume is supplied at low pressure by pipe 12' without materially increasing the pressure in 11.

The gas is preferably preheated hydrogen or high-hydrogen containing gas, such as coke-oven gas, and is preferably supplied directly from the coke-ovens. Other suitable reducing gases may be employed, such as reformed illuminating or oil gas, reformed natural gas, reformed blast furnace gas, and the like, containing hydrogen and/or carbon monoxide.

The general shape of the reduction apparatus 10 may be V-shaped in section, as shown, and suspended across it above the gas box 11 is the hearth 13, preferably made up of an assembly of parts of high temperature resisting steel or cast iron, ceramic, or other refractory material. The hearth 13 comprises a series of adjacent bars 14 which are generally diamond-shaped in cross-section with sides sloping about 30° to the vertical, so as to form the V-shaped channels 14' in and above which the ore bed 0 lies to a depth of 4½ to 12 inches.

The bars 14 are preferably supported and spaced apart the required distance by spacers 16, so as to provide slots 15 on the order of ¼ inch wide between adjacent bars through which the gas enters from the gas box 11. Spacers 16 are parallel flat plates arranged in their lowest position at an angle of about 45° and hinged at an angle on a suitable truss 17, as shown in Figs. 2 and 3.

A draw-bar 18 connects spacers 16 and has a threaded outer end projecting through the end wall of the furnace fitted with a nut and crank combination 18', whereby the spacers 16 may be raised and lowered to raise and lower the grate bars 14. Owing to the increasing angular disposition of spacers 16 to a vertical plane to either side of the center, as shown in Fig. 2, they spread the bars 14 apart as they are raised from the position shown in Fig. 3, so as to increase the width of the gas slots 15 between the bars 14, and vice versa, as they are lowered.

The width of the slots 15 depends upon the depth of the bed 0, the physical nature of the ore, the pressure and velocity of the gas issuing from slots 15, and the area of the hearth, as well as the throughput desired for the apparatus, these factors being variable in accordance with certain principles of the invention to be described. The adjustment in the depth of the bed may be obtained by raising or lowering the discharge dam 21 by means of a crank and pinion combination 21'.

In some instances, it may be preferred that the adjacent hearth bars 14 constituting the hearth 13 be so shaped that the gas passages have a Venturi contour, as shown in Fig. 4, where the side walls of the trough 14' slope at an angle of about 30° to the vertical, and the bottom faces 19 slope at about 45°, the slot 15 thus constituting the throat of the venturi. This nozzle velocity can be regulated by changing the width of the slots 15 as described.

The finely-divided ore is supplied to the hearth 13 at the inlet 20, after being concentrated, and as the pressure gas percolates through the ore

it causes the entire bed to assume a fluid-like state, as described in said copending applications, so that the ore flows from the inlet to the outlet. The gas is preheated by means not shown, so that the ore is reduced by the gas at temperatures on the order of 1100 to 1500° F., below those at which the particles agglomerate or frit together. Accordingly, the material remains in a finely divided state throughout the operation, and may be discharged over dam 21 to briquetting rolls, while still hot and in a reducing atmosphere. The reduced material is accordingly briquetted into self-sustaining units which are uncontaminated by reoxidation, since the reduced particles do not come in contact with air or other oxidation atmosphere, as described in Patent No. 2,287,663, issued June 23, 1942, to applicant, to which reference may be had for further details of the method of handling the material after reduction.

The furnace may be maintained under super-atmospheric pressure, if desired, by sealing the ore inlet either by supplying the ore through a self-sealing valve of the star wheel type 22, operated by gravity or power-driven, or by using a conventional double bell pressure-lock. The spent reducing gas is collected in the hood 23 and is released at the predetermined pressure through a gas pressure-operated valve 24 in the gas outlet 25, the valve being set at the internal gas pressure desired.

Although the fluid-like condition which is imparted to the ore bed, and which causes it to flow in the manner described in said copending applications, requires no additional propulsion, it may be desirable to control and retard the flow and break up any gas bubbles by means of stationary fingers 26, mounted on a suitable frame 27, suspended from the hood of the apparatus. The fingers 26 project downwardly into the ore bed 0, and may extend partly into the V-shaped troughs 14' thereof. The degree of flow control is determined both by the size of the fingers 26 and their depth of immersion in the ore bed, and accordingly the fingers 26 may be raised or lowered to adjust the rate of flow. It may be desirable to move these fingers, for instance at a slower rate than the flow of the ore bed, in order to increase the time of reduction. The fingers may be moved by any suitable mechanism (not shown).

