March 2, 1954 P. H. ROYSTER 2,670,946

APPARATUS FOR MAGNETIC ROASTING

Filed Oct. 31, 1950 2 Sheets-Sheet 1

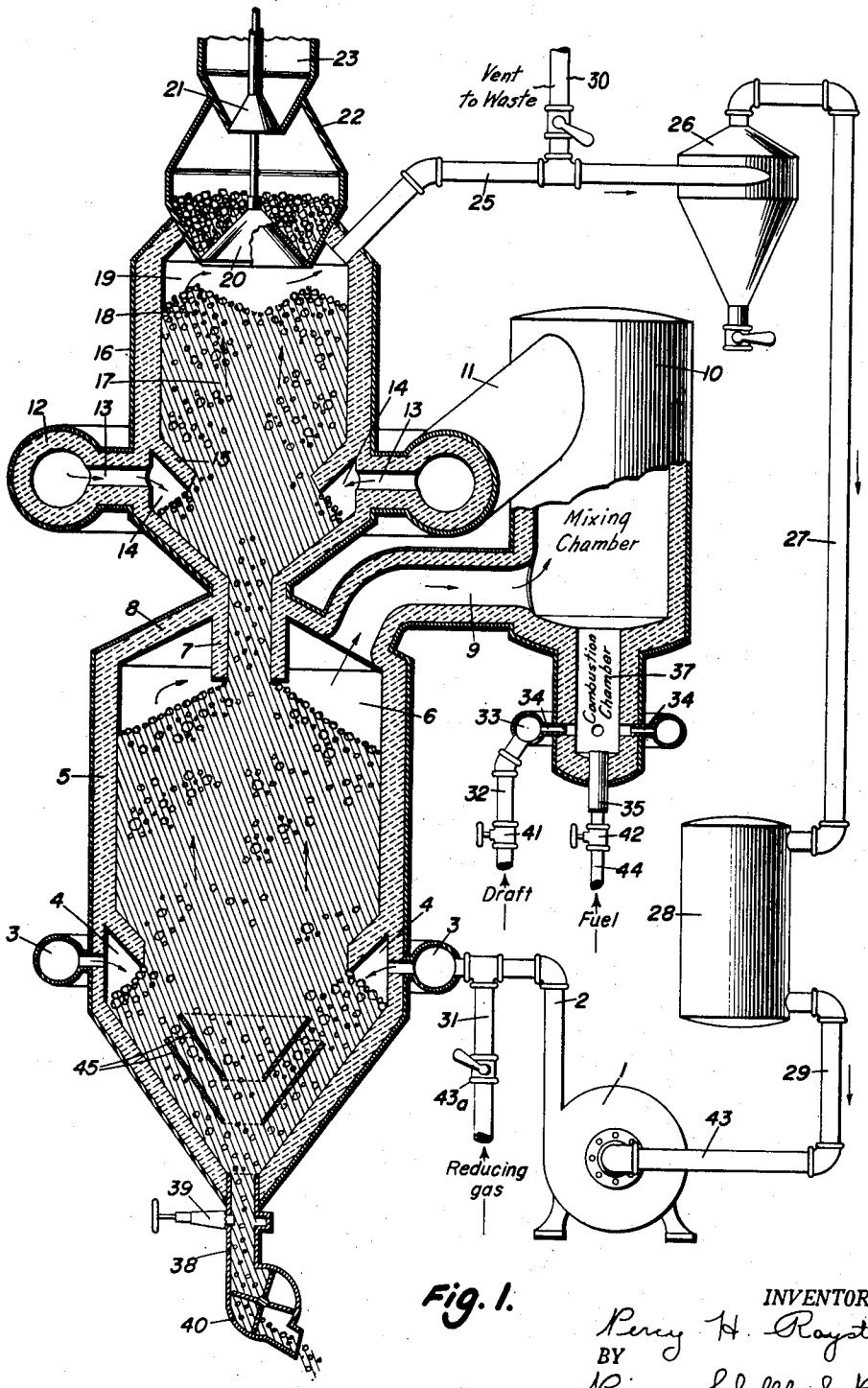

Fig. 1.

