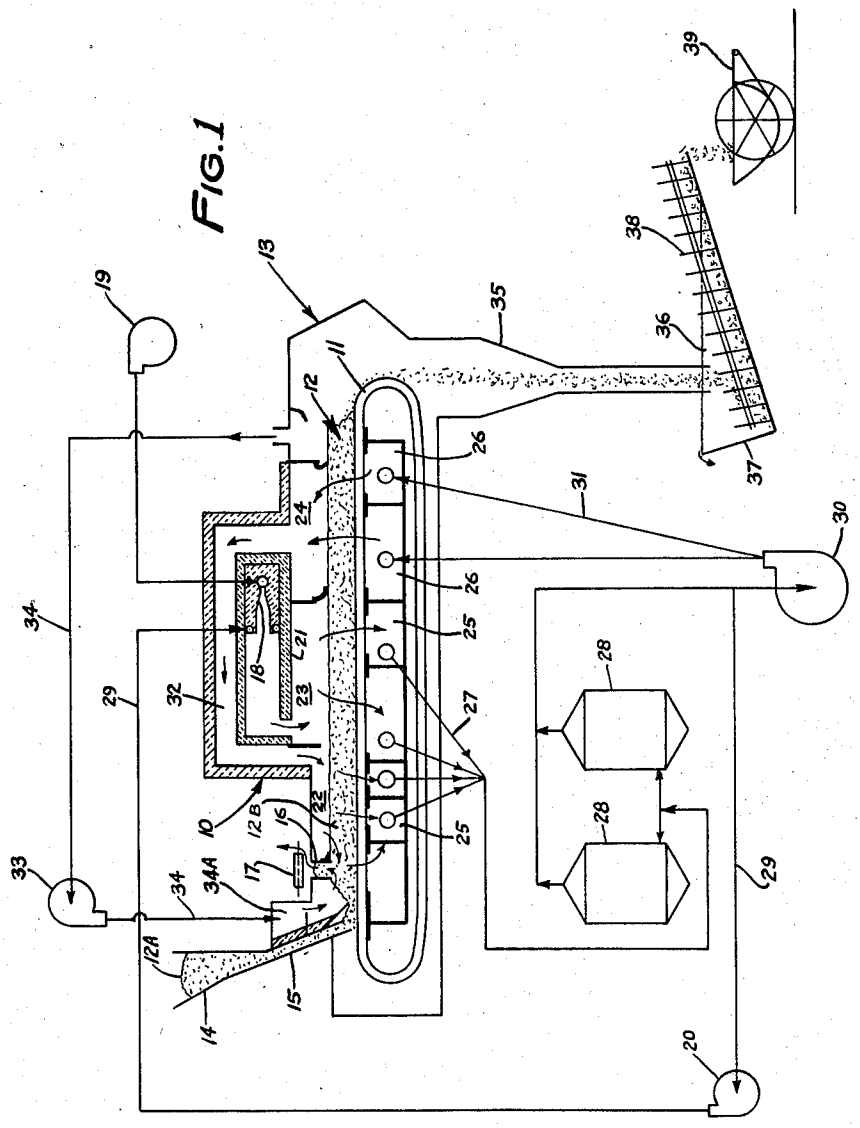
July 19, 1960 N. F. SCHULZ 2,945,755

MAGNETIC ROASTING PROCESS AND APPARATUS

Filed Oct. 31, 1956 5 Sheets-Sheet 1

FIG. 1



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MAGNETIC ROASTING PROCESS AND APPARATUS

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FIG. 2

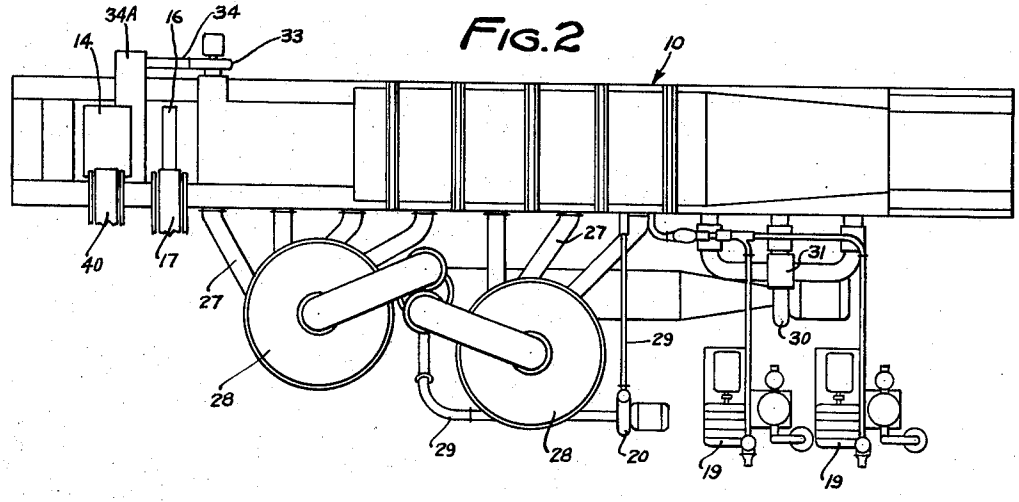
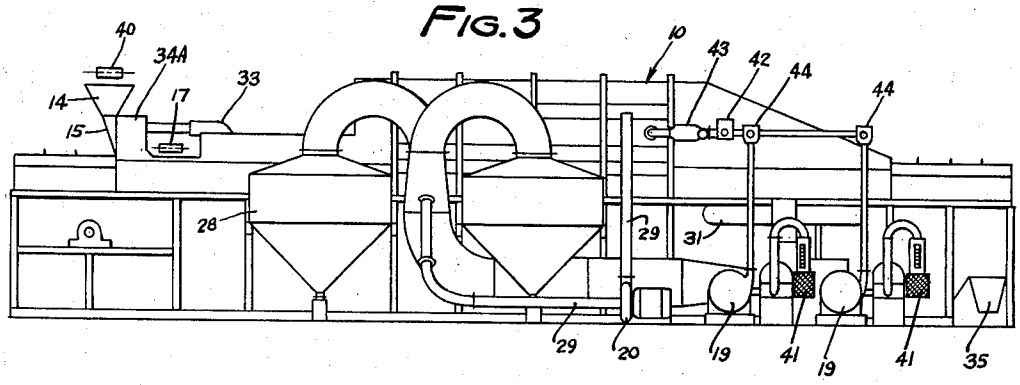