In order to preclude channeling and dusting, owing to uneven and improper percolation of the reducing gas through the ore bed, while obtaining and maintaining the fluid-like condition of the bed, and effective reduction, it has been ascertained that in a reduction apparatus of the type described, a definite relationship must exist between the volume and velocity of the gas for iron ores or other oxides for any sizes passing a 28 mesh screen, which comprises the range of fineness which can be effectively handled. There is always a certain optimum gas volume-velocity condition below which the bed progress is too slow and short-circuiting of the gas current occurs, whereas above this condition the gas is likely to form large bubbles and burst through the bed with consequent channeling and dusting. The shallower the ore bed with a given gas volume, the greater the danger of channeling and the chance of gas bubble formation which actually results in decrease of pressure. In general, for a given fineness and quality of oxide and depth of bed, the gas volume can be increased and the velocity decreased by increasing the width of slots 15 in the manner described, and vice versa, or by increasing the number of slots 15 and vice versa.

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Depending on the nature of the ores and the like, the gas volume and pressure is regulated to obtain most efficient reduction. Gas volume and pressure in gas box 11 may be adjusted by valves or supply pipes 12 and 12'. By increasing the depth of the ore bed, the capacity of a given reducing unit may now be increased to any desirable extent because the flow of the gases may be so regulated as to give substantially perfect percolation of the gas through the heavier ore bed without channeling.

The foregoing conclusions are based upon substantial experimentation and tests made with different ores, which demonstrated the described gas pressure-volume relationship. These demonstrations showed that for proper gas volumes and pressures, obtained as described, the ore moved progressively along the hearth at a uniform rate of speed without dusting and without channeling, or the continuous formation of large gas bubbles, and with an optimum condition of reduction. Inasmuch as the ore was of a fineness of less than 28 mesh, the demonstrations included the range of fineness effectively handled by apparatus embodying the method described, and accordingly the gas pressures and volumes used for different depths of ore bed are also usable for ores within that fineness range, it being only necessary to adjust the gas volume and pressures for different depths of ore beds as indicated. It will be understood the most advantageous relation of depth of bed to velocity and pressure of the gas, must be worked out in actual operation for each type and size of ore unit.

These principles and specifications are applicable not only to elongated hearths of the general type illustrated in Figs. 1 and 3, but also apply to circular reducing apparatus, as for example the type generally classified as the Herreshoff type, in which the several hearths are arranged one above the other to conserve space and heat. When the hearths are so arranged, the ore charged on the uppermost level is partially reduced and is then discharged to the next level where it is further reduced, and finally it is discharged to the lower level where it is substantially completely reduced before being supplied to the briquetting apparatus. A reducing apparatus of this type is illustrated in Fig. 5 of the drawings, wherein three circular hearths, each embodying the characteristics of the hearth of Fig. 1, are supplied with reducing gas in succession. The fresh reducing gas is supplied from supply box 49 to the lowermost hearth 27 where it is partially spent, but since it is supplied in volume in excess of that required for complete reduction of the material on the lower hearth 27, it is supplied directly to the second hearth 28 through which it percolates in the manner described to continue its reducing function, and from there it passes upwardly through the upper hearth 29 where the initial reduction is effected. These three circular hearths 27, 28 and 29, each constructed like that shown in Fig. 1, are mounted above each other within the shaft 30, which has journaled at its vertical axis a rotary shaft 31, driven slowly from a suitable source of power, not shown, and carrying horizontal arms 32, one for each hearth. Each arm 32 carries two or more sets of fingers 33 of thin flexible material such as spring steel from $\frac{1}{4}$ to $\frac{1}{2}$ inch wide. These fingers 33 are mounted on a bar 34 adjustable angularly on arm 32, so that the degree of sweeping action of the fingers 33 may be adjusted. Thus, when arranged at the angle shown

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in Fig. 6, the fingers 33 tend to sweep the ore on the corresponding hearth toward the periphery and equalize the flow rate across the hearth.

