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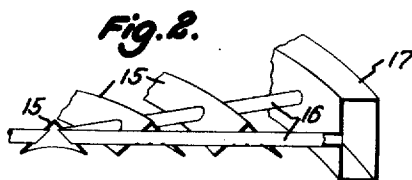
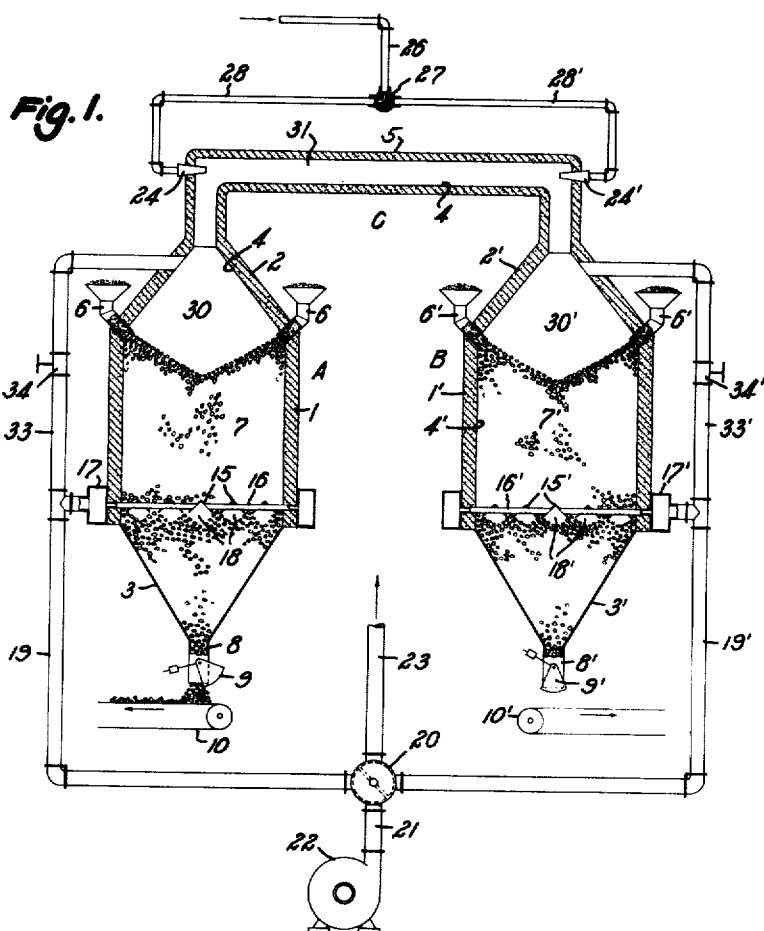
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2,532,335

PROCESS FOR HEAT-TREATING SOLIDS

Filed July 3, 1945

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

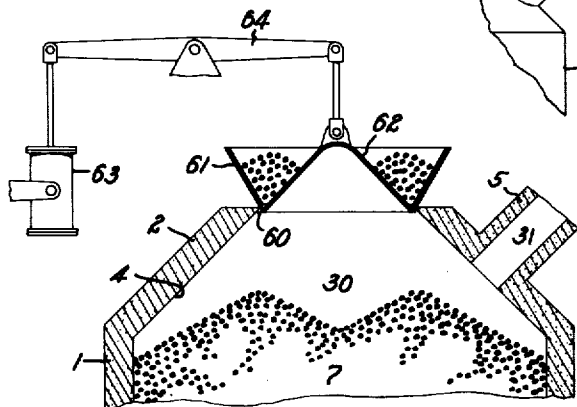
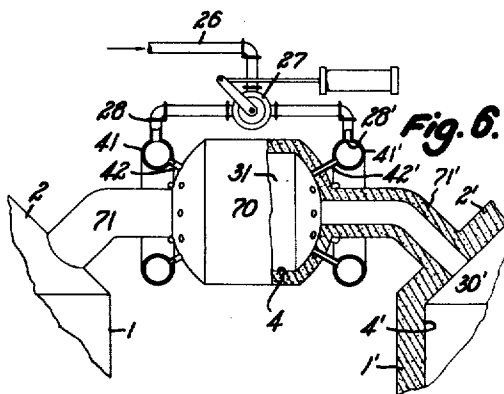
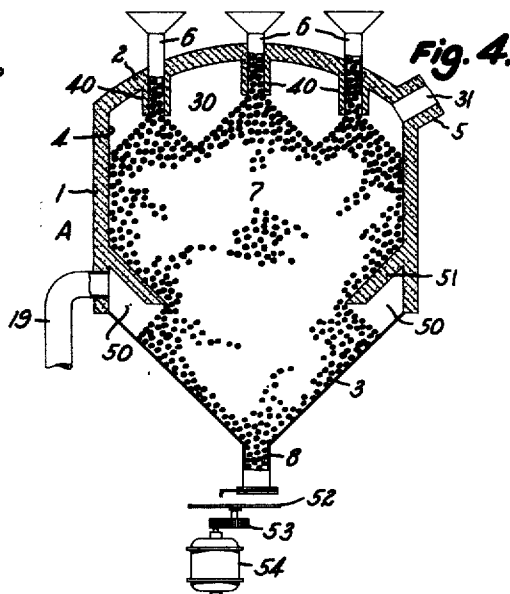
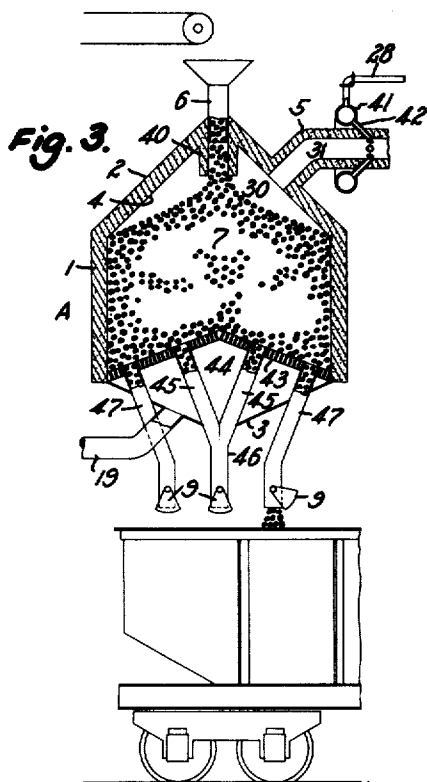


Fig. 5.

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3 Sheets-Sheet 3

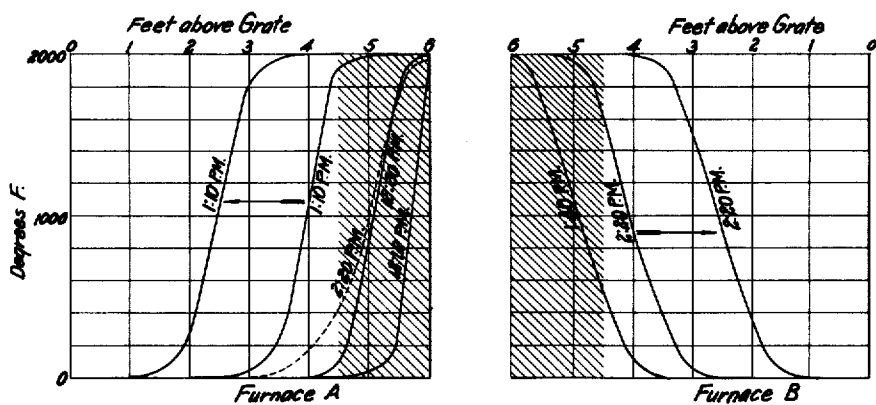
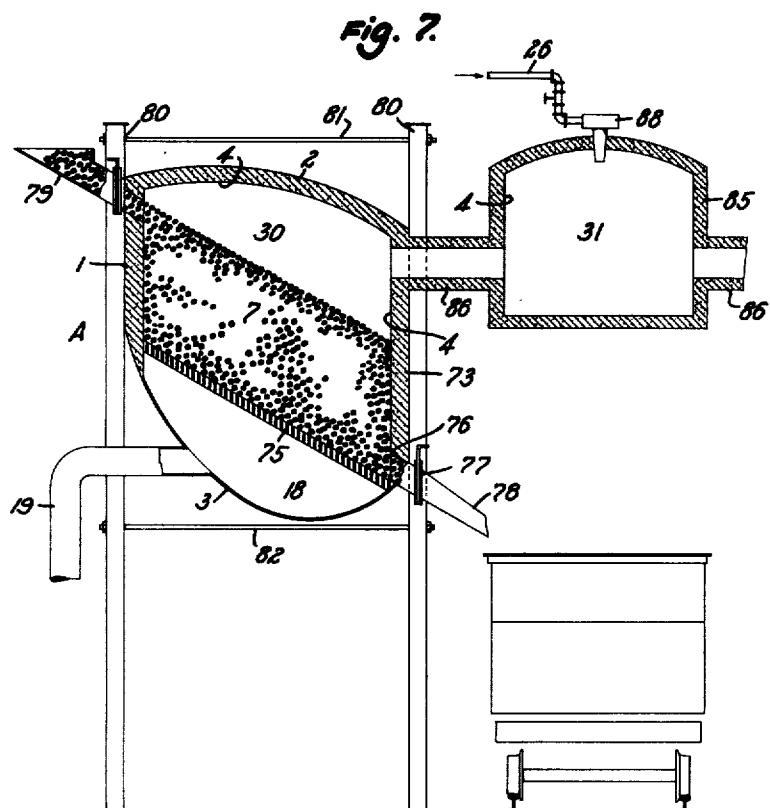


