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2,925,336

PROCESS FOR THE PRODUCTION OF HARD BURNED AGGLOMERATES

Filed July 22, 1957

2 Sheets-Sheet 1

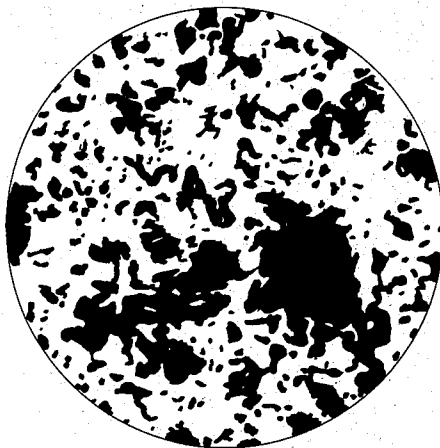


Fig. 6

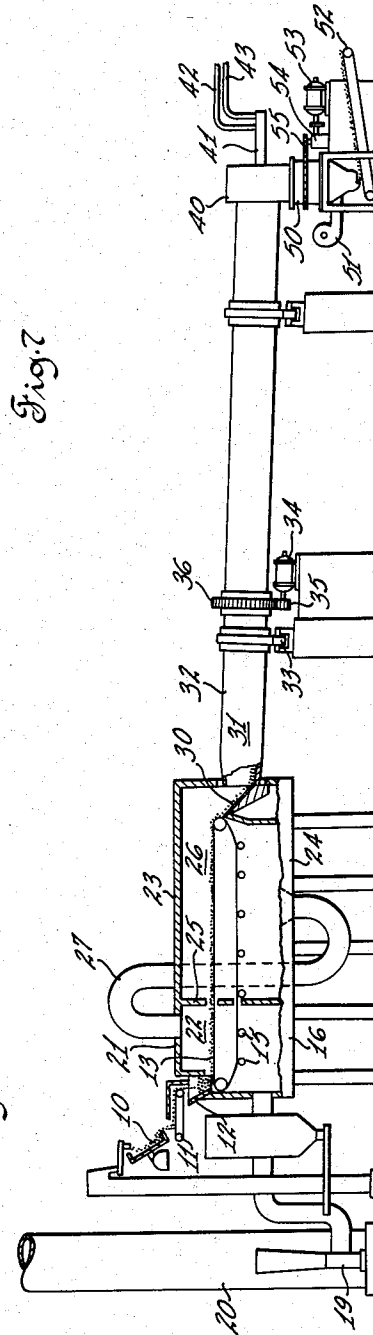


Fig. 7

Fig. 1

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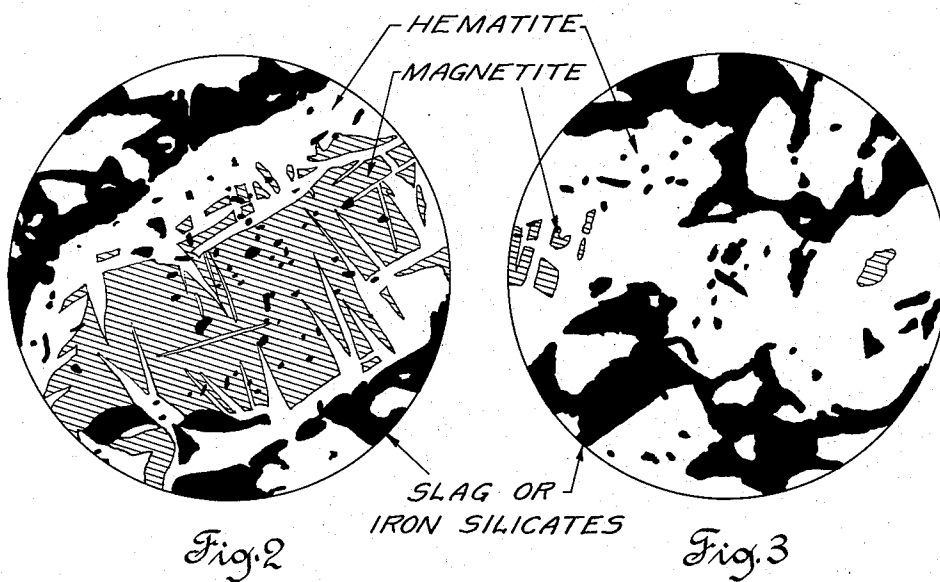
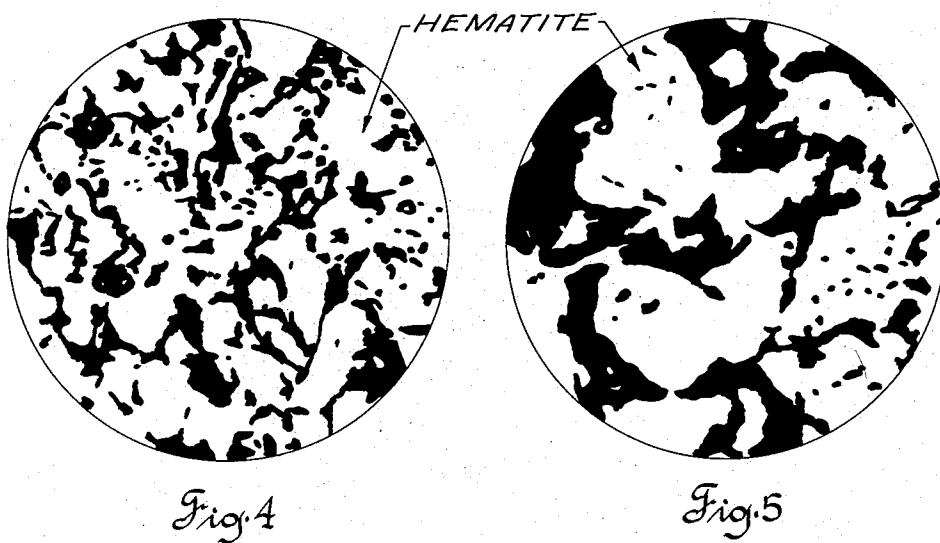
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PROCESS FOR THE PRODUCTION OF HARD BURNED AGGLOMERATES

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2 Sheets-Sheet 2



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1

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PROCESS FOR THE PRODUCTION OF HARD BURNED AGGLOMERATES

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Application July 22, 1957, Serial No. 673,279

11 Claims. (Cl. 75—3)

This invention relates generally to processes for agglomerating iron ores and particularly to processes for making hardened separate pellets of iron ore from finely divided iron oxide ores and concentrates thereof such as magnetite produced from taconites.

It is well known that fine powdery ore is unsuitable for treatment in blast furnaces, open hearth furnaces, and the like used in the iron and steel industries. A number of methods have been tried with varying degrees of success for agglomerating such fine ore particles to make them suitable for handling, shipping and use in blast furnaces or other types of smelting furnaces. Briquetting presses and extrusion pelletizers have been used, however operating maintenance costs have been undesirably high. Sintering, a commonly used method, requires high fuel consumption and as a process for finely divided concentrates has not been acceptable to industry. Sintering is generally used for screened