INVENTOR
Percy H. Royster
BY
Pierce Scheffler & Parker
Attorneys

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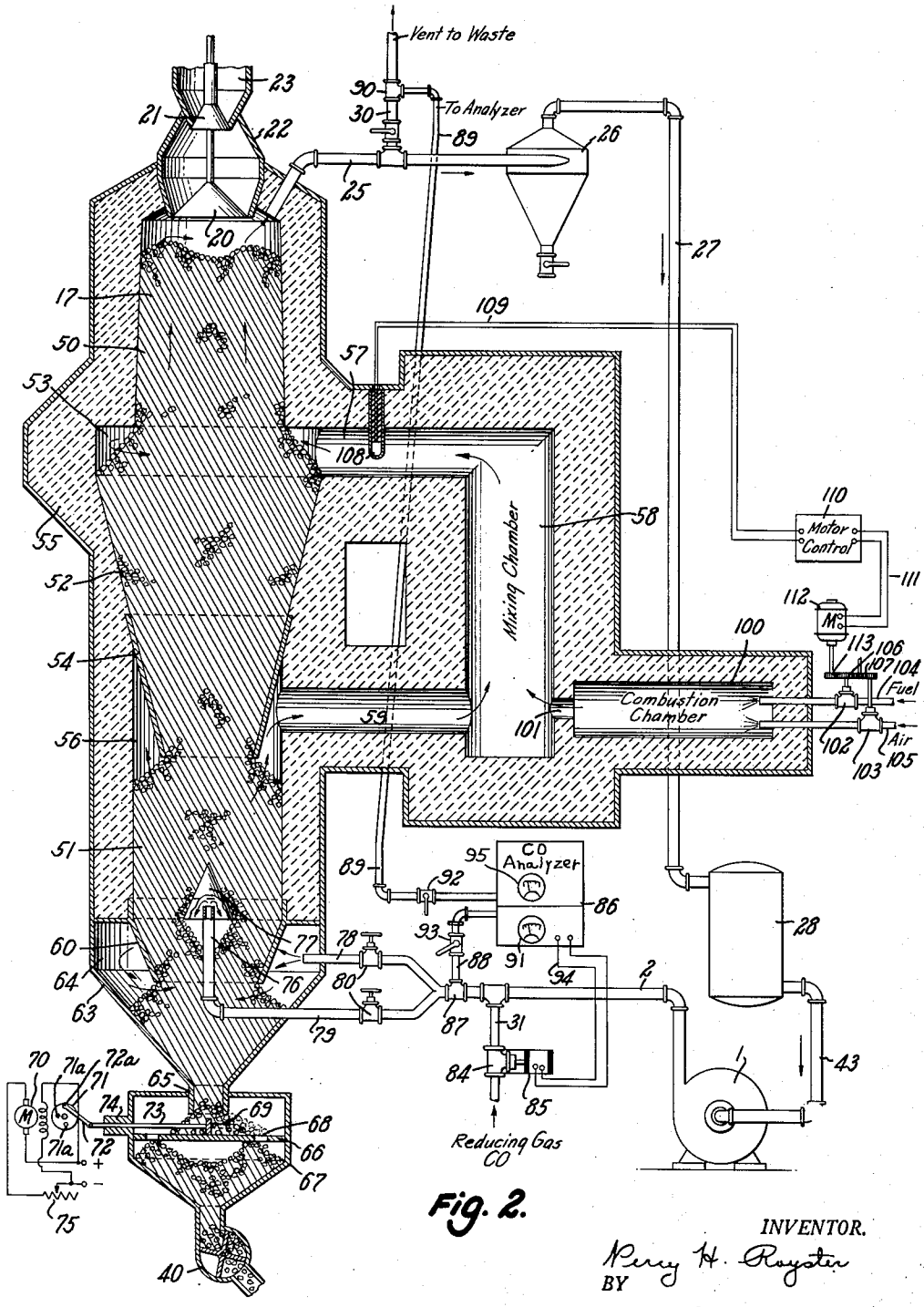

Fig. 2.

INVENTOR.
Percy H. Royster
BY
Pierce Scheffler & Parker
Attorneys

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UNITED STATES PATENT OFFICE

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APPARATUS FOR MAGNETIC ROASTING

Percy H. Royster, Chevy Chase, Md., assignor to Pickands Mather & Co., Cleveland, Ohio, a copartnership

Application October 31, 1950, Serial No. 193,249

4 Claims. (Cl. 266—20)

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This invention relates to the magnetic roasting of ferruginous ores and ore material initially containing substantial amounts of relatively non-magnetic oxidic compounds of iron. The invention concerns a development related to the process described in my copending application Serial No. 695,914, filed September 10, 1946 (Patent No. 2,528,552), and Serial No. 710,747, filed November 19, 1946 (Patent No. 2,528,553), of which latter the present application is a continuation-in-part. In particular, the present invention is concerned with an improved apparatus for thermal treatment of iron ores as a preliminary step in the magnetic concentration thereof.

It is an object of the present invention to provide a thermally efficient and economic apparatus for magnetically roasting low grade iron ores, and other related minerals, e. g., manganiferous iron ores, non-metallurgical chrome ores and other ores commonly designated as "ferrous," the iron contents of which are relatively non-magnetic. The primary objective of the heat treatment herein proposed is to render naturally non-magnetic minerals adaptable to magnetic concentration. In attaining this objective, I propose to remove not more than one-ninth of the oxygen occurring in ferric oxide. That is to say, I propose to reduce the initial ferric oxide largely to magnetite with the specific provision, however, that I cause a minimum of "over reduction"—by which term I mean the carrying of the reduction to a lower state of oxidation than Fe_3O_4—i. e., to produce as little as possible FeO or metallic ("sponge") iron.

According to the present invention, a body of the mineral is caused gravitationally to descend through a first chamber and a second chamber in series. In its descent through the first chamber, the mineral is dehydrated and brought up to reactive temperature, and thereupon all or substantially all of its content of relatively non-magnetic oxidic compounds of iron is reduced to magnetite by means of a current of reactive gas (the composition of which will be described hereinafter, passed countercurrently through the body of mineral. The hot mineral discharged from the first chamber is passed to the second, wherein during its descent therethrough the hot mineral is cooled by means of a countercurrently moving initially relatively cool current of the aforesaid gas. Preferably, the aforesaid first and second chambers are the upper and lower chambers of a substantially vertical shaft furnace—generally similar to that described and illustrated in my copending application Serial

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No. 605,861 (Patent No. 2,533,152)—characterized by an intermediate zone of reduced cross-sectional area communicating between the upper and lower chambers.