Fig. 8.

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UNITED STATES PATENT OFFICE

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PROCESS FOR HEAT-TREATING SOLIDS

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5 Claims. (Cl. 75-5)

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This invention relates to improved modes of heating—e. g., to the drying, or to the drying and further heat-treatment—of mineral solids such, for example, as ores, ore materials, other metallurgical products, non-metallic raw materials such as fireclay, limestone, and phosphate rock, and the like, at temperatures above the boiling point of water but short of actual fusion of the mineral solids, and is concerned with measures for improving the heat economy in such heating methods. The "heat-treatment" herein contemplated includes drying, roasting, baking, calcining, indurating, and the high temperature operations including oxidation of lower oxides, and reduction of higher oxides.

More specifically, the invention relates to the agglomeration of oxide ore fines, e. g., iron ore fines, and similar finely divided metallurgical materials preparatory to reduction of the same. It is particularly concerned with improvements in the step of thermally treating small consolidated masses, e. g., briquets,glomerates,glomerules, ovoids, spheres, balls or pellets, formed in some fashion of moist oxide ore fines whereby to indurate these solid masses or glomerates, i. e., to enhance their strength, ruggedness and resistance to impact, shock, other mechanical stresses and to weathering. The invention includes improved apparatus for use in carrying out the heat-treating operation. By the term "indurated" as herein used is meant a hardened state of the consolidated masses unaccompanied by any substantial or objectionable fusion of the mineral constituents composing the particles.

The invention will, in the following, be more specifically described with reference to its induration aspect, although it should be understood that the invention has other applications as suggested above.

The problem of working up ore fines and other similar finely-divided inorganic solids into objects of such size and structure as would make them economically handleable in a metallurgical furnace such, for instance, as a blast furnace, is very old and has received much consideration. Thus Mason (U. S. Patent No. 307,667), who proposed that iron ore fines and the like be moistened with water which might or might not contain an added binder substance, formed into molded bricks or unmolded irregularly shaped small masses and heat-treated in a quiescent state, suggested that the small masses be bedded in layers of solid fuel and the latter burned whereby to bake or "burn" the ore fines masses in the intervening layers. Later, briquetting without or with

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subsequent heat-hardening was proposed, as were sintering and nodulizing. As a variant to nodulizing and sintering, it was proposed that such ore fines be moistened (without or with added binder substance) and formed into shapes or spheres (variously styled "pellets" and "glomerules") which latter were to be dried and more or less baked but without excessive fusion of the mineral constituents of the ore. One suggested method of carrying out this scheme was to feed a stream of the moistened fines into the upper end of a relatively long inclined rotary kiln at the lower end of which a high temperature was maintained by the combustion of fuel therein; it was hoped that the moist fines would "ball up" at the initial stage of their travel through the kiln, and that the resulting spherical masses would be dried and eventually heat-hardened during their subsequent travel through the hot end of the kiln. Other investigators, finding that the method just described was unsatisfactory in that the balls when dried became too fragile to withstand subsequent tumbling and as a result disintegrated badly, proposed that they be supported, in some obscure fashion, in a quiescent state and without being subjected to breaking stresses while undergoing induration; however, the proposals were not accompanied by any readily understood procedure for effecting the desired result.

It has been found that material disintegration of these pellets, small balls or glomerules during the heating step may be avoided by accelerating the rate at which temperature of at least the outer laminae of the "green" or "raw," i. e., untreated, pellets is raised from below 212° F. to that temperature level, e. g., 1650°–2100° F. in the cases of most iron ores, at which a desirable degree of induration of the ore fines occurs, to the end that such outer layers very rapidly are indurated. For effecting this desirable result I cause a supported layer of the "raw" (that is to say, moist and unbaked or untreated) pellets, initially at a temperature below 212° F., to be traversed by a mechanically propelled current of a treating gas heated to and maintained at a predetermined induration temperature for a period of time sufficient not only to heat-harden the peripheral laminae of the pellets in the supported layer, but also to effect thoroughgoing heating of the entire pellet body to indurating temperature, and thereafter I cause the heat resident in the so-indurated pellets very largely to be transferred to the unheated treating gas which I use in the subsequent heating of the raw pellets.

From a broad procedural viewpoint, the process

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of the present invention comprises establishing two enclosed gas-traversable beds of the solids to be heat-treated; charging untreated solids on the upper bounding surfaces or "stock-lines" of the two beds; removing treated solids from some lower portion or portions of said beds; while, in a first step, forcing a current of gas which may be reducing or which may be oxidizing (such as air) through one of said beds, called the "primary" or "upstream" bed, introducing heat into the gas after its passage therethrough, and causing the gas thereafter to traverse the other bed, called the "secondary" or "downstream" bed; in a second step reversing the roles of the two beds and the direction of flow of the gas current serially through them; continuing the alternation of these two steps, and controlling the input of heat during the two steps to maintain the treating gas at a predetermined treating temperature at the initiation of its flow through the downstream bed. Although the heating of the gas current may be effected in any known manner, e. g., electrically, I prefer to effect it by burning a gaseous, liquid or solid fuel in the treating gas, permitting the products of such combustion to mingle with and dilute said treating gas. The designations "upstream" and "downstream" refer to the position of the beds in the series; the bed which is traversed by the gas first being termed "upstream."

In "firing" briquetted or pelletized iron ores, initially containing 10% moisture, at an indurating temperature of 2000° F., the total heat theoretically required to raise a gross ton of the raw (i. e., untreated) briquets or pellets to this temperature is 1,164,000 B. t. u. where about 80% of the heat (930,000 B. t. u.) represents the sensible heat of the 0.9 gross ton of the resultant baked solids and only about 20% is chargeable to evaporating the initially contained moisture. In view of these thermal requirements, the economic necessity to discharge the solids from the apparatus at low temperature is five times as important as the mere drying and indurating of the solids. Accordingly, in carrying out my process, I prefer to discharge the dried and indurated pellets (or equivalent masses) at a reasonably close approach to ambient air temperature, e. g., near the dewpoint of the exhaust gases, and, equally important, to discharge the treating gas at a relatively low temperature (ideally, of course, at ambient air temperature). Thus I avoid any serious loss of heat in the form either of hot discharged solids or of hot exhaust gases. To attain these two desirable results, I so adjust (a) the duration and periodicity of reversal of the direction of flow of the gas current, and (b) the average rate of removal of the treated pellets (and, of necessity, the average rate of charging of the raw pellets) that the temperature of the exhaust gas does not become unduly elevated and that the treated pellets are substantially "unheated" when discharged.