ore fines of minus one-half inch or less. The product of sintering is a brittle, slag bonded, porous cake and will vary in physical characteristics. Sintering is a process that is used of necessity to reclaim flue dust and ore fines of the sizes obtained as a result of steel plant operations.

Rotary kilns have also been used to make nodules of powdered ore, however to produce the nodules it is necessary to have a slag bonding component or the nodule will not form. An additional result however of the presence of the slag component is the formation of an accretion build-up or ring inside the kiln. The kiln therefore must periodically be bored out to maintain operation. Pellets of ore concentrates are also burned in shaft type kilns. But the shaft kiln is not always dependable because of difficulties in obtaining uniform charging and discharging and uniform movement of material and gases through the interior of the shaft. These difficulties in shaft kiln operation can lead to nonuniform burning, hanging of the charge, and sintering together of pellets in parts of the kiln so as to hinder gas flow and promote further irregularities such as overburned clusters of material in some parts of the charge and underburned pellets in other parts of the charge. Pellets of ore concentrates are also burned on horizontal traveling grates. Several variations of burning on grates have been developed, such as one variation in which finely divided fuel is mixed with the ore before it is pelletized, and in another variation the pellets after they have been formed are coated with a finely divided fuel. With grate type heat hardening equipment side wall structure of some kind must be provided to keep the pellets on the grate. As a result of this side wall structure a nonuniform heat transfer to the pellets takes place.