FIG. 3



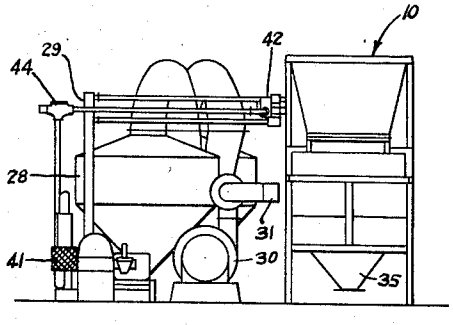


FIG. 4

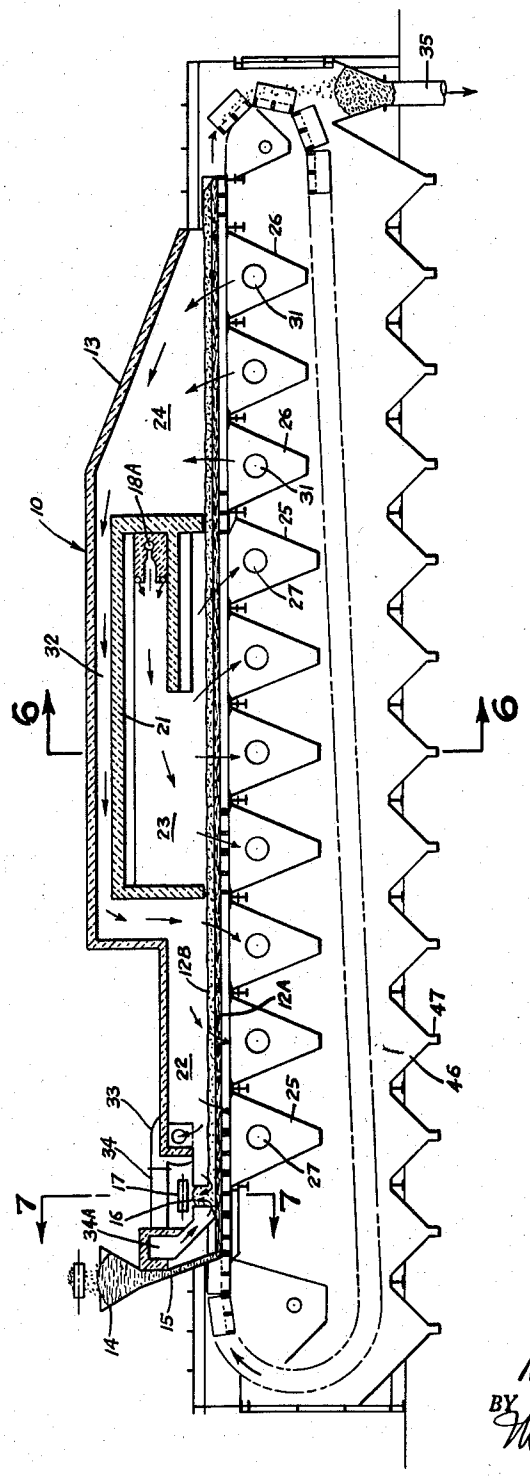
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MAGNETIC ROASTING PROCESS AND APPARATUS

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FIG. 5



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MAGNETIC ROASTING PROCESS AND APPARATUS

Filed Oct. 31, 1956 5 Sheets-Sheet 4

FIG. 6

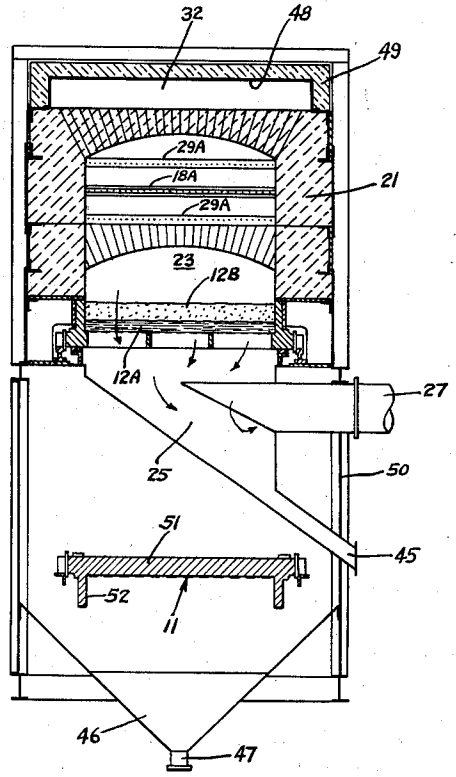
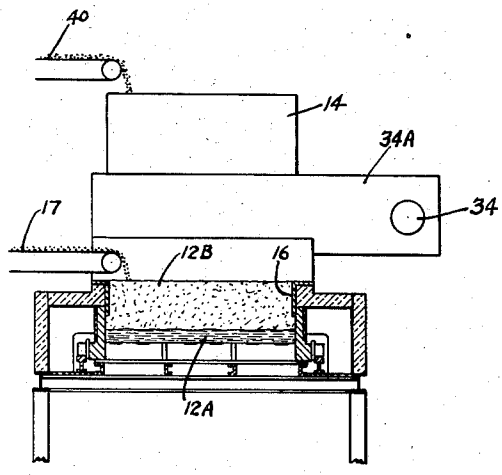