More particularly, my cyclical process may be described as involving: (1) maintaining two gas-traversable assemblages or "beds" of previously indurated pellets; (2) at least the bottom portions of both of which beds are substantially below the treating temperature and (3) at least the top portion of at least one of which beds is at substantially indurating temperature; (4) adding charges of raw pellets continuously or intermittently to the top of the beds; (5) passing a current of treating gas such as air initially

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unheated through the primary bed whereby to cool the bed by the transfer of heat from the pellets to the treating gas; (6) burning a fluid fuel in the so-preheated treating gas whereby to control its temperature to the selected indurating temperature; (7) passing this heated gas through the secondary bed whereby to cool the treating gas, by transfer of heat from the gas to the solids, thereby heating the latter, through the water-vaporizing temperature and thereafter to indurating temperature; (8) exhausting the gas in a relatively unheated condition; and (9) removing from a lower portion of the beds indurated pellets; also in a relatively unheated condition. The direction of flow of the treating gas is reversed, whereby the primary and secondary beds interchange their functional positions, at intervals sufficiently short to assure a relatively low exhaust temperature.

By enclosing the beds of solids in suitably heat-insulated evacuable and refillable heating chambers (hereinafter called merely "chambers") communicating at one end through a suitably heat-insulated combustion zone, furnace chamber or conduit (hereinafter called the "crossover") provided with means, e. g., burners, for admitting a controlled supply of fuel, it is insured that the raw pellets are indurated uniformly and with a minimum of spalling, cracking or disintegration; that the indurated pellets when withdrawn from a chamber are "cold"; and that the amount of fuel to be burned in the combustion zone or crossover exceeds that required for supplying the heat units necessary for vaporizing the initial water content of the raw pellets, by an amount sufficient to meet the heat losses due to thermal conduction of heat through the walls of the chambers and the crossover, and to supply the relatively small amount of degraded energy due to the unavoidable increase in entropy. In the interest of minimizing the blowing cost, I generally prefer to arrange the aforesaid beds of solids to be relatively broad and short, and also to provide amply large open spaces immediately above and below each bed.

By thus broadly extending the area of the free bounding surfaces between the beds and contiguous open spaces, the treating gas, of hydrodynamic necessity, flows uniformly into the downstream bed through the interstices between the pellets. By making the path of gas flow through the bed, between upper and lower (or, lower and upper) bounding surfaces, as short as practicably possible, I attain a minimum drop in gas pressure and hence a minimum blowing cost. The minimum thickness of the bed in the direction of gas flow is determined in part by the time during which I am required to hold the heated pellets at indurating temperature.

From the apparatus aspect, my invention—broadly considered—comprises two thermally insulated heating chambers, of circular, elliptical, rectangular or polygonal cross-section, each of which chambers is provided adjacent the top thereof with means for adding, continuously or in batches, charges of the solids to be treated to a bed or assemblage of similar solids contained in said chamber, and with means for discharging treated solids from a lower part of such bed. Each chamber is provided with means defining in co-operation with a lower portion of the chamber a lower open space, adjacent a lower bounding surface of such bed, adapted to permit ingress and egress of treating gas and exhaust gases into and from such bed. Each chamber is

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so fashioned as to provide an open space above and contiguous with the upper bounding surface of such bed. The two chambers are connected adjacent ends thereof, generally their tops, by a thermally insulated connective conduit or "crossover" permitting free passage of treating gas from an open space adjacent the bed in one chamber to a like open space adjacent the bed in the other chamber. Preferably, the crossover connects the two chambers at spaces above the normal stock lines of the beds. This crossover may and preferably does function as a combustion chamber or transfer flue, and is provided with means, e. g., burners, for introducing a fluid or powdered fuel thereto. The apparatus includes, also, means for positively moving a treating gas serially through the upstream chamber the crossover and the downstream chamber alternately in one direction and in the opposite direction, this last named means including a blower for forcing a gas into, or an exhaustor for removing gas from, the chambers and suitable valved conduits communicating between said blower or exhaustor and the lower open spaces in said chambers. The exhaust ends of the beds within the chambers being always at a relatively low temperature, and the gas brought thereto and discharged therefrom likewise being always suitably unheated or "cool," it is unnecessary to insulate the bottoms of the chambers or the conduits communicating between the latter and the gas blower or exhaustor.

The aforesaid chambers may be designed to exhibit a wide variety of geometric shapes, e. g., columnar, prismatic, cylindrical, pyramidal, or elliptical. The solids-feeding means may consist of various mechanically operated devices, e. g., belts, chains, buckets, screw conveyors, chutes, scrapers, bells, hoppers, and the like. They may also consist in a plurality of spaced vertical or inclined chutes or feed tubes projecting through the roof or an upper insulated side wall of the chamber, which chutes may discharge raw material gravitationally onto the top of the bed either at a plurality of spaced points about the periphery of the upper bounding surface of said bed (in which event the top surface of the bed is an inverted cone whose angle of inclination is the angle of repose of the raw material) or at a plurality of spaced points over the whole top surface of the bed (in which event the top surface of the bed is irregular in contour consisting of a plurality of spaced hillocks with intervening valleys). Or, the solids-feeding means may consist of a single substantially vertical chute projecting through the roof of the chamber and preferably located near or at the center line of the latter, in which event the top surface of the bed is conical or pyramidal in contour, the angle of inclination being again the angle of repose of the raw material. Any portion of a chute extending within the interior of the chamber preferably is formed of heat-resistant material.

Where the chamber is substantially cylindrical in horizontal section and the solids-feeding means is an axially central chute, a bed supporting grate may be positioned adjacent the bottom of the chamber, which grate may be given the form of a horizontal plane, or, to some advantage, may be given a conical form the upward slope of which cone from the wall of the chamber toward its vertical axis is substantially the angle

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of repose assumed by the pellets on the stockline as charged.

While it is desirable to obtain a spatial uniformity in the flow of solids downwardly through the bed, a considerable latitude in the operation is permissible without serious detriment to the efficiency of the process. When treated solids (e. g., pellets) are removed through a central discharge tube at the lower end of a conical bottom to a chamber, there is a tendency for the solids to flow rapidly along the center line and more slowly along the peripheral walls. It is possible, however, to locate baffles or deflector vanes in the conical bottom and thereby attain a satisfactory approach to uniform downward flow of the solids.

Where the chamber is very broad, e. g., in the case of a 20 to 40 foot diameter vertical cylinder, it usually is desirable to provide a plurality of discharge tubes or "take-off points" and to control the relative amounts of solids being removed through the several tubes to effect a substantially uniform down-shift of the bed whenever a batch of treated solids is removed from the bottom of the bed.

Like the heating chambers, the crossover may be variously formed. Thus, it may be given an elongated conduit-like form, or it may consist of a relatively large chamber or furnace connected at opposite ends to said treating chambers by communicating conduits. The fuel-introducing means may consist of a single burner let into the thermally insulated wall of the crossover but preferably consists of a plurality of burners positioned at loci adjacent the ends of said crossover.

The hereinbefore referred to means defining in co-operation with a lower portion of the chamber a lower open space adjacent a lower bounding surface of the bed of solids contained in the chamber may, as stated above, be a grate which supports the bed above the bottom (or a portion of the bottom) of the treating chamber to provide an open space beneath at least a part of the lower portion of the bed. In the alternative, the open space-defining means may comprise a member sloping inwardly and downwardly from the wall of the treating chamber, at a horizontal plane above but adjacent the bottom of said chamber, leaving therebeneath an annular free space of substantially triangular cross-section the sides of which triangle are the lower wall of the chamber, the aforesaid sloping member and the surface presented by solids which have passed said sloping member and have assumed their normal angle of repose between the lower edge of said sloping member and the lower wall of the chamber. Or, said open space-defining means may comprise a louver or plurality of louvers positioned within the lower portion of said chamber and provided with conduits for introducing a gas into or exhausting a gas from, the chamber from beneath said louver or louvers.

The invention will now be described in greater particularity and with reference to the accompanying drawing, in which:

Fig. 1 is a schematic sectional elevation, taken on the vertical axes of the two heating chambers, of one operable form of apparatus for carrying out the process of the present invention;

Fig. 2 is an enlarged fragmentary perspective view, with parts in section, of a detail of construction shown in the embodiment of the invention illustrated in Fig. 1;

Figs. 3 and 4 are schematic sectional elevations

of two modified heating chambers embodying the principles of the invention;

Fig. 5 is a fragmentary sectional elevation showing a further modification particularly of charging means for the heating chambers of the present apparatus;

Fig. 6 is a detail view of a modified form of crossover, with parts broken away to show the interior thereof;

Fig. 7 is a schematic sectional elevation of an additional modification of apparatus in accordance with the invention; and

Fig. 8 is a graph showing thermal gradients obtaining at particular moments within beds of solids undergoing induration treatment in accordance with the process of the present invention.