The raw iron ore or other oxide in finely-divided state, is supplied to the furnace through a hopper 35 at the top from which it is fed at a constant rate through the gas and pressure-lock star wheel valve 36, which is driven by a gear 37 fixed to the rotary shaft 31. A chute 36' discharges the material on to upper hearth 29, where it is at least partially reduced by reducing gas percolating upwardly therethrough from the gas space 38 above the second hearth 28. If desired air or other oxidizing gas may be admitted through pipe 39 into gas space 38 if it is desired to roast or desulphurize the ore on upper hearth 29. Air may be also supplied for supporting combustion of some of the reducing gas and products of reduction, should additional heat be required for roasting or otherwise at the top of the shaft 30. Also, additional hot reducing gas may be supplied to gas space 38 from manifold 40 for augmenting the reduction of the ore on upper hearth 29, and increasing the pressure and volume of the gas, as well as its temperature.

As the ore travels along the slotted multiple V upper hearth 29, aided by the sweeping action of the rotating fingers 33, it reaches the radial slot 41 and is discharged over dam 41', falling to the second hearth 28, through the gas seal star valve 42, which is driven by gear 43 on rotary shaft 31. The partially reduced material is further reduced on hearth 28 as the gas percolates therethrough from gas space 44 above lower hearth 27. Additional hot reducing gas may be supplied to gas space 44 from manifold 40 if desired, to enrich the partially spent gas from the lower hearth 27 or to increase its pressure, or both, and temperature.

As it progresses along the hearth, aided by the sweeping action of fingers 33, the further reduced material discharges through radial slot 45 and gas seal star valve 46, driven by gear 47, upon the lower hearth 27 for final reduction. The hot gas for reduction is supplied from main 48 and is preheated to the proper temperature to effect reduction on the lower hearth 27 at between 1100 and 1500° F., and at the proper volume and pressure, according to the specifications heretofore given for the hearth and depth of ore bed. The gas is delivered to the gas ring or box 49.

As the material on hearth 27 is finally reduced to metallic iron without fusion or sintering, it reaches slot 50, and discharges directly to the briquetting rolls, not shown, where it is compacted into briquettes while still in a reducing atmosphere and still hot, according to aforesaid Patent No. 2,287,663.

It will be observed that the gas progresses upwardly through the successive hearths, any desired number of which may be employed. The gas collected from the gas space 51 above the upper hearth passes out through ring 52 through an automatic pressure responsive valve 53, which is set at the required internal furnace pressure. The spent gas may be reformed and returned, or used for combustion. The purpose of the gas seals 36, 42 and 46 is to prevent the gas from going up through the ore chutes, and hence it is forced to flow up through the openings at the bottom of the V troughs or corrugations forming the base of the hearths. The gas pressure in the furnace is preferably on the order

of ten pounds, which is the usual pressure at which coke oven gas is distributed through steel works, but it may be lower or higher, but always sufficiently high to be of substantial moment in increasing the reducing capacity of the unit. It is evident that if the pressure is one atmosphere, or fifteen pounds, above the barometric, then twice as much gas being contained in the unit, the rate of reduction may be nearly doubled. When natural gas is used, which may be available at much higher pressure, these pressures may be profitably applied to accelerate the rate of reduction.

No precautions need to be taken against fine ores dropping through the openings in the V hearths, because only the finest will drop through the narrow slots, and these require the shortest time for reduction. They will fall on the hearth below, and the only effect would be to reduce their time in the reducing furnace. In the lowest hearth on the other hand, the falling through of ore fines into the gas ducts might be objectionable. This can be avoided by using in the bottom section a slotted hearth so designed that no ore can fall through, the gas in this case entering through substantially horizontal or curved slots so designed as to prevent the falling through of ore. A type of such design is shown in said Westling application.

All of the gas may be applied at the bottom of the unit to the lowest hearth. The spent gases, after bubbling through the first hearth, penetrate into the second, and from the second into the third and so on to the top, where the final spent gases are taken from the unit. Each successive hearth would then have a weaker reducing gas, but the reducing strength of the original gas, the volume and temperature of the gas and the amount of ore coming through the unit against the flow of the gas would have to be proportioned so that the equilibrium of reduction will be reached in the top hearth at its temperature. In order to make the unit more flexible in this respect, and also in order to reduce the velocity of the gas going through the ore bed on each hearth, its velocity is kept down to the desirable point, that is, low enough so that the gases will not pick up the fines from the bed and whirl them up into the slots of the hearth next above. Not all of the gas need be admitted at the bottom, but some fresh gas may be admitted to one or more hearths above, as described. By regulating the amounts of the additional gas inflow to the upper hearths, the process can be so regulated that the equilibrium is nearly reached, and the values of the reducing power of the hydrogen and CO in the gas are utilized to the limit.