FIG. 7



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MAGNETIC ROASTING PROCESS AND APPARATUS

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FIG. 9

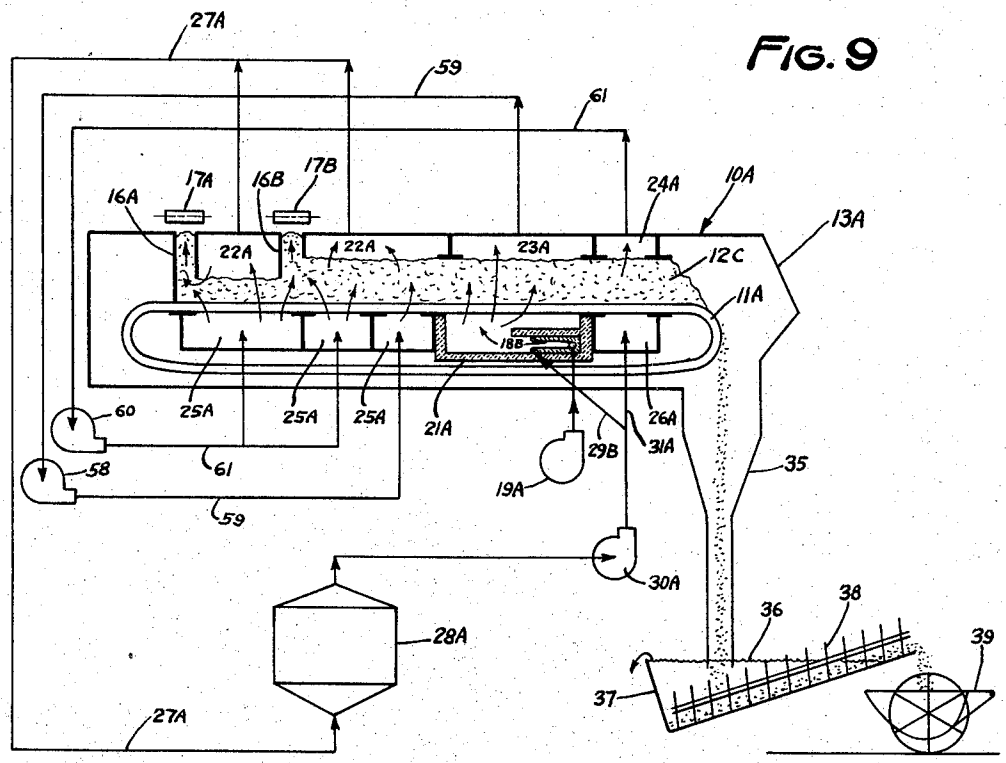
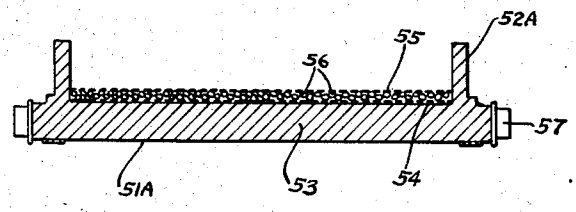


FIG. 8



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2,945,755

MAGNETIC ROASTING PROCESS AND APPARATUS

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Filed Oct. 31, 1956, Ser. No. 619,443

18 Claims. (Cl. 75—1)

This invention relates to a method and apparatus for roasting ores and more particularly to roasting iron ores containing non-magnetic iron oxides to convert those oxides to magnetic oxide.

There are large reserves, in Minnesota and elsewhere, of low grade iron ore which are becoming of increasing interest and importance in our Nation's economy as richer ores and more easily concentrated materials are becoming less readily available. There are large quantities of taconite in which the principal iron minerals are not strongly magnetic and thus do not lend themselves readily to magnetic separation methods. There are also large tonnages of intermediate ore materials in which the iron content is higher than in the average taconite but which also are not magnetic. In some cases, these materials have proven to be difficult to concentrate by simple gravity methods of treatment.

It is well known that the red, very weakly magnetic ferric oxide minerals can be converted to the black, strongly magnetic magnetite by heating the material to a moderate temperature in a reducing atmosphere. Such minerals, after subjection to this type of roasting treatment, can then be concentrated by magnetic separation as presently used to recover concentrate from magnetic taconite.

It is the principal object of this invention to provide an improved method of roasting iron ores to convert the non-magnetic oxides to magnetic oxide and to an improved apparatus for carrying out that process.

Other objects of the invention will become apparent as the description proceeds.

To the accomplishment of the foregoing and related ends, this invention then comprises the features hereinafter fully described and particularly pointed out in the claims, the following description setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principles of the invention may be employed.

The invention is illustrated by the drawings in which the same numerals refer to corresponding parts and in which:

Figure 1 is a schematic representation of a downdraft roasting system showing a vertical section taken on a line extending longitudinally of the furnace;

Figure 2 is a top plan view of one form of downdraft furnace according to this invention;

Figure 3 is a side elevation of that roasting furnace;

Figure 4 is an end view of the discharge end of the furnace;

Figure 5 is an enlarged vertical section taken through the length of the furnace;

Figure 6 is a transverse vertical section taken on line 6—6 of Figure 5 and in the direction of the arrows;

Figure 7 is a similar vertical section taken on line 7—7 of Figure 5 and in the direction of the arrows;

Figure 8 is a transverse vertical section through a modified form of grate pallet; and

Figure 9 is a schematic representation of an updraft roasting system showing a vertical section taken on a line extending longitudinally of the furnace.