In Fig. 1, illustrating an apparatus for use in the induration of pellets of moist magnetite fines, are shown a pair of similar heating chambers A and B, with their appurtenances, and an elongated tubular crossover C interconnecting A with B. In A, 1 is a generally cylindrical vessel, 20 feet in internal diameter and 10 feet in height, having a conical roof 2 and a conical bottom 3. The side walls and roof of the vessel are provided with a refractory lining 4, as is the U-shaped crossover 5 connecting A and B at the apices of their roofs. The bottom 3 is sheet metal, unlined. 6, 6 represent eight hopper-mouthed feed tubes or chutes, equally spaced about the junction of roof 2 with vessel 1, adapted gravitationally to feed raw pellets into the heating chamber and upon the top of a bed of pellets 7 contained therein. At the apex of bottom 3 there is provided a generally cylindrical discharge tube 8 equipped with an adjustable discharge gate 9 by which treated pellets may be discharged from the heating chamber onto belt conveyor 10.

A plurality of annular, spaced, louver arches 15 are positioned, in a horizontal plane adjacent the junction of the bottom 3 with vessel 1, within the heating chamber. The louver arches 15 communicate, by way of eighteen radially disposed sets of gas conduits 16 with an annular gas chamber 17 surrounding the base of vessel 1. Louver arches 15 provide a plurality of annular open spaces each of which is bounded by the under surfaces of said louver arches and by the free surfaces formed by pellets which have passed said louver arches in the course of their descent through A and have assumed their angle of repose thereunder. 18, 18 are gas conduits communicating between annular gas chambers 17 and a reversing valve 20. 21 is a gas conduit communicating between valve 20 and a blower 22, while 23 is an exhaust conduit.

Heating chamber B is similar to heating chamber A, and its several parts have, in Fig. 1 and in this description, been given the same reference numerals as like parts of chamber A but primed.

24 is a burner projecting through the thermally insulated wall of crossover 5 at a locus adjacent the junction of the latter with the top of heating chamber A, while 24' is a similar burner in a like location with respect to heating chamber B, each of burners 24 and 24' being so positioned as to discharge gaseous fuel axially into a generally straight portion of the crossover. 26 is a fuel gas line, 27 is a three-way valve, and 28 and 28' are branch fuel gas lines communicating between valve 27 and burners 24 and 24', respectively.

30 represents an open space above bed 7 in chamber A; 31 represents the interior space of

crossover C; and 30' represents an open space above bed 7 in chamber B.

As shown in Fig. 1, I may provide means for by-passing gas to open space 30 in heating chamber A (and, in like manner, to open space 30' in heating chamber B), said means being a pipe 32, provided with valve 34, which pipe 32 leads from conduit 19 to said open space.

Operation of the apparatus just described will be described in the following specific example.

Example 1

Atmospheric air is forced by motor driven blower 22 at the rate of 20,000 cu. ft. per minute standard air, at 1.27 p. s. i. g. (lbs. per sq. in. gauge) and conduit 21 into reversing valve 20 and thence through cold air conduit 19 into the annular gas chamber 17 of heating chamber A. Air is fed from this annulus through the radially disposed gas conduits 16 to the lower open spaces 18 beneath the concentric louver-arches 15. Air escapes around the lower edges of the louvers 15 and flows vertically upward through bed 7, from which it emerges into upper open space 30 immediately adjacent the upper boundary surface or "stock-line" of bed 7. From upper open space 30, the air passes through open space 31 of the elongated, refractory-lined "crossover" C to discharge into upper open space 30' within heating chamber B. Fuel from fuel line 26 is fed through burner 24 into space 31, wherein combustion is effected and thermal energy is added to the gas stream. The amount of fuel introduced through burner 24 is controlled to maintain the gas stream entering open space 30' at a predetermined and controlled treating temperature, e. g., 2000° F. Bed 7' of heating chamber B is similar to bed 7 of heating chamber A. Gas at 2000° F. flows downwardly through this bed and exhausts into lower open spaces 18' beneath the louver-arches 15 positioned in heating chamber B; from which arches it flows radially outwardly by way of conduits 16' to annulus 17' and is returned through cold air conduit 19' to the reversing valve 20, from which it escapes through exhaust conduit 23. This is termed "direct flow."

In "reverse flow," reversing valve 20 is rotated 90° and air from blower 22 flows through conduit 19', annulus 17', louver-arches 15 into bed 7', whence it flows upwardly to discharge into open space 30'. The supply of fuel to the burner 24 is diverted by reversing the valve 27, and fuel is supplied to burner 24'. Air from open space 30' traverses crossover C from right to left, reacting in passage with the fuel introduced through burner 24'. The temperature of this gas stream is maintained at 2000° F. as in direct flow. Gas from crossover C flows through open space 30, downwardly through bed 7, escaping by way of louver-arches 15 into annulus 17 and conduit 19 to flow through reversing valve 20 and to discharge through exhaust conduit 23. The operation of the process is carried out by continuing repetitive alternation of direct and reverse flow.

Untreated pellets are fed into heating chambers A and B through the eight feed tubes 6, 6, equally spaced about the perimeter of the chamber. Pellets similarly are introduced into chamber B through feed tubes 6', 6'. The raw ore pellets introduced on the stock-line of beds 7 and 7' through these feed-tubes roll down, radially inwardly, to form on each bed a free surface as an inverted cone with an angle equal to the angle of repose of the raw pellets. Baked, dry, cold, treated pellets are removed through dis-

charge tubes 8 and 8' positioned at the bottom cone.

In the operation described, 980 G. T. (gross tons—2240 lbs.) per day of raw pellets containing 11% moisture are fed through the eight feed tubes 6, 6 and 870 G. T. per day of finished product are removed through discharge tube 8. The treated pellets may be removed (by suitable adjustment of discharge gate 9) continuously at the rate of 1352 lbs. per minute, or may be removed in periodic batches—for example, 12 G. T. at 20 minute intervals or 6750 lbs. at 5 minute intervals. It will be noted that when a given volume of treated pellets is removed through discharge tube 8, an equal volume of raw pellets automatically flows onto the stock-line through feed-tubes 6.

In the operation of the furnace, the rate at which the pellets are removed through discharge tubes 8 and 8' is limited by the requirement that the pellets remain essentially cold when removed. The operator may at his option remove varying sized batches from the bottom either of chamber A or of chamber B, or from both, at any convenient interval with the requirement that when the temperature of the pellets as discharged tends to increase to an objectionable extent above the dew-point of the gases discharging from exhaust conduit 23, the rate of removal of the pellets shall be decreased until the temperature of the discharged pellets is lowered sufficiently. The control of the reversing valve 20 is covered by similar considerations: the apparatus may conveniently be maintained on direct flow as long as the gases discharging through exhaust conduit 23 remain substantially at the dew-point of the gases, e. g., 167° F.; when the temperature of the exhaust gases tends to rise to an objectionable extent above this temperature, reversing valve 20 is rotated 90° and a reverse flow is initiated.

It is an essential characteristic of the present process that it is always possible to avoid any material loss of heat whether in the form of sensible heat of insufficiently cooled pebbles or of insufficiently cooled exhaust gases, this desirable result being easily obtained in practice by controlling the average rate of removal of pellets from the bottoms of the two heating chambers and by controlling the time of reversal of valve 20.

The temperature at which the pebbles are heated may readily be controlled, within a very few degrees, by controlling the quantity of gaseous fuel introduced through burners 24 and 24', this control being easily maintained by introducing suitable thermocouples (not shown) into open spaces 30 and 30'.

In the above operation, the spherical pellets exhibit an average diameter of 0.837 inch, a particle density of 202 lbs. per cu. ft. 36.4% voids and 129 lbs. per cu. ft. bulk density dry basis.