It is an essential feature of the present invention that the furnace structure is so arranged that a large part of the gas after its upward passage through the lower chamber is diverted from the latter and is caused to traverse a mixing chamber which receives hot combustion gases from a combustion chamber wherein fuel combustion is maintained. Heat is thus imparted to the gas stream in the mixing chamber, after which "thermal boosting" and gas is introduced adjacent to the bottom of the upper chamber and passes upwardly in countercurrent thermal and chemical relationship with the ore materials descending therethrough.

A significant feature of the present invention is the realization of "thermodynamically restrained" reduction. The ferric oxide content of the mineral is subjected to chemical interaction with a reactive gas, the composition of which is carefully controlled to present concentrations of CO_2, CO, H_2, and H_2O in such proportions that the only thermodynamically stable phase in the quartenary system Fe—C—H—O is Fe_3O_4. When I start, therefore, with ferric oxide, the reducing action of the reactive gas can convert Fe_2O_3 into Fe_3O_4 only, and "over reduction" to form FeO and Fe is chemically impossible regardless of the amount of reactive gas employed, the temperature of the gas or the time and intimacy of the contact between the gas and solid. In order to achieve this desired result, a large portion of the gas discharging from the first or upper chamber (after passage through the two chambers in series) after the removal of suspended dust, the condensation of excess moisture and cooling, is caused to re-enter the system adjacent the bottom of the lower chamber. I: (1) bleed to waste a part of this discharged gas, (2) introduce into it a controlled amount of reducing gas whereby to produce an "enriched carrier gas," which I force upwardly through the lower chamber; (3) remove the major portion of the gas after passage through the lower chamber and transfer it into a mixing chamber connected with a combustion chamber into which (4) I inject a suitable fuel, e. g., oil, natural gas, powdered coke, blast furnace gas, coke-oven gas, or other industrial fuel, while at the same time (5) introducing a restricted amount of draft air, controlled in amount to provide, as nearly as possible, just enough oxygen to convert the combusti-

bles of the fuel into CO_2 and H_2O without causing a residual excess remanent amount of oxygen; and (6) reintroduce this gas from the mixing chamber into the bottom of the upper chamber.

A further object of the present invention is to provide for automatic control over the flow of the make-up reducing gas into the gas circulating system to the end that the circulating gas will be maintained at a substantially uniform richness in CO.

Yet another object is to provide automatic control of the combustion chamber unit so that a substantially uniform gas temperature is maintained as well as a constant ratio of fuel to combustion air which will assure complete combustion without any remnant free oxygen.

The novel apparatus for carrying out the process covered by the claims of my aforesaid parent application Serial 710,747, will be more readily understood by reference to the following specific description taken in conjunction with the appended drawings in which Fig. 1 is a somewhat diagrammatic representation of one embodiment with the furnace component shown in vertical central section. Fig. 2 is a view similar to Fig. 1 illustrating a modified construction for the furnace component and showing additional automatic controls for regulating admission of the make-up reducing gas and controlling the fuel-air input to the combustion chamber.

With reference now in particular to Fig. 1, the recirculating carrier gas is forced by a motor-driven blower 1, into which it is admitted by conduit 43, through cold gas inlet conduit 2 into bustle pipe 3 surrounding the second or lower cylindrical reaction chamber 5. Reducing gas, in amount controlled by the proper setting of valve 43a, enters inlet conduit 2 by way of conduit 31 from a source (not shown) of such reducing gas, commingling with the recirculating carrier gas to constitute the "enriched carrier gas" before its entrance into bustle pipe 3. A plurality of openings spaced circumferentially about chamber 5 permits the flow of enriched carrier gas from bustle pipe 3 into annular open space 4 within chamber 5, from which latter space the gas flows into the column of ore descending through 5, and passes upwardly therethrough. Chamber 5 is so constructed as to provide an open space 6 at its top, which space 6 serves as a gas-collecting space to receive the gas passing upwardly through the ore column in chamber 5. The gas flows from space 6 through transfer conduit 9 into mixing chamber 10 wherein its temperature is raised in suitable amount by hot combustion gases produced in a combustion chamber 37 and delivered to the lower end of chamber 10. The resulting thermally enhanced enriched carrier gas discharges from mixing chamber 10, through conduit 11 into bustle pipe 12 positioned around upper cylindrical chamber 16 adjacent the bottom of the latter. A plurality of circumferentially spaced, thermally insulated blow pipes 13, 13 permit the entrance of gas from bustle pipe 12 into open space 14 positioned annularly about the lower perimeter of chamber 16. The resulting "spent gas" passing from 17 traverses the stockline 18 at the top of column 17, enters open space 19 maintained at the top of, and serving as a gas-collecting space in, chamber 16.

The spent carrier gas discharges from space 19 by way of exhaust main 25; is stripped of entrapped solids (e. g., dust and fume) in passage through dust collector 26; and is transported through clean-gas line 27 into cooler or scrubber 28 wherein its temperature is reduced and excess moisture is removed. In treating ores which produce a large amount of extremely fine dust, it is or may be advantageous to install a Cottrell electrostatic precipitator in the return gas circuit 25, 26, 27, 28 and 29.