Broadly stated, the invention contemplates the roasting of crushed low grade iron ore by passing hot reducing gases vertically through a relatively thin, horizontally moving bed of hot solids and to an improved moving grate furnace for carrying out the roasting. The ore is first crushed to pass about a 1 inch screen and preferably to pass about a ½ inch screen or finer. Because a bed of this crushed ore would be quite resistant to the flow of gases the moist feed is rolled in a balling drum to form the ore into "green" or moist compacts (or balls) in order to improve the permeability of the bed of ore to the flow of gases. This treatment is especially effective with a horizontally moving bed type of operation since the ore particles, after they are once laid in place, have no further relative motion until the chemical reactions are completed and the bed is discharged over the end of the machine.

When using a downdraft furnace, to protect the grates of the roasting furnace from reaching high temperatures which would be harmful, a protective hearth layer of coarse previously treated ore is preferably first laid down on the travelling grate. This hearth layer is desirably about 3–5 inches deep. The prepared agglomerated ore is fed to the traveling grate by means of a shuttle conveyor which distributes it across the width of the furnace. A shallow feed slot provides an opening for the ore to enter and also for an escape of spent gases. The ore to be roasted is desirably laid down as a uniform layer about 5–7 inches deep resting on the hearth layer.

As an alternative, instead of using a hearth layer of previously treated ore, a layer of cast iron or steel balls has been used with satisfactory results. However, as a practical matter, any layer of solid material permeable to gas flow is suitable. High heat transfer surface area and high heat capacity along with mechanical stability are desired. The shape of the particles is immaterial except that spheres give the most permeable and least likely to clog bed while more intricate shapes improve the heat transfer.

The ore is dried, heated and reduced by drawing or forcing hot gases through the relatively thin bed of solids in a direction generally normal to the direction of motion of the grate. The moving grate furnace with a thin permeable bed of ore on the grates makes possible the easier provision of a relatively uniform flow of gases to all parts of the ore layer than does the tall column of a shaft furnace, for example. The spent gases emerging from the bed of ore are warm and are laden with the water extracted from the moist ore feed and from the combustion of hydrocarbon fuel. These gases are cooled to extract most of the water and are returned to the furnace to pass through the bed of reduced ore, extract most of the sensible heat and return it to the feed end of the furnace. Excess spent gas escapes through the feed opening and in doing so gives up most of its sensible heat to the ore and picks up some moisture.

When using the downdraft form of apparaus illustrated and described in Figures 1 through 7 of this application the ore is dried, heated and reduced by drawing the hot gases downwardly through the bed of ore and is cooled by passing the recirculated spent gases upwardly through the ore. The opposite course of flow may be used with equal effectiveness. One of the determining factors in choosing the direction of flow is the tolerance of the equipment to high temperature. If the grates and blowers are designed to withstand temperatures of 1200° F. or more the ore may be dried by updraft in a system such as is illustrated in Figure 9. Be-

cause of the difficulties caused by water condensation drying of the ore is limited to layers of about 6 inch depth. It is possible to dry several 6 inch layers successively by feeding at several points. In this manner it is possible to carry a thicker bed and permit the treatment of a greater tonnage per hour on a given machine.

Although many fuels may be used, it is preferred to use natural gas both as a source of heat and of reducing gas. Natural gas, as such, is a poor reducing agent but it is burned with a deficiency of oxygen to release the necessary heat and the remaining combustibles, carbon monoxide and hydrogen for the most part, are delivered in usable form for reduction purposes. The temperatures are controlled by mixing the gases emerging from the combustion chamber with spent gases. The composition of these gases can be closely controlled so as to provide an effective reducing agent.

The partially cooled, reduced ore is discharged through an enclosed sealing chamber into a water quenching bath to prevent reoxidation. The ore is then in a magnetic form adapted to concentration by well known magnetic separation means.

Referring now to the drawings, in Figure 1 there is shown a schematic representation of one form of the roasting system of this invention operated on downdraft and built around the roasting furnace shown in a vertical longitudinal section. The furnace **10** comprises an endless grate **11** adapted as is well known in the art to be moved continuously in a horizontal path to carry a body of ore **12** on its upper flight longitudinally through the furnace.

This grate may be any one of several types conventionally used in pelletizing furnaces, sintering furnaces, stokers and the like. One of these is an endless chain grate consisting of a pair of tension chains running over head and tail sprockets and carrying rods through the chains on which are mounted many cast iron tuyeres which support the moving bed of ore. The chain and tuyeres slide on cast iron wear plates. In a sintering machine the grate consists of a long series of pallets which are not mechanically connected but are merely pushed along horizontally until they reach the end of the machine where they are carried around on large sprockets to their return track. At the feed end of the machine they are lifted by a mechanically driven sprocket and pushed forward.

The grate is enclosed in a housing indicated generally at **13**. A hopper **14** is positioned at one end of the furnace to contain a supply of previously roasted and screened ore **12A** for feeding through a slot or chute **15** through the housing wall to the grate. Chute **15** is substantially the width of grate **11** to deposit a hearth layer across the entire width of the grate. A second slot or chute **16** located downstream from the first is provided in the furnace housing to feed the unroasted ore **12B** which forms the bulk of the body of ore **12** which is moved through the furnace on the grate. Chute **16** likewise extends substantially the width of the grate and is fed from a shuttle conveyor **17** to maintain a uniform level of ore in the chute.