Fig. 3 illustrates a modification of the heating chamber A shown in Fig. 1. In this modification, a single solids-feeding chute 6 is employed, the same being positioned at or adjacent the vertical axis and at the apex of roof 2 of generally cylindrical vessel 1. Chute 6 is projected for a short distance into the interior of the heating chamber, which projected portion, illustrated at 40, preferably is formed of or faced with refractory material. In this form the upper boundary surface of bed 7 is conical, with an inclination equal to the angle of repose of the solids so introduced. Between this stock-line and

roof 2 is an upper open space 30, functionally equivalent to upper open space 30 in the apparatus shown in Fig. 1, in communication with open space 31 of crossover 5.

The burner, in this modification, consists of a bustle-pipe 41 and a plurality of spaced tubes 42 communicating between 41 and the interior space 31 of crossover 5; tubes 42 introduce gaseous fuel into 31 laterally, i. e., essentially in the same direction as that of gas passing from upper open space 30 into and through 31.

43 is a conically shaped grate whose inclination is substantially equal to the angle of repose of the solids on the stock-line of bed 7 which said grate supports. 44 is a lower open space between grate 43 and the bottom 3 of the heating chamber.

45, 45 represent a plurality of spaced branch discharge tubes for discharging treated solids from a zone intermediate the apex and the base of conical grate 43 to a collecting discharge tube 46 provided with an adjustable discharge gate 9. 47, 47 represent a plurality of spaced discharge tubes, equipped with adjustable discharge gates 9, for discharging treated solids from a zone at or adjacent the base of grate 43. By suitable adjustment of the several discharge gates 9 the descent of bed 7 can be controlled so that all of the solid bodies constituting bed 7 shall have been equally treated.

The operation of the apparatus illustrated in Fig. 3 is generally the same as that of the apparatus shown in Fig. 1.

In the modification shown in Fig. 4, the roof 2 of heating chamber A is generally rounded. A plurality of spaced solids-feeding chutes 6 are employed, yielding an irregular stock-line consisting of a plurality of relatively uniformly spaced cones merging at their bases, their inclination being equal to the angle of repose of the solids so introduced. The lower open space for ingress and egress of treating gas, represented at 50 in Fig. 4, is provided by a relatively steeply sloping lateral wall 51 depending from side wall 1 of the heating chamber, which lateral wall functions to constrict bed 7, at the level of said wall, and thereafter to permit the solids of the bed to roll outwardly thereunder to the confining chamber wall 1 (or to its conical bottom 3).

In this modification, air in direct flow is forced from conduit 19 into annular open space 50 and thence through the lower free surface of bed 7 into and through bed 7 and to upper open space 30.

Fig. 4 further illustrates an alternative form of solids-discharging means. The conical bottom 3 of the heating chamber is provided with a central discharge tube 8. Spaced below 8 is a revolving plate 52 driven, through gears 53, by motor 54. Revolution of plate 52 permits continuous discharge of treated solids from the chamber, the rate of discharge being governed by the rate of revolution of the plate. Solids flowing onto plate 52 from tube 8 may be removed from the plate by any suitable means, such as a scraper (not shown).

Fig. 5 illustrates application of a bell and hopper top, such as is used on blast furnaces, to the heating chambers of the present apparatus. In this form of construction the conical top of the heating chamber is truncated to provide a relatively large opening 60, into which opening is fitted the hopper 61. 62 represents a conventional bell actuated by pivotally supported

pneumatic cylinder and piston device 63 through bell beam 64. Use of this solids-feeding device yields an irregular stock-line in that the solids are fed to the top of bed 7 in an annular pile and roll down over the bed surface until they have attained their normal angle of repose.

Fig. 6 illustrates a modified construction of crossover applicable to any of the heating chambers herein described. In this case, the crossover comprises an enlarged, refractory-lined, generally cylindrical combustion chamber 70 communicating with upper open spaces 30 and 30' of heating chambers A and B, respectively, through refractory-lined conduits 71 and 71', respectively. The fuel gas-introducing means is, in this case, essentially the same as that shown in Fig. 3. Fig. 6 illustrates the use of a mechanically actuated 3-way valve 27 for diverting gaseous fuel from 26 either to burner bustle pipe 41 or to burner bustle pipe 41'.

Fig. 7 represents a heating chamber, of generally rectangular cross-section, having a bed-supporting grate 75 which slopes downwardly from one wall 1 to the opposite wall 73 of the heating chamber at an angle equal to the angle of repose of the solids undergoing treatment. Treated solids are discharged from the bottom of bed 7 through a plurality of spaced channels 76, discharge gates 77 and discharge chutes 78 arranged along the low side of the chamber wall 73; by suitable adjustment of gates 77 a desirably close approach to uniform descent of bed 7 through the heating chamber can be realized. As treated solids are so removed, the descent of bed 7 enables "raw" solids gravitationally to feed onto the sloping stock-line of bed 7 from a plurality of spaced chutes 79 provided along the top of side wall 1 of the heating chamber, i. e., opposite that side wall in which the above-described discharge means are arranged. The bed 7 of the heating chamber illustrated in Fig. 7 is, in cross-section, a parallelogram two opposite angles of which are equal to the angle of repose of the solids; it is or desirably may be relatively broad and shallow.

As indicated in Fig. 7, the side walls 1 and 73 of the chamber are supported by a plurality of generally vertical structural members 80, 80, maintained in substantial parallelism by a plurality of upper and lower tie rods 81 and 82, respectively.

Fig. 7 illustrates a modified form of thermally insulated crossover somewhat similar to that shown in Fig. 6. It comprises a generally rectangular combustion chamber 85 communicating with upper open spaces 30 and 31' through conduits 86 and 86', respectively. Fluid fuel is introduced from valved pipe 26, into the combustion chamber 85 through one burner 88 or through a plurality of such burners spaced along the axis of chamber 85.

As will be appreciated, the form of construction illustrated in Fig. 7 lends itself to ready enlargement as to its length, by horizontally extending side walls 1 and 73, top 2 and grate 75, and by providing additional discharge and feed means for the so-provided extension of the heating chamber. To accommodate such an extension of the heating chamber, the combustion chamber 85 similarly may be longitudinally extended and may be connected to heating chambers A and B by a plurality of conduits 86 and a plurality of conduits 86', respectively, with additional burners 88 spaced along the extended roof.

In the operation of this apparatus; in direct

flow, air is forced through conduit 19 into lower open space 18 of heating chamber A and passes upwardly from the latter space through bed 7 to upper open space 30 and thence through conduit 86 combustion chamber 85 and conduit 86' into the upper open space of the similar heating chamber B (not shown in Fig. 7) and after passage through the latter ultimately is exhausted to atmosphere. In reverse flow, air is forced through chamber B conduit 86' combustion chamber 31 and conduit 86 into upper open space 30 of heating chamber A and thence through bed 7 to the lower open space 18 and through conduit 19 to the reversing valve 20 and exhausted to atmosphere. During these steps, fluid fuel may be continuously introduced by burner or burners 88 into combustion chamber 85 and burned in the current of treating gas, the amount of fuel so introduced being so controlled as to insure that treating gas passing from said combustion chamber into the upper open space 30 (or 30') is maintained at a predetermined optimum treating temperature, and treated solids are discharged in such manner that bed 7 has a relatively even descent and that a relatively even layer of raw solids is fed onto the stock-line.

As will be understood, particular modifications shown in Figures 3 to 7 inclusive may be combined in one apparatus. For instance, the crossover shown in Fig. 7 might be employed with the heating chambers shown in Fig. 1, or the burner arrangement shown in Fig. 1 might be employed in either of the crossovers shown in Figs. 6 and 7. The bell-and-hopper feeding means of Fig. 5 might be employed in connection with the chamber bottom constructions shown in Figs. 1, 3 or 4. Plural discharge tubes, such as are in Fig. 3, might be employed with the heating chamber illustrated in Fig. 1. It will be understood, also, that the discharge means may be so constructed and arranged as to provide for continuous (but controllably variable) discharge of treated solids, or for intermittent operation as desired.

Referring to the above specific example of operation, it will be seen that the treating gas (air) is always greatly in excess of the amount required for combustion of the fuel introduced through burners 24, 24', and therefore the treating gas entering the downstream bed is always strongly oxidizing.

It is to be understood that the positioning of the fuel-introducing means in the crossover as disclosed above is, while preferred, not necessary. The fuel can be let into open spaces 30, 30' by means (usually the above-described burners) positioned in the roofs, 2, 2' of chambers A and B of Figs. 1, 3, 4, 5 and 7 and so operated that the introduced fuel is mixed with the treating gas and combustion of the fuel is substantially completed before the thermally enriched treating gas passes into the second bed.