It has been established that the product from the traveling grate and the shaft kiln have certain physical characteristics which are evidenced by the ability of pellets produced by these two means to withstand degradation from handling, shipping and stockpiling which the pellets are subjected to before they are finally placed in a blast furnace. The product from these processes has been

2

subjected to a tumbling test developed to establish an index of pellet resistance to degradation. It has been determined that these pellets when subjected to the established tumbling test produce from 13 to 15 percent minus 28 mesh fines. These fines have been observed to result from both pellet breakage and surface abrasion. Such fines produced by the handling and shipping of the pellets are detrimental to smelting processes.

The principal object of the present invention is to provide a new and improved process for heat treating agglomerates of finely divided iron ore to produce hard durable pellets which when subject to the established tumbling test referred to will produce virtually no broken pellets and will reduce fines produced by abrasion to the order of only 1 to 5 percent, thus producing a pellet of vastly superior resistance to degradation from handling and shipping.

Another object of the present invention is to provide a new and improved process for producing a more uniformly burned pellet of finely divided iron ore.

Another object of the present invention is to provide a new and improved process for heat treating pellets of iron ore in which dust and fines produced during early stages of the process will during later stages of the process be welded to the pellets before the pellets have completed their processing and are discharged from the processing equipment.

The process according to this invention is applied to a material comprising finely divided magnetite iron ore in a moist condition such as is generally produced by magnetic concentration of magnetic taconites.

The finely ground moist ore concentrate is first formed into small agglomerates or green water bound pellets. The pellets may be formed in any desired known manner such as by briquetting, extrusion processes, balling drums or balling pans. Briquetting or extrusion processes are less desirable than balling drums or pans. With balling drums or balling pans it is well known that pellets can be produced without a binder or plasticizer other than water, however it may sometimes be desirable to utilize an additive such as a fraction of a percent of bentonite.

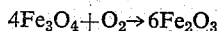
The green pellets are formed into a body of pellets that is movable as a body with individual pellets being at rest within the body. This may be accomplished by forming the pellets in a layer upon a movable gas permeable support such as a grate. It has been found that a layer of about seven inches deep will give good results with green pellets averaging in size between one-half and three-fourths of an inch in diameter.

At least first and second gas confining zones are established through which the body of the pellets can be conveyed. With a body of pellets such as a layer on a moving grate, the first and second gas confining zones may be established by all structure around the grate. The body of pellets is conveyed through the first and second zones and discharged into a third zone. The pellets are tumbled through this third zone. The third zone may be established by providing apparatus such as a generally horizontal rotary kiln. Rotation of the rotary kiln about its central axis will achieve the desired tumbling action of the pellets.

A flow of highly heated strongly oxidizing gases is effected that is countercurrent to path of movement of the tumbling pellets. This may be accomplished by providing a combustion device at the discharge end of the rotary kiln and admitting air to the discharge end of the kiln in quantities in excess of the requirements to support combustion of fuel. After the highly heated oxidizing gases have passed through the third zone these gases are passed through the body of the pellets within the second zone and then again through the body of pellets in the

first zone. This may be accomplished by directing the gases discharged from the rotary kiln into the wall structure defining the second zone and directing these gases to pass downwardly through the body of pellets on the grate within the second zone. The gases after they have passed through the body of pellets in the second zone can be directed from the wall structure defining the second zone to the wall structure defining the first zone and then directed to make a second pass downwardly through the body of pellets in the first zone.

The temperature of the oxidizing gases and the rate of movement of the body of pellets through the first and second zones are correlated to heat treat the pellets sufficiently to withstand the tumbling action in the third zone wherein the final hardening of the pellets takes place. This is accomplished by first heating the pellets in the first zone sufficiently to drive off the moisture from the pellets and dry them. Then additional heat is applied to the pellets in the second zone to preheat and initiate the conversion of the magnetite in the pellet to hematite. This is accomplished by heating the pellets in the highly oxidizing atmosphere to a temperature between approximately 1600° F. and 1800° F. This transformation can be symbolically expressed by the formula



After having reached a temperature of at least approximately 1600° F., the grains comprising the pellets are at least superficially oxidized to hematite. During the oxidation reaction, individual grains of transformed hematite bridge together by grain growth and recrystallization, in the solid state, without reaction with available silica, to initiate a structure of the mineral component forming the pellet. The oxidized pellet, having been raised to a temperature of from 1600° F. to 1800° F. has developed, from the grain growth of its mineral constituent, sufficient strength to withstand the tumbling action in the third zone. This crushing strength of pellets on the second is of the order of one to two hundred pounds. The amount of bridging of the grains of the pellets, in the temperature range existing in the second zone, is sufficient to give strength to the pellet to withstand tumbling in the third zone but will not cause the pellets to stick together because of the small amount of contact between the pellets.