Cool, clean, spent carrier gas from scrubber 28 is carried through conduits 29 and 43 to the inlet of blower 1. A sufficient amount of the gas is bled through valved bleed-line 30 tapped from the exhaust main 25 to maintain continuously uniform pressure throughout the closed circuit.

The composition of the spent gas passing through cold gas main 2 generally exhibits a CO_2 content in the neighborhood of 20 to 25%. After passage through chamber 5, the gas exhausting through conduit 9 contains large amounts of CO_2 and H_2O which would tend to "smother" combustion if also done in mixing chamber 10. For this reason I prefer to combust the fuel and air in the separate chamber 37. I introduce draft air through draft main 32 into bustle pipe 33 from which the draft is conveyed through the plurality of conduits 34, 34 into the combustion chamber 37. Fuel is introduced into chamber 37 by means of water-cooled burner 35. The relative amounts of fuel and draft air forced into chamber 37 are carefully controlled by regulating the opening of draft valve 41 and the opening of fuel valve 42 whereby, as exactly as possible, just sufficient draft oxygen is introduced to effect the perfect combustion of the fuel. I prefer to employ an automatic control of these two valves actuated by orifices (not shown in Fig. 1) positioned in draft main 32 and fuel main 44.

The ore material to be magnetically roasted is charged into hopper 23 of the double bell-and-hopper feed equipment illustrated at top of chamber 16. By opening the little bell 21, charge material is introduced into gas seal 22, wherein it rests on the big bell 20. At suitable frequent intervals bell 20 is lowered, permitting the material in the gas seal to fall on the stockline 18 of the charge column 17 in chamber 16. The big and little bells and gas seal illustrated in the drawings are of the type conventionally employed in blast furnace practice. I contemplate, in many instances, using in lieu of the illustrated bell-and-hopper feed equipment any one or more of the conventional types of charging equipment employed in gas producers, which may variously be chain conveyors, belt conveyors, rotating disks, star-gates, or the like.

In describing the column of charge material contained in chambers 5 and 16 as "continuously descending" I construe the latter term specifically to include, of course, a downward motion of these charge columns taking place intermittently in recurrent steps, since the overall effect of such interrupted descent is identical with that experienced with an uninterrupted continuously downward flow of solids.

The provision of the gas-collecting plenum chamber 6 above the charge column in chamber 5 is an essential feature of the present apparatus. The volume of space 6 should be ample, in relation to the volume of gas discharging from the charge column in chamber 5, to promote maximum uniformity of flow of gas through this column. Such ample space can be provided by positioning the refractory tube 7 in the top of chamber 5, the length of conduit 7 being sufficient to maintain the upper free surface of the

lower charge column at a suitable distance from the conical top 8 of chamber 5. The connecting conduit 7, which I term herein the "isthmus," should be relatively small in cross-sectional area compared with the cross-sectional areas of chambers 5 and 16. In order to reduce the amount of gas flowing upwardly from chamber 5 to chamber 16 by way of this isthmus, the major portion of this gas stream may be diverted through conduit 9 to combustion chamber 10.

It should be noted that if substantial amounts of gas were to flow upwardly through conduit 7 into chamber 16, this portion of the gas would arrive at the bottom of the charge column 17 with a gas composition which would differ from the composition of the gas entering the column from annular open space 14. Were such short-circuited gas to leak from chamber 5 through isthmus 7 into chamber 16 in relatively large amount, objectionable irregularity in gas composition would be encountered, which irregularity would have an adverse effect on the efficiency of reduction in chamber 16. The exact dimensions of isthmus 7 would depend on the size of the ore particles being treated and on their physical characteristics: the diameter of isthmus 7 should be sufficiently large to avoid mechanical jamming of the material flowing therethrough.

In Fig. 1 of the drawing I have shown a mechanism for removing the finished solid product from the bottom of chamber 5. Ore leaves the inverted conical bottom of chamber 5 through discharge conduit 38, at a rate controlled by the speed of revolution of the impeller in star-gate 40. This star-gate is preferably actuated by a variable speed geared motor. The rate at which the ore material is moved through the duplex shaft furnace can thus be controlled by suitable adjustment in the speed of the star-gate motor. It is convenient to provide a shut-off valve 39 positioned in discharge conduit 38 whereby the flow of material therethrough can be completely stopped.

In order to attain maximum thermal efficiency for the present process, it is essential to realize a maximum uniformity of flow both in regard to the upward flow of gas in chambers 5 and 16 and in regard to the downward flow of solids in these chambers. Since the finished product moving through the hopper-bottom of chamber 5 is at a relatively low temperature, I generally prefer to install adjacent this hopper-bottom a plurality of inverted truncated cones 45, 45, made of sheet steel or of cast iron. These conical baffles are dimensioned, and positioned concentrically with respect to the cone of the hopper-bottom, whereby to promote uniformity of flow of solids in chamber 5. The device has long been known and its use is conventional. I have not shown similar conical baffles positioned in the conical bottom of upper chamber 16 since, in the more usual case, I do not recommend their use there. It is true that increased uniformity of solid flow (and therefore of gas flow) is promoted by such baffles, but, because of the higher temperature prevailing in the bottom of chamber 16, operating difficulties are sometimes encountered in maintaining these baffles in actual practice. I do not, however, disclaim the use of such baffles in upper chamber 16.