Example 2

The capacity of the apparatus described in Example 1 is relatively small. For treating a commercial tonnage, i. e., a million or more tons per year, the apparatus illustrated in Figure 7 is appropriate. The rectangular chambers A and B are 24 feet wide and 80 feet long (measured at right angles to the plane of the drawing). The beds 7 and 7' are 6 feet in vertical extent. The grate bars 75 are tipped at the angle of repose assumed by the pellets as fed on the stock-line, say, at 37°. The horizontal section of each bed

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is 1920 sq. ft.; the cross-section taken parallel to the plane of the grate is 2400 sq. ft. The density of the pellets being 129 lbs. per cu. ft. (dry basis), the weight of pellets in the bed is 665 gross tons (G. T.) when dry. At 45 minute intervals, 165 G. T. of finished product is removed by opening gate 77, and, concurrently, charges weighing 186 G. T. are fed on the stock-line from 78. The bed then consists in a lower layer 4.5 feet in vertical height of heat-hardened pellets on the top of which rests an 18-inch layer of raw pellets.

A flow of 61,000 cu. ft. per min. of atmospheric air (the treating gas) is forced through the bed. Producer gas at the average rate of 4900 cu. ft. per min. is introduced through burner 88. This fuel gas has the composition: CO_2 4.8, CO 23.4, C_2H_4 0.3, H_2 9.7, CH_4 2.4, N_2 59.4, exhibiting a gross heating value of 137.4 B. t. u. per cu. ft. and a net heating value of 129.7 B. t. u. per cu. ft. This is sufficient fuel to maintain the temperature in the open space 30 above the downstream bed at 2000° F. The volume of treating gas entering open space 30 is 66,200 cu. ft. per min., and the treating gas has the composition: CO_2 2.44, O_2 17.75, H_2O 2.25 and N_2 77.66, being thus strongly oxidizing (as was the treating gas in Example 1). As the gas flows downwardly through the 18 inch layer of raw pellets (initial moisture content 11%), a "heating wave" moves downwardly at the rate of 0.4 inch per min. This rate of heating is equivalent to a production of 3.65 G. T. per min. of dry pellets or 5270 G. T. per day. When the heating wave is first established at the upper surface of the layer of raw pellets, the average temperature gradient is 215° F. per inch. As the wave moves downwardly, the surface temperature of the pellets is raised from 60° F. to 2000° F. at the average rate of 86° F. per minute.

The to-and-fro motion of the several thermal waves in beds 7 and 7' may best be described by reference to Figure 8. In this drawing, the temperature distribution in chamber A is shown in the left-hand diagram, where vertical distance above the grate is given as abscissae, and temperatures in degrees F. are given as ordinates, and a similar diagram is shown for chamber B on the right. It is assumed that the operation is started at noon, at which time—for simplicity of explanation—all of the pellets in both chambers are assumed to be at 0° F. The apparatus is started on "reverse flow," the air from the blower 22 traveling vertically through chamber B upwardly, through open space 30', cross-over 86', 31 and 86, from right to left, and then downwardly through chamber A. By fuel combustion in the crossover, the temperature in open space 30 above bed 7 is maintained at 2000° F. After 12 minutes of reverse flow, the temperature distribution in chamber A is shown in the graph marked "12:12 p. m.," the 1000° isotherm being 4.8 inches below the stock-line. In the next 20 minutes, the thermal wave is displaced downwardly in chamber A to the position shown by the graph marked "12:30 p. m." At 12:45, the 1000° isotherm reaches the plane of contact of the raw pellets with the dry pellets, i. e., 18 inches below the stock-line. In order to be assured that the lowest layer of the raw pellets has been heated to a satisfactory treating temperature, say, 1900° F., it is necessary to continue reverse flow until 12:56. If it is desired to bring the coldest pellet in the layer to 1950° F., it is necessary to continue reverse flow until 1:10 p. m., when the temperature distribution is as shown

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in the right-hand graph of the two marked 1:10 p. m.

At this stage, it is possible to remove an 18-inch layer from the bottom of bed 7 in chamber A, in which case the temperature distribution is shifted abruptly downwardly 18 inches but without change in wave form, thus bringing the 1000° isotherm to a plane 2½ feet above the grate. At 1:10 it is then possible to charge a second 18-inch layer of raw pellets in chamber A and to continue reverse flow until 2:20 p. m. at which epoch the second charge will have been heated well above 1900° F.

With equal efficiency, it is possible at 1:10 p. m. to rotate reversing valve 20 and initiate "direct flow," having of course removed an 18-inch layer of finished product from the bottom of chamber B and simultaneously having fed in an 18-inch layer of raw pellets at the top of bed 7'. In direct flow, air from the blower 22 entering through the grate 75 at the bottom of chamber A passes upwardly through bed 7 being preheated in such passage to 1950° F. In this event, the supply of producer gas to the burner 88 may well be shut off, since the temperature of the treating gas flowing from left to right through the cross-over is already preheated to the treating temperature without the necessity of any fuel combustion. In direct flow, a thermal wave is established in bed 7' in chamber B in every respect similar to the previously described graph marked 12:12 p. m. in chamber A. This heating wave moves downwardly through bed 7' at the rate of 0.4 inch per minute.

As the cold air flows upwardly through bed 7 in "direct flow," the pellets therein are cooled down to entrant temperature (0° F.), and a "cooling wave" is forced upwardly through bed 7. The velocity of ascent of this cooling wave, however, is 0.52 inch per minute. The temperature of the air traversing the cross-over remains preheated essentially to 1950° F. until 1:55 p. m., whereupon the temperature of the preheat begins to diminish, somewhat slowly at first but with increasing rapidity, such that at 2:04 p. m. the temperature of preheat would have become as low as 1000° F. In order to maintain a constant treating temperature, it therefore is necessary continually to increase the flow of producer gas to burner 88 during the course of the direct flow. In operating the gas producer, it is frequently inconvenient to supply fuel gas to the burners at such a rapidly varying rate and in such an intermittent manner. It is obviously simple to even-out the flow of gas to the burners by opening the by-pass valve 34. When 61,000 cu. ft. per min. of air is blown upwardly through bed 7 as described above, the velocity of ascent of the cooling wave is 0.52 inch per min. If the stream of air from the blower is divided and if only 46,000 cu. ft. per min. is forced upwardly through bed 7 and 15,000 cu. ft. per min. is diverted around the bed, flowing through by-pass conduit 33 (not repeated in Fig. 7) and partially opened by-pass valve 34, the upward velocity of the cooling wave in bed 7 is decreased to 0.4 inch per minute, being thus identical with the velocity of descent of the heating wave in chamber B. With this operation, part of the air is preheated in passing upwardly through chamber A throughout the duration of the direct flow. When the 46,000 cu. ft. per min. of air preheated by passage through bed 7 commingles with the unheated 15,000 cu. ft. per minute which has by-passed the bed, it is found that 4900 cu. ft. of

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producer gas, admitted through the burner 88, is sufficient to maintain the temperature in the open space 30' above the bed 7' at 2000° F. This method of by-passing a suitable amount of air has the effect of holding the demand for producer gas constant. In the several applications of the present process, I contemplate using blast furnace gas, water gas, natural gas, coke-oven gas, and other gaseous and liquid fuels, e. g., oil or tar. In almost every case, a uniform supply of fuel to the burners is found technically desirable.

It should be understood that the thickness of the batch or layer of raw pellets charged on the stock-line can be varied over a rather wide range. As was pointed out, at 1:10 p. m. it was optional whether the operator removed an 18-inch layer of product from the bottom of chamber A or from the bottom of chamber B. In either election, it was not necessary to change, at that time, from "direct" to "reverse" flow. In fact, it was not necessary or particularly helpful for the operator in charge of removing finished pellets from the bottoms of the chambers to inform the operator in charge of reversing the valve 20 when he removed pellets from a chamber, or to tell him how much he removed, or from which chamber. In actual operation, I usually recommend that the control of valve 20 be delegated to a suitable electrically operated device controlled by a thermocouple placed in the exhaust main, and so adjusted that valve 20 is reversed whenever the exhaust gas rises to some chosen figure which may well be 150°, 250° or 300° F., or some such temperature. In like fashion, the removal of treated pellets from chambers A and B may be controlled automatically to fit some chosen time cycle, e. g., every 45 minutes or 75 minutes; with the provision that a temperature-measuring device be located in thermal contact with the discharged pellets, whereby the out-flow of pellets will be stopped automatically whenever the temperature of the pellets at discharge exceeds a selected limit such for example as 120° or 220° F., or the like. The productive capacity of a given chamber will, of course, be increased by setting a liberal upper limit on the discharge temperature of the pellets and of the exhaust gases. Such an increase in tonnage is gained, of course, at the expense of lowered thermal efficiency.