The downstream edges of the lower ends of chutes **14** and **16** are spaced from the surface of grate **11** by a distance corresponding generally to the desired depth of the ore layer at those points and thus may act as doctors to apply the layers of the desired thicknesses. The upstream edge of the lower end of chute **14** need be just high enough to permit passage of the bare grate **11**. The upstream edge of the lower end of chute **16** may be spaced from the grate by a slightly greater distance than the downstream edge of chute **14** to form a continuously rolling toe of wet incoming feed which is dried by recirculating gases as explained hereafter.

A burner **18** is positioned above the grate **11** downstream from the feed slots. The burner is fed through a plurality of apertures with a mixture of natural gas and air from an air-gas mixer and blower **19** adjusted to admit insufficient air for complete combustion of the natural gas. In a manner explained in greater detail hereinafter cooled gas from a recycle gas blower **20** is recirculated to the mouth of the burner to regulate and control the temperature. The burner is enclosed in a refractory housing **21** within the furnace housing. By thus mounting the burner in a combustion chamber that is almost completely surrounded by warm circulating gases, as explained hereafter, the sensible heat contained in the converted natural gas is utilized.

The roasting furnace is divided generally into three treating zones, a preheating or drying zone **22**, a reaction or roasting zone **23** and a cooling zone **24**. Flexible sealing members may be used to separate the treating zones. A plurality of plenum chambers or wind boxes are disposed under the upper flight of grate **11** in communication with the spaces in and above the ore body **12**. The wind boxes **25** disposed below the preheating and roasting zones **22** and **23** are maintained at negative pressure with respect to the zones above them to draw the hot gases downwardly through the ore body. The wind boxes **26** disposed below the cooling zone **24** are maintained at positive pressure to force cooled gases up through the hot ore.

The warm spent gases drawn by wind boxes **25** from the preheating and drying zone **22** and from the burner through roasting zone **23** are carried by ducts **27** to one or more cooling towers **28** where the gases are cooled and moisture is extracted. A portion of the cooled gases is returned by blower **20** through duct **29** to the burner to assist in control of the reaction gas temperature and composition. The remainder of the cooled gases is circulated by blower **30** and ducts **31** to wind boxes **26** and is forced up through the hot ore body in the cooling zone **24**. The cooled gases there extract most of the sensible heat from the ore. A portion of these reheated gases is then circulated by blower **33** and duct **34** to a preheating gas chamber **34A** and then to that portion of preheating zone **22** lying between the hearth layer and main layer feeder slots. Part of these gases passes downward through the toe of new feed from slot **16** and part escapes upward through the new feed to raise its temperature slightly, remove a portion of the surface water and to displace entrapped air. The rest of the gases from the cooling zone is recirculated through duct **32** around the burner housing to the portion of the preheating zone downstream from chute **16** where it gives up heat to the ore.

The cooled roasted ore is discharged by gravity from the end of the grate **11** into a discharge hopper **35**. The end of hopper **35** is submerged beneath the surface of water **36** contained in a trough or tank **37** to quench the roasted ore and prevent reoxidation and to provide a gas tight seal for the furnace housing. A spiral **38** removes the product from tank **37** and delivers the dewatered product to a suitable conveying means, such as buggy **39**. The overflow from the dewatering classifier is passed through a magnetizing coil and a dewatering hydroclassifier. The thickened solids from the hydroclassifier are fed to a drum type magnetic separator for separation of the magnetic iron ore.

The atmosphere within the roasting furnace is maintained under slight positive pressure at all times to assure reducing conditions by insuring against admission of oxidizing gases. The water seal at the discharge from the furnace insures against inward air flow. The spent gases may escape through the ore hoppers where the outward flow of these gases under slight pressure guards against admission of air with the ore feed. The spent gases escape in an amount roughly proportional to the amount of natural gas and air admitted to the burner.

An exemplary layout of a downdraft ore roaster and auxiliary equipment is shown in Figures 2 through 7. Although differing slightly in form from the furnace

shown in Figure 1 the furnace of Figures 2 to 7 is the same in all essentials and the same numbering system is employed. As shown in Figures 2, 3, 5 and 7 a shuttle conveyor 40 is provided for feeding the ore for the hearth layer to hopper 14. Filtered air intakes 41 are provided for the gas-air mixers 19. A manual reset automatic gas valve 42 is provided in the line between the mixers and the burner along with an automatic fire check 43. This same line also has safety blowouts 44 as a precautionary measure.

The plenum chambers 25 and 26 are preferably provided with a chute 45 for collecting dust which may drop or be drawn through the grate. The bottom wall of the furnace housing is provided with a plurality of hoppers 46 each fitted with a cleanout spout 47 having an air tight cap to collect any residual product and dust which may fall off the return flight of the grate.

As best shown in Figure 6 the burner housing 21 is comprised of fire brick or similar refractory material. Duct 32 for circulation of the gases for preheating is comprised of a sheet steel duct 48 suitably enclosed by insulation 49. The lower furnace housing is comprised of a sheet metal enclosure 50. The individual pallets 51 comprising the travelling grate 11 are preferably provided with sidewalls 52 to assist in retaining the ore on the grate. The portions 29A of recycle gas pipes 29 which enter into the burner combustion chamber are provided with a multiplicity of drilled ports to distribute the recycled gas. Similarly, the burner pipe 18A is provided with a plurality of ports. Although the furnace as illustrated is especially adapted for use with gaseous fuels it may also be adapted for use with liquid or solid fuels where such use is practical. In the modified form of apparatus shown in Figures 2 to 7 spent gases for introduction to chamber 34A for preheating the new feed from slot 16 are drawn from the gases in zone 22 instead of being drawn directly from the discharge end of the furnace as shown in Figure 1.