The operation of my present apparatus can perhaps be best described in terms of specific examples of ore material treated therein.

Example

The starting material is a lean hematite ore which exhibits the following analysis, on a dry basis:

Fe_2O_3	67.50
MnO_2	0.22
P_2O_5	0.08
SiO_2	22.15
Al_2O_3	4.43
CaO	0.41
MgO	0.18
CO_2	0.47
Combined water	4.48
Alkali	0.08
Moisture as received	15.25

This ore contains 15.25% moisture as charged. The apparatus as shown in the accompanying drawing has the following dimensions: upper chamber 16 has inside diameter of 20 feet and a vertical height between open space 14 and stock-line 18 of 16 feet. Ore is charged at the rate of 1590 gross tons (G. T.) per 24-hour day. Blower 1 forces 14,430 cu. ft./min. (standard conditions, 60° F., 29.92 inches Hg) of cold, clean spent carrier gas through cold gas conduit 2. This gas has the following composition:

CO_2	21.68
CO	0.57
H_2	0.06
H_2O	4.05
N_2	73.64

Reducing gas is forced through valved conduit 31 into conduit 2. This gas has the following composition:

CO_2	0.62
CO	34.28
H_2	1.84
H_2O	0.36
N_2	62.80

The above reducing gas may be, and preferably is, produced in a slagging type gas producer. The recirculating carrier gas and the reducing gas commingle and flow into the bustle pipe 3 with the following gas composition.

CO_2	18.11
CO	6.56
H_2	0.36
H_2O	3.46
N_2	71.51

This "enriched carrier gas" flows at the rate of 17,393 cu. ft./min. upwardly through chamber 5, and, discharging through open space 6, flows through conduit 9 into mixing chamber 10. Fuel oil is forced through burner 35 at the rate of 4.38 gallons per minute, and 5860 cu. ft. of draft air is forced (by a draft blower, not shown) through bustle pipe 33 and blow pipes 34, 34 into auxiliary combustion chamber 37. The products of this fuel combustion commingle with the gas entering through conduit 9, attaining uniformity of composition in chamber 10, and discharge through conduit 11, with the following analysis:

CO_2	16.71
CO	4.67
H_2	0.26
H_2O	6.42
N_2	71.94

This thermally enhanced enriched carrier gas

flows into bustle pipe 12 at the rate of 23,630 cu. ft./min., and passes by way of blow pipes 13, 13 into open space 14 and thence enters charge column 17 by passage under the inverted truncated concentric conical shield 15. As this gas ascends the descending ore column 17, reduction is effected in the lower portion of chamber 16, and the "spent gas" resulting from this reduction in passing through the ore in the neighborhood of stockline 18 dehydrates the combined water associated with the Fe_2O_3 and evaporates the moisture content of the ore. The water vapor removed in the present case is 9700 cu. ft./min. (measured at 60° F. and 29.92 in. Hg). The resulting wet spent gas discharging through open space 19 and discharge conduit 25 has the following analysis:

CO_2	14.83
CO	0.16
H_2	0.02
H_2O	34.48
N_2	50.51

This gas, after passage through dust collector 26, is cooled to about 85° F. by passage through scrubber 28 and the large amount of water evaporated from the ore is condensed therein and removed from the gas.

Before cleaning and cooling the spent gas, I bleed through bleed main 30 about 8600 cubic feet per minute of such gas and return the remainder through conduit 43 to blower 1.

The evaporation of moisture from the ore and the dehydration of the material therein, in the present instance, absorb a large amount of heat, viz., 455,000 B. t. u. per minute. To a large extent, this absorption of heat is compensated by the production of 310,000 B. t. u. per minute of heat generated by the exothermic reduction of Fe_2O_3 to Fe_3O_4 by the combined action of the CO and the H_2 of the enriched carrier gas. The net thermal effect of these two factors, however, is that 145,000 B. t. u. per minute of heat are absorbed.

The fuel requirements of the process are largely dominated by the loss of heat experienced from discharging the spent gas through conduit 25, and the finished solid product through conduit 38, at temperatures above atmospheric. The spent gas discharges from open space 19 at 395° F., thus carrying away 230,000 B. t. u./min. The solids are discharged through conduit 38 at 510° F., corresponding to a heat loss of 151,000 B. t. u./min.; thus bringing the thermal requirements of the process up to 526,000 B. t. u./min. A considerable loss of heat through the bricklining of the two chambers and the combustion zone is experienced, amounting to 19,000 B. t. u./min. The total thermal input required to maintain the apparatus at a steady state is, therefore, 545,000 B. t. u./min.