To provide final heat treating of the pellets, the pellets are discharged from the second zone into the third zone where they are tumbled and subjected to highly heated oxidizing gases to maintain and develop the hematite structure within each pellet to complete the network of bridged hematite crystals. This is accomplished by subjecting the pellets to a maximum temperature in the range of at least about 2200° F. but not more than about 2450° F. thereby maintaining the pellets at a temperature below the sintering temperature of the ore. "Sintering temperature," as used herein, means that temperature at which the incipient fusion of certain constituents of the ore particles occurs. When the pellets have reached a temperature of about 2200° F. a continuous network of hematite crystals will exist in the pellets which has caused an increase in pellet strength. In addition dust or fines that might have resulted from the movement of the pellets prior to their attaining adequate strength to resist degradation are picked up by the tumbling pellets thus providing an extremely low percentage of fines and dust in the gases passing through the second and first zones. The additional filtering action of the gases passing through the body of pellets in the second and first zones results in an overall reduction of dust and fines produced.

Since the maximum temperature of the pellets is not permitted to exceed approximately 2450° F. the hematite in the pellets will not thermally decompose back to magnetite. Since there will be no magnetite in the pellets

and since the pellets will not be raised to decomposition temperatures there will be no slag produced. By eliminating the possibility of slag formation the danger of ring formation in a rotary kiln is also eliminated. High pellet strength is assured by the absence of slag. Slag or iron silicates are the weakest component in the pellet and pellets containing such are brittle and have a much lower crushing strength than that attained by the heat treatment in the third zone of this process.

The pellets produced by this process are so hard that they will scour the lining of refractory equipment such as the rotary kiln which may be used for the final burning.

For convenience and clarity, the process will be further described as proposed to be continuously carried out on equipment of the traveling grate and rotary kiln type shown schematically in Fig. 1 of the drawings.

Fig. 2 is a drawing of a microphotograph of a pellet that has been dried and preheated to initiate the conversion of magnetite in the pellet to hematite. This figure also shows that individual grains of hematite are bridging together by grain growth and recrystallization in the solid state. The gray area in the grain shown is magnetite and the white area is oxidized magnetite, transformed to hematite.

Fig. 3 is a drawing of a microphotograph of a pellet as shown in Fig. 2 when very little of the magnetite remains in the grains and substantial bridging of the grains has taken place.

Fig. 4 is a drawing of a microphotograph of a pellet that has been heated sufficiently to substantially complete the conversion of magnetite to hematite and develop a network of bridged crystals having sufficient strength to withstand the tumbling action during the final burning of the pellets according to this process.

Fig. 5 is a drawing of a microphotograph similar to Fig. 4 but to greater magnification showing the bridging together of individual grains of hematite to provide the network referred to.

Fig. 6 is a drawing of a microphotograph of a pellet after final burning according to this invention. In this figure it can be seen that when a pellet has been burned according to this invention in a temperature range of at least about 2200° F. but not more than about 2450° F. that recrystallization and grain growth will have taken place to provide a continuous network of hematite crystals within the pellet to provide greatly increased pellet strength over that shown in Figs. 4 and 5.

Fig. 7 is a drawing of a microphotograph of a pellet showing the effect of overheating the pellet during final burning. This shows a pellet that has been burned to over 2400° F. It can be seen that the gray areas which are magnetite are beginning to reappear as the hematite in this temperature range converts back to magnetite.

For convenience and clarity, the process will be further described as it may be continuously carried out on the equipment shown schematically in Fig. 1 of the drawing. Green water bound pellets of concentrated magnetite ore may be formed in a pelletizing pan 10 of conventional construction. The pelletizing pan 10 may discharge pellets on a conveyer belt 11 for transferring them to a hopper 12 that in turn deposits them on a moving grate 13.