In Figure 8 there is shown a form of moving grate in a transverse vertical cross-section wherein metal balls form a permanent hearth layer. The individual pallet 51A is in the form of an open horizontal rectangular frame having side walls 52A and two or more transverse beams 53. Supported on the frame are a plurality of spaced apart horizontal grate bars 54 forming an open bottom wall or horizon of grates for the pallet. Parallel to the bars 54 but spaced apart from them are a plurality of grate bars 55 forming a similar open wall or horizon of grates for supporting the ore layer. In the space between bars 54 and 55 there are loosely packed a plurality of mineral balls 56, preferably iron or steel, and having a diameter such that they do not pass between the bars of the grates. These balls form a permanent hearth layer. They are packed between the horizons of the grate loosely enough that there is some slight relative movement between the balls at the ends of the furnace to keep the spaces between the balls clear and open for the free flow of gases through the moving grate. The pallet is provided with rollers 57 by which it is supported on rails during its course of travel through the furnace. By the use of this form of grate the necessity of screening, transporting and continuously feeding a circulating protective hearth layer is eliminated.

Figure 9 shows a schematic representation of another form of the roasting system of this invention operated on updraft. The furnace 10A is shown in vertical longitudinal section. The furnace includes an endless grate 11A adapted to be moved continuously in a horizontal path to move a body of ore 12C on its upper flight longitudinally through the furnace. The grate is enclosed in a housing indicated generally at 13A.

One or more chutes 16A and 16B are provided through the housing to supply ore to the grate. Because of difficulties caused by water condensation drying is limited to layers of about 6 inch depth. As previously mentioned, with updraft drying it is possible to dry several such layers successively by feeding at several points making possible the use of a thicker bed and greater capacity for a given machine. The chutes extend transversely substantially the width of the grate. The lower ends of the successive chutes extend down to serve as a metering doctor for an ore layer of the desired thickness. Each chute is provided with a shuttle conveyor 17A—17B from which it is fed.

A burner 18B is positioned below the grate 11 downstream from the feed slots. Preferably, the burner is fed through a plurality of apertures with a mixture of natural gas and air from an air-gas mixer and blower 19A adjusted to admit insufficient air for complete combustion of the natural gas. In a manner explained in greater detail hereinafter cooled gas from a recycle gas blower 30A is recirculated to the mouth of the burner to regulate and control the temperature. The burner is enclosed in a refractory housing 21A within the furnace housing.

This form of roasting furnace is likewise divided generally into three treating zones, a preheating or drying zone 22A, a reaction or roasting zone 23A and a cooling zone 24A. A plurality of plenum chambers or wind boxes are disposed under the upper flight of grate 11A at both ends of refractory combustion chamber housing 21A in communication with the spaces in and above the ore body 12C. The spaces above the ore body are, in effect, also wind boxes maintained at negative pressure. The wind boxes 25A disposed below the preheating zone 22A are maintained at positive pressure with respect to the zones above them to force the hot gases upwardly through the ore body. The wind box 26A disposed below the cooling zone 24A is maintained at positive pressure to force cooled gases up through the hot ore.

Hot reducing gases are drawn upwardly from the burner and combustion chamber into the reaction zone 23A where the ore is roasted and the hot spent gases are drawn from the reaction zone 23A by a blower 58 through ducts 59 and recirculated to one of wind boxes 25A. Rewarmed spent gases are drawn from the cooling zone 24A by blower 60 through ducts 61 and recirculated to wind boxes 25A. The warm gases from wind boxes 25A are forced up through the newly fed ore in the zone 22A where they dry and preheat the ore layer. Where, as here, the ore is fed in several successive layers the gases forced through the wind box farthest upstream dry and preheat the first layer of ore. A successive ore layer is fed on top of the dried layer and gases from a wind box farther downstream are forced through the dried layer with little or no loss of heat and through the new feed to dry and preheat it.

The hot gases from the preheating and drying zone 22A are carried by ducts 27A to one or more cooling towers 28A where the gases are cooled and moisture is extracted. A portion of the cooled gases is returned by blower 30A through duct 29B to the burner to assist in control of the reaction gas temperature and composition. The remainder of the cooled gases is circulated by blower 30A and duct 31A to wind box 26A and is forced up through the hot ore body in the cooling zone 24A. The cooled gases there extract most of the sensible heat from the ore. These reheated gases are then circulated through duct 61 to wind boxes 25A and the preheating zone 22A where it gives up heat to the ore. Part of these gases escapes upward through the new feed to raise its temperature slightly, remove a portion of the surface water and to displace entrapped air.

As in the downdraft form of the invention, the cooled roasted ore is discharged by gravity from the end of the grate 11A into a discharge hopper 35. The end of hopper 35 is submerged beneath the surface of water 36 contained in a trough or tank 37 to quench the roasted ore and prevent reoxidation and to provide a gas tight seal for the furnace housing. A spiral 38 removes the

product from tank **37** and delivers the dewatered product to any suitable conveying means, such as buggy **39**. The product is separated as heretofore described.