It should be observed that the cooling effect of the enriched carrier gas ascending through the column in reaction chamber 5 is insufficient to cool the solid particles to a nearer approach to atmospheric temperature than the 510° F. indicated above, due to the excess heat capacity of the solids above the 17,000 cu. ft./min. of gas ascending therethrough. It is, of course, possible to increase the amount of recirculating carrier gas, thereby reducing the temperature of the solids discharged through conduit 38 and thereby decreasing the loss of heat due to the discharge of heated solids. However, when the volume of recirculated gas is increased with the same flow of solids through the apparatus, the heat capacity of the gas traversing upper chamber 16 exceeds the amount of heat required to heat the solids descending therethrough and the temperature of the gas discharging from stockline 18 is increased. Considerable latitude is permissible in regulating the amount of carrier gas which is recirculated per ton of ore charged. The requirements for maximum thermal efficiency are: (1) the amount of reducing gas introduced through conduit 31 shall be proportioned with respect to the iron content of charged material and to the degree of conversion from Fe_2O_3 to Fe_3O_4 which is desired, whereby to attain a high efficiency of utilization of the reducing gas; and (2) the amount of fuel introduced through burner 35 and of draft through bustle pipe 33 shall be proportioned so that complete combustion of the fuel will be realized without remanent excess of oxygen or of unburned combustibles.

With regard to requirement "1" above, if more CO and/or H_2 is introduced through conduit 31 in enriching the carrier gas than is required to effect the conversion of all the ferric oxide in the ore to magnetite, the excess CO and H_2 will remain unoxidized and will be discharged through exhaust conduit 25, thus wasting the excess reducing agent.

In the above illustration, the reducing gas employed is the product of a slagging type gas producer and the fuel is a petroleum liquid. This selection of reducing gas and fuel is appropriate to operations carried out at an iron mine, e. g., in the Lake Superior region, distant from sources of natural gas, coal and coke and other industrial fuels. Whenever the ore mine is located near a blast furnace and steel plant, it may be advantageous to use producer gas both as reducing agent and as fuel. Where natural gas is available, this natural gas may readily enough be used as fuel, and the reducing gas may readily enough be relative pure H_2 obtained by the thermal decomposition of the natural gas. Innumerable combinations of reducing gas and fuel appear appropriate, depending on the geographical location and character of the ore to be treated.

A modified construction for the furnace apparatus and controls is illustrated in Fig. 2 and, for convenience in comparison with the construction of Fig. 1, those components which are of like construction in both Figs. 1 and 2 bear like reference numerals.

With reference now to Fig. 2, the ore treating furnace proper from a viewpoint of construction principles is basically the same as that shown in Fig. 1, the principal differences between the two residing in the configuration of the section or isthmus of restricted cross-section connecting the upper and lower furnace chambers, the arrangement for admitting carrier gas to such chambers, and the arrangement of the combustion chamber.

In Fig. 2, the vertical furnace includes an upper chamber 50, a lower chamber 51, and a chamber 52 intermediate the upper and lower chambers all being in vertical alignment and preferably cylindrical in transverse section. The wall of upper chamber 50 preferably has a slight, diverging taper in the downward direction and ore 17 to be treated is admitted into the top of chamber 50 by way of hopper 23 and double bells 20, 21 as previously described with reference to the Fig. 1 furnace.

The intermediate chamber 52 is generally conical with the wall preferably converging (as measured in the downward direction) at an angle of not more than 15° from vertical to assure free flow of the ore along the wall and thus eliminate the possibility of forming stagnant ore. The upper end of intermediate chamber 52 is larger in diameter than the lower, discharge end of upper chamber 50 at the junction between the two thus establishing an upper annular plenum space 53 into which the hot carrier gases are delivered from conduit 57 leading from the vertically disposed mixing chamber 58.

At the discharge end of chamber 52 there is provided a conical shell 54 preferably made from a good heat resisting material such as "Inconel," a high nickel ferrous alloy that will retain its shape and strength under the temperatures and loading conditions encountered in the furnace. The wall of insert 54, which forms a continuation of the brickword wall portion 55 of chamber 52, extends for a considerable distance into the lower chamber 51 and since the lower discharge end of shell 54 is of smaller diameter than that of lower chamber 51, a second, intermediate annular plenum space 56 is established at the upper end of chamber 51 for collecting and discharging enriched carrier gases preheated by the ore charge in chamber 51 into a gas diverting conduit 59 which leads to the lower entrance end of mixing chamber 58.

The discharge end of lower chamber 51 is fitted with a tapered metallic shell 60, converging in the downward direction which discharges into a larger convergingly tapered shell 63 to thereby establish a third, lower annular plenum space 64 into which relatively cool enriched carrier gas is delivered for flow upwardly through the downwardly descending ore column 17 in chamber 51.

The lower vertical discharge mouth 65 of shell 63 empties the ore onto a horizontal plate 66 supported directly beneath mouth 65 by the side walls of a discharge chamber 67, the plate 66 being provided with a plurality of apertures 68 through which ore drops into the lower end of shell 67 for final discharge through star gate 40. A rake 69 is arranged to reciprocate across the upper face of plate 66 by means of a motorized drive consisting of a variable speed motor 70 driving an eccentric plate 71 to which is coupled one end of crank 72, the other end of crank 72 being connected to the rake handle 73 which slides in bearing sleeve 74. Eccentric plate 71 is preferably provided with a plurality of apertures 71*a* at different radial distances from the center of rotation usable selectively to receive the coupling pin 72*a* of crank 72 so that the stroke of the rake can be correspondingly adjusted, and motor 70 is provided with a variable resistance 75 in its armature circuit so that the frequency with which rake 69 reciprocates can also be adjusted. These two controls for the rake are used to regulate the rate at which the ore column will be permitted to descend through the furnace structure, and the considerable height of the ore column below plenum space 64 in combination with the air tight shell 63 and chamber 67 set up a back pressure sufficient to prevent any appreciable loss of enriched carrier gas entering chamber 64 downwardly through the discharge gate 40.