The rate of flow of fuel gas into the combustion chamber is preferably controlled automatically in response to thermocouples located in the open spaces above the two beds. In this fashion, the operation of the process can be made wholly automatic and no attention from the operator need be required.

Example 3

The two examples given above have been explained in terms of the heat-hardening of pellets or spheres of iron-ore fines which resulted from the concentration of low-grade iron ore, such as the taconites of Minnesota. Because of the fine grain-structure of this material, it is necessary to fine-grind raw ore in order to effect satisfactory concentration. The cost of fine-grinding is not inconsiderable. I have found that if I charge these silicious ores into the apparatus herein described and heat-treat them to a temperature above the alpha-beta quartz transformation point and thereafter cool the mineral to room temperature or thereabouts, the mechanical strength of the quartz is impaired with the result that subsequent fine-grinding is more easily effected. Since most silicious iron ores contain only neg-

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ligible amounts of water, this preliminary heat treatment can be carried out with little fuel and at small expense. The apparatus and operation described in Example 2 heat-treats relatively dry silicious ore at the rate of 7000 G. T. per day with an average producer gas consumption of 800 cu. ft. per minute.

Example 4

In delivering iron ore from mine to blast furnace, the cost of transportation is always significant and frequently a major factor. Many Lake Superior ores analyze 11% moisture with 2.5 to 3.5% combined water, while carrying a freight charge of several dollars per ton. It is, therefore, a specific objective of the present process to dry and roast ores at the mine, if for no other reason, in order to save freight. An example is a Mesabi ore containing 53.25 Fe with 11.60% moisture and 3.70% combined water. When dried by my process, there is a 15.30% decrease in weight equivalent to a 30 to 40¢ per ton of ore freight saving. The dry analysis of this ore is 60.21% Fe. It exhibits an iron content of 63.5% Fe, however, when heat-treated by the present process. Since the operating cost of the heat treatment seldom exceeds 10¢ to 15¢ per ton, the economy of the process is obvious.

Example 5

In the previous four examples, no change in the chemical composition of the mineral treated was illustrated. In my present invention, I do not preclude changes in chemical composition. The calcination of "nodules" from North Dakota manganese ores is in point. Such nodules may exhibit the following analysis: Mn 18.00%, Fe 11.60%, moisture 6.00%, and CO₂ 32.20%. The nodules comprise mixtures of dolomite, siderite and rhodochrosite. By heat-treating the material at 2200°, for example, the carbonates are calcined and the nodules lose 38.2% in weight. The dried and calcined nodules analyze 29.00% Mn and 18.95% Fe. In transporting these nodules to a furnace plant, the 38% saving in freight is more than sufficient to pay for the cost of the heat-treatment.

Example 6

The chemical reaction illustrated in Example 5 was merely the simple thermal decomposition of the carbonates of Fe, Mn, Ca and Mg. In Examples 1 to 5, the "treating gas" was in each case oxidizing. In many technically important applications of the present invention, however, it is desirable to carry out reduction reactions. Perhaps the simplest illustration of this is the "magnetic roasting" of silicious iron ores. In attempting to concentrate low grade iron ores, magnetic separation has been found expedient and effective. The method, of course, is normally applicable only to such ores as are naturally magnetic. Many low grade iron ores are hematites. A typical example is an ore containing 32.0% Fe (as Fe₂O₃), 50% SiO₂, 3% Al₂O₃ and 1.5% H₂O. In magnetically roasting this ore, I may prefer to use apparatus as illustrated in Figure 3. The treating chambers A and B could have an inside diameter of 32 ft. A special "treating gas" is recirculated by blower 22 at the rate of 120,000 cu. ft. per min. (standard volume) to which is continuously added 7400 cu. ft. per min. of producer gas of the composition given in Example 2. This recirculating treating gas is preheated to 1300° F. in passage through the upstream chamber and at entrance into the downstream

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bed exhibits a composition: CO_2 15.42, CO 2.10, H_2 1.33, H_2O 7.20 and N_2 73.95%. Such a gas is "mildly reducing," by which I mean it is effective in reducing Fe_2O_3 to Fe_3O_4 , but is not sufficiently reducing to convert Fe_3O_4 to FeO . In passing through the heated ore, reduction takes place and ferric oxide is converted to magnetite. The composition of gas exhausting from the downstream chamber is: CO_2 16.82, CO 0.70, H_2 0.35, H_2O 8.18%, and N_2 73.95%.

In flowing through the downstream chamber, a "reducing wave" is established in the bed which moves at the rate of 0.82 inch per minute thereby heating and "magnetically roasting" 3.44 G. T. of ore per minute (5000 G. T. per day). The reduction of ferric oxide to magnetite by CO is strongly exothermic. The rate of heat generation in the present case amounts to 380,000 B. t. u. per minute, far in excess of the heat necessary to compensate for the loss of heat through the brick lining of the apparatus and for the thermodynamically degraded heat lost in insufficiently cooled exhaust gases. The process operates with little or no fuel. In carrying out the above described process, the operation is identical with that described in Examples 1 to 5 with the exception that the "treating gas" is a mixture of re-cycled exhaust gas (transferred from exhaust conduit 23 to the inlet of the blower by a conduit, not shown) somewhat enriched with 6.16% of producer gas. In order to maintain constant volume in the circuit, it is necessary to discharge some 6% of the recirculating gas during each passage around the re-entrant circuit.

It is to be understood that the heat-treatment described in Example 6 is recommended when it is contemplated to concentrate magnetically a low-grade high-silica iron ore which is naturally non-magnetic. The heat treatment described in Example 6 converts hematite to magnetite and, at the same time, causes the silica to pass twice through the alpha-beta quartz transformation, thereby weakening the mechanical strength of the silica and facilitating fine-grinding. The magnetically roasted ore is then ground and magnetically separated. The magnetic heads or concentrates are rolled into pellets which may then be heat-hardened according to the methods described in Examples 1 and 2.

All of the examples given above have been illustrated in terms of metallic ores. The technical operations chosen for illustration have included removal of moisture, dehydration of combined water, thermal decomposition of carbonates and the conversion of hematite to magnetite. It is unnecessary to state that I contemplate the thermal treatment of quite a number of other minerals of which clays, bauxite, phosphate rock, chrome ore, manganese ore, and pyrites are suggestive. I contemplate applying the principles of the present invention to other reduction reactions, such for example as the conversion of magnetite to FeO , as well as reducing FeO to metallic iron. In other technical applications, I contemplate oxidizing FeO to magnetite and also oxidizing magnetite to ferric oxide.

One commercially important operation to which my process is applicable is that of subjecting high-sulphur ore to an oxidizing roast. Rather extensive reserves of iron ores are known, here and abroad, which are accessible, cheap and metallurgically acceptable except for their high content of sulphur as sulphide. The presence of any considerable amount of sulphide in iron ore renders the latter unacceptable as blast furnace

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charge material. Such high-sulphur ore is heat-treatable at elevated temperature, by my process, using an oxidizing gas (air) as the "treating gas," whereby to oxidize the sulphur content of the ore to sulphur dioxide, which latter escapes in the exhaust gas, leaving the iron as Fe_2O_3 . The reaction being exothermic, little or no fuel is required.

In the above several descriptions of my process and the conjugate illustrations of the apparatus adapted to carrying out the principles of the invention, I have made specific reference in each case, for the sake of simplicity of description, to two treating chambers only. It is to be understood, of course, that in any commercial operating plant I could employ a plurality of heating chambers. Thus, I may construct eight chambers which I may connect to form four pairs of chambers which I may choose conveniently to operate in parallel. Each of such pairs easily enough may be provided with individual blowers or equally well a single blower may be used to supply the treating gas to all four pairs.