The invention is further illustrated by means of the following example:

An iron ore containing 34.84% Fe and having a ferrous iron to total iron ratio of less than 0.02 was crushed to —½ inch, yielding the following size distribution:

Size range:	Weight, percent
+0.371"	14.04
—0.371"+4 mesh	22.44
—4 +6 mesh	6.54
—6 +8 mesh	4.75
—8 +14 mesh	4.98
—14 +28 mesh	5.97
—28 +48 mesh	5.49
—48 +65 mesh	2.48
—65 +100 mesh	2.64
—100 mesh	30.67

The unsized ore was agglomerated in a balling drum where the free moisture was increased to 10%, and the wet, balled ore was fed to the roasting apparatus through the feed slot **16** at 1580 pounds dry ore per hour, forming a charge layer **12B** six inches deep at a grate speed of 2.9 inches per minute. Product returns, 1140 pounds per hour, screened to +6 mesh were fed from hopper **14** to form a 4½-inch hearth layer **12A** between the grate **11** and the charge layer **12B**.

The agglomerated ore in the charge layer was successively dried with hot, dry, spent gases passing downward through the ore bed in the drying section **22**; reacted with the combination of CO, CO_2, H_2, and H_2O present in the high temperature gas stream passing downward through the ore bed, thereby chemically converting any iron oxides present to Fe_3O_4, magnetite, in the reaction section **23**; and cooled by a stream of cool spent gas passing upward through the ore bed in the cooling section **24**. The cooled product was collected from the system under water in a mechanical ore classifier.

Natural gas—1000 B.t.u./s.c.f.—at 22.17 s.c.f.m. and air at 164.58 s.c.f.m were supplied through a proportional mixer-compressor **19** at 3 p.s.i.g. to a drilled port burner tube **18A** and burned in a refractory combustion chamber to form gaseous combustion products containing CO and H_2, approximately as given in the following table:

Gas	Combustion Products	Recycle Gas	Reactant Gas
	Percent	*Percent*	*Percent*
CO_2	6.9	11.1	9.6
N_2	66.4	81.3	76.0
CO	4.3	1.8	2.7
H_2	4.3	2.1	2.9
H_2O	18.1	3.5	8.7
O_2	0.0	0.2	0.1

The 196 s.c.f.m. of combustion products and 360 s.c.f.m. of recycled gas supplied from the gas coolers **28** by a blower **20** through the drilled port distributor pipes **29A** were mixed in the space at the burner mouth to form a reaction gas mixture at 1200° F. and supplied to the reaction chamber **23**. (The expressions "s.c.f." and "s.c.f.m." mean "standard cubic foot" and "standard cubic foot per minute." "Standard" in this instance means with the gases under standard temperature and pressure conditions.)

The reaction gas mixture supplied both sensible heat and reducing agent as it passed downward through the ore bed to the wind box **25** below, emerging at a mean temperature of about 500° F. The spent gases then passed upward countercurrent to 70° F. cooling water in the packed cooling towers **28**.

Part of the 80° F. saturated gas from the coolers **28** was moved to the reaction gas mixing chamber and the balance was moved by blower **30** upward through windboxes **26**, through the hot reduced ore bed to the chamber **24** above the cooling section and the discharge chamber, thereby cooling the product and providing warm dry gas for drying the incoming feed. Most of the gas from the cooling section moved through a large conduit **32** surrounding the combustion assembly, and then downward through the ore bed from the drying chamber **22** into windboxes **25** and back to the gas coolers **28**. The balance of the warm dry gases was moved by blower **33** from the discharge chamber into an enclosed space **34A** between the two feed slots **15** and **16**, and through the continuously rolling toe of the wet incoming feed layer, which was thus warmed and dried sufficiently to prevent condensation and subsequent compact disintegration in the drying section. The cool, moist gas so formed escaped from the system through the feed slots **15** and **16** at a rate equal to the rate of gas accumulation from the combustion chamber.

It is apparent that many modifications and variations of this invention as hereinbefore set forth may be made without departing from the spirit and scope thereof. The specific embodiments described are given by way of example only and the invention is limited only by the terms of the appended claims.

I claim:

1. A process for roasting ores which comprises the steps of crushing the ore, moistening and rolling the damp crushed material to agglomerate the fines, distributing the resulting ore compacts in a relatively thin layer of substantially uniform thickness on the upper surface of a horizontally moving grate adapted to move the bed in sequence through a drying zone, a reaction zone and a cooling zone, passing warm non-oxidizing gases through the bed of ore in the drying zone to dry and preheat the ore compacts, passing hot reducing gases through the bed of ore in the reaction zone to decrease the oxygen content of the ore, cooling and partially dehydrating the spent non-oxidizing and reducing gases from the drying and reaction zones, recirculating a portion of said cooled and dehydrated spent gases to said cooling zone for passage through the reduced ore to cool the same, discharging said cooled reduced compacts from said grate and recirculating the spent gases from said cooling zone to the drying zone.

2. A process according to claim 1 further characterized in that a portion of the cooled and partially dehydrated spent gases is recirculated to said reaction zone for admixture with the hot reducing gases to assist in regulating the temperature of the reducing gases.

3. A process according to claim 1 further characterized in that said reducing gases are derived from the combustion in situ of natural gas in the presence of insufficient oxygen to effect complete combustion.

4. A process according to claim 1 wherein the ore is an iron ore crushed to pass a ½ inch screen.

5. A process according to claim 1 further characterized in that said reducing gases are derived from the combustion in situ of fuel in the presence of insufficient oxygen to effect complete combustion.

6. A roasting process for converting non-magnetic iron oxides to magnetite which comprises crushing mine run iron bearing rock, moistening and rolling the damp crushed material to agglomerate the fines, distributing the resulting ore compacts in a relatively thin layer of substantially uniform thickness across the width of the upper surface of a horizontally moving grate adapted to move the ore bed in sequence through a drying zone, a reaction zone and a cooling zone, drying and preheating the ore compacts by passing warm non-oxidizing gases downwardly through the bed of ore in said drying

zone, decreasing the oxygen content of the iron minerals to about the composition of magnetite by passing hot reducing gases downwardly through the ore bed in the reaction zone, cooling and dehydrating said spent non-oxidizing and reducing gases, recirculating said cooled and dehydrated spent gases to said cooling zone for passage upward through the reduced ore to cool the same, discharging said cooled reduced compacts from said grate and recirculating the spent gases from said cooling zone to the drying zone.