In addition to introduction of enriched carrier gas into plenum space 64, such gas is also introduced directly into the body of ore in chamber 51 by means of a pipe 76 arranged vertically and centrally within chamber 51, a conical shield 77 being provided over the outlet end of the pipe to facilitate distribution of the gas and preventing clogging of the pipe by ore.

As in the Fig. 1 construction, spent carrier gas discharges from the upper end of upper chamber 50 by way of exhaust conduit 25, stripped of solids in dust collector 26, transported through conduit 27 into cooler or scrubber 28 where its temperature is reduced and excess moisture is removed, and thence delivered through conduit 43 to the suction side of lower 1. Also as in Fig. 1, a sufficient amount of the carrier gas is bled through the bleed conduit 30 tapped from exhaust conduit 25 to maintain continuously uniform pressures throughout the closed circuit.

From the pressure side of blower 1, cool and clean carrier gas is transported through conduit 2 and distributed by a Y joint to a branch conduit 78 leading to plenum chamber 64 and branch conduit 79 leading to the vertical pipe 76. Preferably adjustable valves 80 are interposed in the conduits 78, 79 to adjust the division of the total gas in conduit 2 between branch conduits 78, 79.

Reducing gas (rich in CO), in sufficient quantity to replace that used in the reduction of the manganese and iron oxides and the small amount lost through the bleed line 30 to the end that the carrier gas will always be of the same "richness" when entering the furnace, is admitted to conduit 2 through supply pipe 31 in which is located a valve 84 controlled by solenoid 85.

Provision is made in Fig. 2 for continuously analyzing the enriched carrier gas just prior to entering the furnace, and automatically regulating the flow of reducing gas into the gas system at this point in accordance with the gas analysis so that a substantially uniform degree of "richness" is maintained. For this purpose I preferably use an industrial type of gas analyzer known to the trade as a Bailey meter. The construction of the meter is well known and hence in the interest of simplifying the drawings has been illustrated simply by box 86. The CO enriched carrier gas is tapped from the circulating system just prior to entering the furnace by a T connection 87 and carried through conduit 88, which may include a shut-off cock 93, to the analyzer 86. The CO content of the enriched carrier gas can be recorded or as shown registered on meter 91. For automatic control purposes, there is also produced a control voltage variable inversely with the departure of the CO content of the enriched carrier gas from the predetermined degree of richness desired to be maintained, and such voltage is applied over line 94 to the solenoid 85 controlling the degree of opening of the valve 84 in the CO gas supply line 31. Hence valve 84 will be moved to a more open position with increased energization of solenoid 85 as the CO content of the enriched carrier gas drops below the predetermined value desired to be maintained, and conversely, valve 84 will move to a more closed position whenever the CO content rises above the predetermined value.

Provision is also made for continuously analyzing and indicating the CO content of the minor fraction of spent gas vented to waste through pipe 30. To this end there is provided a conduit 89 extending from T connection 90 in pipe 30 to the analyzer 86, and the CO content is read on meter 95. Conduit 89 may also include a shut-off cock 92.

For heating the enriched carrier gas where the larger portion of it leaves the lower chamber 51 (since plenum chamber 56 and conduit 59 offer

a path far less resistant to gas flow than the ore column restricted in cross sectional area at the relatively small discharge end of cone 54), I provide a combustion chamber 100 disposed horizontally. Fuel and combustion air enter chamber 100 from the right end as viewed in the drawing, and the hot combustion gas leaves chamber 100 through a constricted outlet 101 that discharges into the lower end of mixing chamber 58 opposite the discharge end of conduit 59. The enriched carrier gas entering chamber 58 through conduit 59 thus mingles intimately with and is heated by the combustion gases discharged through the restricted outlet 101. The restriction 101 assures complete combustion within the combustion chamber proper and prevents the flame from being blown out by the carrier gas sweeping into mixing chamber 58.

As previously expained with respect to the Fig. 1 construction, it is most desirable to maintain such a ratio between fuel and combustion air that just enough oxygen is introduced to convert all the combustibles of the fuel into CO_2 and H_2O without causing any residual excess of free oxygen. To this end I have shown gear actuated valves 102, 103 in the fuel and air conduits 104, 105 respectively, the gear 106 of valve 102 being meshed with the gear 107 of valve 103, and the two gears being so sized as to maintain the desired ratio of fuel-to-air flow into combustion chamber 100 throughout the range of fuel and air adjustment.