There is no known essential reason, within the principles of the present process, which requires me to arrange such treating chambers in parallel pairs. As a matter of fact, I may employ six treating chambers arranged in series, with a single blower, and, I may operate by forcing a treating gas such as air to traverse the six chambers in series, causing the gas to flow upwardly through the first, third and fifth chambers and downwardly through the second, fourth and sixth chambers, on "direct flow." Interconnecting conduits or cross-overs are, in such case, positioned to connect the first chamber with the second, the third with the fourth, and the fifth with the sixth, at the top or between the respective upper open spaces. Connecting conduits might be positioned to interconnect the bottom of the second chamber, or lower open space, with the third, and the fourth with the fifth. One or more combustion chambers may be positioned in the gas circuit. In general, in operating a plurality of chambers quite a variety of parallel, series and parallel-series arrangements may be employed. For simplicity of definition and ease of illustration, it has been thought that the detailed description of the operation of a single pair would be sufficient to indicate the proper methods of applying the invention to the many obvious permutations and combinations which may appropriately be used in interconnecting the several treating chambers and in routing the treating gas therethrough.

In the alternative, one of the two or more "treating chambers" may function purely as a thermal regenerator, i. e., may be a thermally insulated chamber containing a gas-traversable bed of heat-absorbing solids, such as fire-clay shapes, sandstone pebbles, dead burned dolomite, chromite, fused alumina, and other refractory bodies, including particles heat-treated in a prior operation. These solids may remain in the chambers for any chosen length of time without being moved or replaced. In this arrangement, the operative steps are the same as described in Example 1, with the difference that material to be treated is treated only in one-half of the cycle. This of course decreases the productive capacity of the apparatus but not its thermal efficiency.

It has been pointed out above that the volume of a "batch" may be varied within rather wide

limits. It is specifically to be understood that the "batch" may be as large as the bed itself, and that in operation the whole bed may be withdrawn to leave the chamber completely empty for the moment, and thereafter a single batch may be charged to form a one-batch bed. While the chamber is empty, the flow of treating gas therethrough is terminated. In this operation, the bed is stationary while under treatment. Such operation incurs some loss of heat in the exhaust gas at the end of a heating cycle.

I claim:

1. Process of indurating consolidated masses, such as briquets, spheres, pellets, or the like, consisting of moist oxidic iron ore fines and similar finely divided metallurgical materials preparatory to reduction of the iron oxides in a reduction furnace such as a blast furnace, involving heating such pellets to an elevated temperature at which induration of the pellets occurs, which comprises establishing two substantially vertical gas-traversable columns of previously indurated pellets which columns are relatively shallow with respect to their cross-sectional area, maintaining at least the top portion of at least one of said columns, called the first column, at substantially indurating temperature, periodically adding a layer of raw moist pellets to the top of the other column, called the second column, said layer being limited in vertical height so as to avoid crushing therein, passing a current of air upwardly through at least the upper portion of the first column whereby to transfer heat from hot pellets therein to the air current, burning a fuel in the so-preheated air, after the same has traversed said first column, in quantity sufficient to raise the temperature of the air to indurating temperature, passing the so-heated air and products of such combustion downwardly through at least the upper portion of the second column, in the ratio of from about 8 to about 15 cubic feet of the heating gas per each 1 pound of initially raw moist pellets in said layer, whereby promptly to raise the temperature of the freshly charged layer of initially raw moist pellets therein by heat transfer from the heated gaseous current to and through the water-vaporizing temperature to indurating temperature, exhausting the resulting cooled gas to atmosphere, terminating the passage of gas serially through said first and second columns before the bottom portion of the second column has become materially heated, removing a layer, of limited thickness of indurated and cooled pellets from the bottom of said first column and adding a like volume of raw moist pellets to the top of said first column, passing a current of air upwardly through at least the upper portion of said second column, burning a fuel in the so-preheated air current, after the same has traversed said second column, in quantity sufficient to raise its temperature to indurating temperature, passing the so-heated current of gas downwardly through at least the upper portion of said first column, in the ratio of from about 8 to about 15 cubic feet of the heating gas per each 1 pound of initially raw moist pellets in the layer so added, whereby promptly to raise the temperature of the top layer of initially raw moist pellets therein by heat transfer from said heated gaseous current to and through the water-vaporizing temperature and to indurating temperature, exhausting the resulting cooled gas to atmosphere, terminating the passage of gas serially through said second and first columns before the bottom portion of said first

column has become materially heated, and repeating the alternation of steps.

2. Process of indurating small consolidated masses, such as briquets, spheres, pellets, or the like, consisting of moist oxidic iron ore fines and similarly finely divided metallurgical materials preparatory to reduction of the iron oxides in a reduction furnace such as a blast furnace, involving heating such pellets to an elevated temperature at which induration of the pellets occurs, which comprises establishing two beds of previously indurated pellets within two thermally insulated chambers each bed being bounded at the top and adjacent the bottom by two broadly extended boundary surfaces adapted to the ready ingress and egress of gases, the bed being relatively shallow with respect to its cross-sectional area, maintaining at least the upper boundary surface of one of said beds, called the first bed, at substantially indurating temperature, placing on the upper boundary surface of the other bed called the second bed a layer of raw moist pellets spread substantially uniformly over said surface, at least the lower part of said second bed being at substantially the temperature of the ambient air when said layer is placed, said layer being limited in vertical height so as to avoid crushing pellets therein, propelling a current of initially substantially unheated air through at least the upper portion of the first bed from the lower boundary surface to and through its upper boundary surface whereby to cool the hot pellets therein and to heat the air flowing therethrough, burning a fuel in the air, after travel through the first bed, in quantity sufficient to maintain the temperature of the air and associated combustion products at indurating temperature, passing the so-heated air and products of combustion downwardly through at least the upper portion of the second bed from its upper boundary surface to and through its lower boundary surface whereby promptly to heat the freshly charged layer of raw moist pellets therein by heat transfer from the gas to and through the water-vaporizing temperature and to indurating temperature, continuing the downward passage of air and combustion products through said second bed for a period sufficient to effect substantially complete induration of the pellets in said layer, exhausting the resulting cooled gas to atmosphere thereupon discharging a limited portion of pellets from the bottom of said first bed, placing on the upper boundary surface of said first bed a substantially uniform layer of raw moist pellets substantially equivalent in volume to the portion discharged from the bottom of said bed and reversing the direction of passage of said air serially through said beds.

3. Process defined in claim 1, wherein the said treating gas is oxidizing.

4. In the process of heat-treating and indurating small consolidated masses of moist ore fines and the like, the steps which comprise establishing two gas traversable beds of previously heat-treated and indurated masses of ore fines the upper portions of which are at an elevated temperature; adding a charge of essentially unheated untreated masses of moist ore fines to the top of one of said beds and removing an equivalent volume of heat-treated and indurated masses from the bottom of said bed; forcing an initially unheated treating gas upwardly through the other of said beds thereby preheating the treating gas and simultaneously cooling initially hot masses resident in said other bed; further heating

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the preheated treating gas to at least indurating temperature; and causing the heated treating gas to pass downwardly through the first mentioned bed, the hot gas impinging on said wet charge whereby rapidly to heat the latter through drying temperature to indurating temperature.

5. In the process of heat-treating and indurating small consolidated masses of moist ore fines and the like, the steps which comprise establishing two gas traversable beds of previously heat-treated and indurated masses of ore fines; adding a charge of essentially unheated untreated masses of moist ore fines to the top of one of the beds and removing an equivalent volume of heat-treated and indurated masses from the bottom of said bed; heating a treating gas to at least indurating temperature; causing the heated treating gas to pass downwardly through the said bed, the hot gas impinging on wet masses resident in the top portion of the bed whereby rapidly to heat the latter through drying temperature to indurating temperature; terminating the passage of hot gas into said bed before the masses in the bottom of said bed have become excessively heated; thereupon passing a current of initially substantially unheated treating gas upwardly through said bed thereby preheating said current by heat transfer from initially hot masses resident in said bed and transferring heat from said current to essentially unheated wet masses freshly

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deposited at the top of said bed; thereafter heating the treating gas to at least indurating temperature and passing the so-heated gas downwardly through the other of said beds; and repeating the alternate downward and upward passages of treating gas serially through said beds.

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