7. A process according to claim 6 further characterized in that a portion of the cooled and dehydrated spent gases is recirculated to said reaction zone for admixture with the hot reducing gases to assist in regulating the temperature of the reducing gases.

8. A process according to claim 6 further characterized in that said reducing gases are derived from the combustion in situ of natural gas in the presence of insufficient oxygen to effect complete combustion.

9. A process according to claim 6 further characterized in that the iron ore is crushed to pass a ½ inch screen.

10. An apparatus for roasting ore compacts which comprises an endless movable grate, means supporting the upper flight of said grate for a course of travel in a generally horizontal plane, drive means for moving said grate, a closed housing surrounding said grate and defining three treating zones, feed means extending through the housing wall in the first zone at the upstream end of the grate, said feed means comprising a first feed box for applying a hearth layer to said grate and a further feed box downstream from the first for applying a main layer of ore compacts on top of the first, burner means within the housing spaced above the grate in the second zone and downstream from the feed means, discharge means in the third zone at the downstream end of the grate, wind box means under the grate for drawing spent gases through the grate from the first two zones and further wind box means under the grate for forcing spent gases through the grate into the third zone, cooling means connected to the first wind box means and means connecting said cooling means with said second wind box means, a gas distributing chamber positioned above the grate between the first and second feed boxes, duct means connecting said chamber with said last treating zone and means for recirculating spent gases from said last treating zones to said chamber.

11. An apparatus for roasting ore compacts which comprises an endless movable grate, said moving grate being comprised of two horizons of grates with the space between said horizons filled with loosely packed metal balls selected from the group consisting of iron and steel, means supporting the upper flight of said grate for a course of travel in a generally horizontal plane, drive means for moving said grate, a closed housing surrounding said grate and defining three treating zones, feed means extending through the housing wall in the first zone at the upstream end of the grate for applying ore compacts to the grate, burner means within the housing adjacent to the grate in the second zone and downstream from the feed means, discharge means in the third zone at the downstream end of the grate, windbox means adjacent to the grate in each of said zones connected with blower and duct means for inducing the flow of reducing gases from the burner through the second zone and inducing the flow of spent gases through the first and third zone, cooling means connected in the system between the first and last treating zones, further duct means connecting said last and first treating zones and means for recirculating spent gases through said duct.

12. An apparatus for roasting ore compacts which comprises an endless movable grate, said movable grate being comprised of two horizons of grates having the space between said horizons filled with loosely packed mineral balls, means supporting the upper flight of said

grate for a course of travel in a generally horizontal plane, drive means for moving said grate, a closed housing surrounding said grate and defining three treating zones, feed means extending through the housing wall in the first zone at the upstream end of the grate for applying ore compacts to the grate, burner means within the housing spaced above the grate in the second zone and downstream from the feed means, discharge means in the third zone at the downstream end of the grate, windbox means under the grate for drawing spent gases through the grate from the first two zones and further windbox means under the grate for forcing spent gases through the grate into the third zone, cooling means connected to the first windbox means and means connecting said cooling means with said second windbox means, duct means connecting said last and first treating zones and means for recirculating spent gases through said duct.

13. Apparatus according to claim 12 further characterized in that said balls are comprised of a metal selected from the class consisting of iron and steel.

14. An apparatus for roasting ore compacts which comprises an endless movable grate, means supporting the upper flight of said grate for a course of travel in a generally horizontal plane, drive means for moving said grate, a closed compartmentalized housing surrounding said grate and defining three treating zones, feed means extending through the housing wall in the first zone at the upstream end of the grate for applying gas-permeable layers of ore compacts on the grate, a burner means within the housing adjacent to the grate in the second zone for continuously producing a hot gas mixture consisting essentially of CO, CO_2, H_2, H_2O and N_2 and being substantially oxygen-free by combustion of a precisely controlled fluid mixture of carbonaceous fuel and an oxygen-containing gas, said hot gas mixture being mixed with cooler recycled spent gases of controlled humidity thereby forming a reaction gas mixture of adequate and controllable temperature and composition, means at the downstream end of said grate for discharging the roasted ore compacts from the apparatus under conditions such that the roasted ore compacts are not readily oxidized in air and such that air is prevented from passing into the apparatus, windbox means under the grate in each of the three treating zones connected with blower and duct means for inducing the flow of hot reducing gas mixture from the burner means through the layer of ore compacts in the second zone and inducing the flow of spent gases through the layer of ore compacts in the first and third zones, and gas cooling and dehydration means connected between the gas outlets from the first and second zones and the spent gas inlets to the third zone and to the burner means.

15. Apparatus according to claim 14 further characterized in that said moving grate is comprised of two horizons of grates and the space between said horizons is filled with loosely packed mineral balls.

16. Apparatus according to claim 14 further characterized in that gas distributing chambers are positioned above the grate between consecutive feed box means, duct means are provided connecting said chambers with the gas outlet from the third zone and means are provided for inducing the flow of spent gases from said third zone to the portions of the first zone between said consecutive feed box means.

17. Apparatus according to claim 14 further characterized in that said feed means is comprised of a first feed box means for applying a gas-permeable hearth layer to said grate and further feed box means for applying gas-permeable layers of ore compacts on top of said hearth layer.

18. Apparatus according to claim 17 further characterized in that said balls are comprised of a metal selected from the class of iron and steel.

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