It is also preferable to maintain the thermally enhanced enriched carrier gas discharging through conduit 57 into plenum chamber 53 at a constant temperature. To this end, a temperature sensing device such as thermocouple 108 placed in conduit 57 is electrically connected by wires 109 to a control unit 110 of conventional design and which therefore has been illustrated only in "block" form. Control unit 110 translates departures in temperature in conduit 57 measured by thermocouple 108 from a predetermined temperature level into control voltages which feed over wires 111 to motor 112 and cause the shaft of the latter to rotate in one direction or the other dependent upon the sense of the departure in temperature of the gas in conduit 57 from the predetermined value desired to be maintained. The shaft of motor 112 drives gear 113 which meshes with gear 106 and hence valves 102, 103 controlling flow of fuel and air, respectively will be regulated simultaneously and automatically to vary the fuel and air as may be necessary to maintain constant gas temperature in conduit 57. Basically, the modified furnace construction shown in Fig. 2 operates in the same manner as has already been explained in connection with the Fig. 1 embodiment and hence no further description of operational details is deemed necessary.

In conclusion, I wish it to be understood that the two embodiments of the improved furnace structure which have been described and illustrated are to be considered as typical rather than limitative and hence may be subjected to various changes in the construction and arrangement of component parts without departing from the spirit and scope of the invention as defined in the appended claims.

I claim:

1. Apparatus for treating ferruginous ore material, wherein the iron content consists mainly of a non-magnetic oxidic compound of iron, with reducing gas to render the ore material adaptable for magnetic concentration, said apparatus comprising, a pair of superposed ore treating chambers, gas-tight means for feeding ore to be treated to the upper end of said upper chamber, gas-tight means for extracting treated ore from the bottom of said lower chamber, means adjacent the lower ends of said chambers to provide lower open spaces adjacent lower free surfaces of a column of ore therein, a passageway conduit connecting the lower end of said upper chamber with the upper end of said lower chamber for gravitational feed of ore from the upper to the lower chambers, the relationship between the lower end of said passageway conduit and the upper walls of said lower chamber being such as to define an upper open space of substantial extent above the upper free surface of a bed of ore in said lower treating chamber when the latter is filled to the highest level attainable by gravitational feed of ore through said passageway conduit, means for feeding a reducing gas to the lower open space of said lower chamber for upward flow through and extraction of heat from the bed of ore contained therein, a mixing chamber, a conduit leading from the upper open space of said lower chamber to the inlet end of said mixing chamber, a conduit leading from the outlet end of said mixing chamber to the lower free space of said upper chamber for delivering thermally enhanced reducing gas to the latter for passage upwardly through a bed of ore in said upper chamber to effect the conditioning, heating and reduction thereof, a combustion chamber disposed adjacent said mixing chamber and adapted to supply hot combustion gases to said mixing chamber, a conduit leading from the upper end of said upper chamber for exhausting spent reducing gas and entrained moisture therefrom, a scrubber for said spent reducing gas connected to the last mentioned conduit, means in said last mentioned conduit for bleeding off spent reducing gas, a conduit connecting said scrubber with said gas feeding means, and means for adding replenishment reducing gas to the gas fed to the lower open space of said lower chamber by the aforementioned reducing gas feeding means.

2. Apparatus for treating ferruginous ore material, wherein the iron content consists mainly of a non-magnetic oxidic compound of iron, with reducing gas to render the ore material adaptable for magnetic concentration, said apparatus comprising interconnected upper, intermediate and lower ore treating chambers arranged in vertical superposed relation and adapted to be substantially filled with a column of the ore, said intermediate chamber having a converging taper as measured in the downward direction of not more than 15° from vertical, the upper inlet end of said intermediate chamber being larger than the adjacent outlet end of said upper chamber to thereby establish a first plenum space at the junction of said upper and intermediate chambers, and the lower outlet end of said intermediate chamber being smaller than and penetrating the inlet end of said lower chamber to thereby establish a second plenum space between the walls of the intermediate and lower chambers, gas-tight means for feeding ore to be treated onto the stockline of the ore column in said upper chamber, gas-tight means for extracting treated ore from the bottom of said lower chamber whereby said ore column will be caused to descend gravitationally through said chambers, gas conduit means interconnecting the top of said upper

chamber and the bottom of said lower chamber, a vertical mixing chamber, gas conduits connecting said first and second plenum spaces respectively with the upper outlet and lower inlet ends of said mixing chamber, a horizontal combustion chamber disposed adjacent the lower end of said mixing chamber, the combustion gases passing to said mixing chamber from said combustion chamber through an outlet of restricted area, means admitting fuel and air to said combustion chamber in a predetermined ratio for producing combustion gases without an excess of oxygen, said ore treating chambers, said mixing chamber, said gas conduits and said gas conduit means forming a substantially closed circuit for the circulation of reducing gas upwardly through said chambers, a recirculating pump in said gas circuit, means for bleeding spent gas from said gas circuit at a locus adjacent the top of said upper chamber, and means for admitting replenishment gas to said gas circuit at a locus intermediate the pressure side of said pump and the bottom of said lower chamber.

3. Apparatus for treating ore material as defined in claim 2 wherein a third plenum space is also provided adjacent the bottom end of said lower chamber, and which further includes a branch conduit discharging a portion of the gas from said conduit means into said third plenum space and a second branch conduit discharging the remainder of the gas from said conduit means directly within said lower chamber.

4. Apparatus for treating iron ore material as defined in claim 2 and which further includes means for extracting and analyzing a sample of the gas in said circuit at a locus adjacent said spent gas bleeding means, and means controlled by said analyzing means for regulating admission of replenishment gas into said gas circuit.

PERCY H. ROYSTER.

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