The grate 13 is a gas permeable grate with openings fine enough to retain the pellets being handled, and will be of heavy cast iron bar or perforated plate construction of heat resistant steel. As shown, the grate 13 is of the same general type as is now known in the sintering machine art and consists of an endless chain of grates traveling over mechanically rotated supporting rolls 15. The upper portions of the grate 13 will be supported mechanically by known structure (not shown) placed between the rolls.

Beneath the generally horizontal working surface of the grate 13 and under the feed end, a first suction box 16 is arranged with an opening connected to an exhaust

5

fan 19 and a stack 20 for discharging gases from the first suction box 16 to the atmosphere. Above the suction box 16 and adjacent the feed end of the grate 13 is a hood 21 extending over the grate 13 to create a first chamber 22 through which all material on the grate 13 must pass.

Adjacent the first hood 21 and in the direction of grate travel is a second hood 23 over a second suction box 24 which with wall structure 25 forms a second zone 26 through which all material on the grate must pass. The second suction box 24 which is beneath the second zone 26 is connected to the first hood 21 by a tube 27 to direct gases that have passed through the grate 13 in the second zone 26 to the first hood for passing such gases through the grate moving through the first zone 22.

Adjacent the end of the traveling grate 13 remote from the feed hopper 12 is an inclined surface 30 for receiving pellets from the traveling grate and discharging the pellets into a third zone 31 within a rotary kiln 32. The rotary kiln 32 may be of relatively conventional construction having roller supports 33 for supporting the kiln at various points along its entire length. The kiln may be rotated in the conventional manner by providing a motor driven shaft 34 and gear 35 for engaging a girth gear 36 around the body of the kiln 32. The end of the rotary kiln 32 remote from the traveling grate 13 is enclosed with a firing hood 40. A burner 41 may be provided that projects inwardly through the hood 40 that is supplied with fuel through a tube 42 and primary combustion air through a tube 43. A cooler 50 may be provided directly beneath the firing hood 40 for receiving the burned pellets from the kiln 32. Secondary air for cooling the pellets may be injected into the cooler structure by a secondary blower 51. It is desirable that the cooler be of the type having cooling air passing upwardly or countercurrent to descending pellets. After the pellets have been cooled they may be discharged from the bottom of the cooler 50 onto a conveyer 52 for delivering the cooled pellets to some convenient or desirable location. The cooler 50 may be of the general type described and claimed in the copending United States application of Otto G. Leliep, Serial Number 591,321, filed June 14, 1956. With this type of cooler the cooler body is rotated about a vertical axis as shown by a motor 53 driving a speed reducer 54 which in turn drives a gear 55 that turns the cooler body about a central vertical axis.

The process is carried out on the described apparatus by placing the green water bound pellets on the grate 13 thus forming a body of pellets that is movable as a body with individual pellets being addressed within the body of pellets. As previously stated, it has been found that a layer of about seven inches deep will give good results with green pellets averaging in size between one-half and three-quarters of an inch in diameter. The body of pellets established on the grate 13 is then passed through the first zone 22 and then through the second zone 26 and discharged into the third zone 31 established within the rotary kiln 32. The pellets are then tumbled through the third zone 31 in the kiln 32 and discharged into the cooler 50. The pellets will tumble through the kiln as a result of the rotation of the rotary kiln about its central axis and the fact that the kiln is tilted downwardly toward the cooler.

A flow of highly heated strongly oxidizing gases is effected that is countercurrent to the movement of the pellets through the third zone 31. Fuel and primary combustion air delivered through the tubes 42, 43 connected to the burner will provide a flame extending into the rotary kiln. The quantity of air supplied by the secondary blower 51 for countercurrent flow through the pellets in the cooler 50 will insure a sufficient excess of air being admitted to the rotary cooler to provide the strongly oxidizing heated gases required by this process.