With this multiple hearth arrangement the reduction is progressive from top to bottom and as the oxygen in the fresh oxide on the top hearth is more available than that in the largely reduced material on the bottom hearth, the partially spent gas percolating through the oxide on the top hearth is still capable of reducing some of this fresh oxide, even when no fresh gas is mixed therewith. This same condition takes place on the intermediate hearths, i. e., a smaller proportion of unoxidized gas is available, as it rises through the furnace to deoxidize the more easily reducible material.

Accordingly, by making the bed on the top hearth of Fig. 7 thin, by adjusting its dam 41' to a low height, and gradually increasing the depth of the beds on the succeeding hearths by

adjusting their dams accordingly, rising gas of progressively decreasing reducing power is utilized to treat progressively decreasing volumes of material, as well as more easily reduced material. In this way the full reducing power of the gas may be utilized economically, and without liability of reoxidation of the material.

In both illustrated forms of furnace, the volume of gas may be increased to accommodate increased volume of oxide to be reduced, with a corresponding decrease in the velocity of the gas percolating through the material. In the furnace of Fig. 5, the decrease in velocity of the gas through the successive beds is effected substantially automatically, as the depth of the beds increase when dams 41' are raised, since the gas percolates at a slower rate through the bottom bed owing to its greater depth, and hence the velocity of the rising gas through the upper beds is decreased, the additional gas volume necessarily being supplied separately to each bed from manifold 40, controlled by the several corresponding valves, or by means of a separate gas supply, not shown, but similar to 12' in Fig. 1.

Although the method of this invention has been described in connection with several physical embodiments of furnace, it is susceptible of use in other types of furnace, and the latter may also be altered within the scope of the appended claims.

I claim:

1. In apparatus for reducing finely-divided metallic oxide material, the combination of a multiple channel hearth having gas apertures therein, means for supplying reducing gas from beneath the hearth for flow through the apertures thereof to reduce the same and simultaneously maintain the material in a state of suspension so that it flows along the hearth, an adjustable dam at the discharge end of the hearth for adjusting the depth of the bed, and means for adjusting the volume and velocity of the gas supplied to the hearth in accordance with increase or decrease of bed depth resulting from raising or lowering said dam.

2. In apparatus for reducing finely-divided oxide material, the combination of a plurality of closely-spaced parallel bars of substantially triangular cross-section forming a hearth having a plurality of substantially V-shaped grooves having bottom slots, a gas chamber beneath said hearth, means for supplying reducing gas to said chamber for flow through said hearth slots, and means for feeding a bed of the finely-divided material to one end of said hearth for reduction by said gas.

3. In apparatus for reducing finely-divided oxide material, the combination of a plurality of closely-spaced parallel bars of substantially triangular cross-section forming a hearth having a plurality of substantially V-shaped grooves having bottom slots, a gas chamber beneath said hearth, means for supplying reducing gas to said chamber for flow through said hearth slots, means for feeding a bed of the finely-divided material to one end of said hearth for reduction by said gas, and an adjustable dam at the discharge end of said hearth for regulating the depth of the bed on the hearth.

4. In apparatus for reducing finely-divided oxide material, the combination of a plurality of closely-spaced bars forming a multiple channel hearth, said bars having a cross-section forming upwardly venturi-shaped slots between them, means for supplying reducing gas to the lower

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ends of said slots for upward flow therethrough, and means for feeding a bed of the material on said hearth for treatment by said gas at reducing temperatures.

5. In apparatus for reducing finely-divided oxide material, the combination of a plurality of closely-spaced parallel bars of substantially triangular cross-section forming a hearth having a plurality of substantially V-shaped grooves having bottom slots, a gas chamber beneath said hearth, means for supplying reducing gas to said chamber for flow through said hearth slots, means for feeding a bed of the finely-divided material to one end of said hearth for reduction by said gas, and means for adjusting the spacing between

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said bars to vary the width of said slots and the consequent supply of reducing gas therethrough.

6. In apparatus for reducing finely-divided oxide material, the combination of a plurality of closely-spaced parallel bars forming an oxide material bed supporting hearth having gas slots between the bars, a gas chamber beneath said hearth, means for supporting said bars, and mechanisms for spreading said means to each side of the center of said hearth to spread the bars supported thereby for increasing the width of the gas slots between the bars, whereby the supply of gas to the bed is increased at will.

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