6

The highly heated oxidizing gases, after they have passed through the third zone 31 in the rotary kiln 32 countercurrent to the flow of tumbling pellets within the kiln, are delivered to the interior of the hood 23 defining the second zone 26 over the pellets on the moving grate. The exhaust fan 19 associated with the stack 20 will draw the heated oxidizing gases from the second zone 26 above the moving grate 13 through the pellets on the moving grate and into the second wind box 24 below the grate and then through the tube 27 to the hood 21 defining the first zone 22 over the moving grate. From the first zone 22 the gases will be drawn downwardly through the pellets on the grate into the first wind box 16 beneath the first zone from where the gases will pass to the atmosphere up through the stack 20. Sufficient quantity of air must be provided to cool the pellets to a temperature at which they can be handled, maintain combustion of the fuel admitted through the burner and to maintain a flow of strongly oxidizing gases through the zones of treatment established to treat the pellets. It has been determined that these requirements can be met by admitting sufficient air through the cooler to provide in the kiln about 50 percent more air than that theoretically required to maintain the combustion of fuel. It has also been determined that optimum thermal efficiency for the process will result from providing about 240 percent more air than that required to maintain combustion of the fuel necessary to create the temperatures required to carry on the process.

The temperature of the oxidizing gases required in this process is determined and controlled by the amount of fuel burned and the amount of air and the preheat temperature of such air admitted to the rotary kiln. The temperature of the oxidizing gases and the rate of movement of the body of pellets through the system is correlated so that the oxidizing gases, which at the discharge end of the rotary kiln 32 are maintained at about 2450° F., are at the grate end of the rotary kiln about 1800° F. As the gases pass into the second zone 26 and downwardly through the bed of pellets into the second wind box 24 some of the heat will be transferred from the gases to the moving pellets. The depth of the layer of pellets on the grate 13 and the rate at which the pellets are moved through the second zone will determine how much the pellets are heated in the second zone and how much heat will remain in the gases that reach the second wind box. These factors are to be controlled so that the gases delivered to the first zone 22 above the moving grate will be of the order of 500 to 900° F. The temperature ranges referred to in each of the three zones, the first two over the moving grate and the third in the rotary kiln, have been determined to be practical so that the rate of pellet transfer through the three zones can be controlled in accordance with the objects of this invention. With the temperatures of the order referred to the rate of pellet transfer through the zones 22, 26, 31 can be controlled so that within the first zone the pellets will be heated sufficiently to drive off substantially all of the moisture from the pellets and provide dry pellets for treatment in the second zone. Additional heat is applied to the pellets within the second zone to preheat them and initiate the conversion of the magnetite in the pellet to hematite. As previously stated this is accomplished by heating the pellets in the highly oxidizing atmosphere to a temperature between approximately 1600° F. and 1800° F. Figs 2, 3, 4 and 5 show the transformation that takes place within the pellets before they are discharged into the third zone 31 within the rotary kiln 32. Fig. 2 shows a grain of what was magnetite as it is changing to hematite. The white area is hematite and the light gray area magnetite. The dark gray spots within the pellet shown in Fig. 6 are particles of silica which are slag forming agents and would form a slag if they were to combine with magnetite. However, before the pellet reaches a tempera-

7

ture which will allow the silica to react with the magnetite, the magnetite will have changed to hematite. As the magnetite changes to hematite the needles of hematite that can be seen in Fig. 2 project themselves into the remaining areas of magnetite as the conversion takes place. This figure also shows the beginning of grain growth and recrystallization of the pellet that begins to form a network of bridged grains. Fig. 3 which is slightly greater magnification than Fig. 2 shows grains of the pellet that have almost completely changed from magnetite to hematite. It can be seen that very little of the gray area, which is magnetite, remains in these grains. It can also be seen that the grain growth has proceeded to make a substantial bridge between the three principal grains shown in this figure. As the pellets continue to travel through the second zone the last remaining magnetite will continue to convert to hematite. Fig. 4 shows a pellet that has completely converted from magnetite to hematite. It can be seen in this figure that recrystallization has taken place and grain growth has proceeded sufficiently to create a network of joined grains that can be seen in Figs. 4 and 5. Fig. 5 is similar to Fig. 4 but to greater magnification. The grain growth and bridging of individual grains to initiate a network of crystals shown in Figs. 2, 3, 4 and 5, will impart increased physical strength to the pellet in the range of from one to two hundred pounds crushing strength depending on the extent of the development of the network within the pellet. Pellets are thereby provided having sufficient strength to withstand the tumbling action in the third zone 31 within the rotary kiln 32. At the temperature ranges established in the first and second zones there will not be sufficient bridging of grains of the mineral constituents to cause separate pellets to stick together because of the merely slight amount of physical contact between the separate pellets.

When the pellets are discharged from the moving grate 13 into the third zone 31 within the rotary kiln 32 they are burned to a temperature of about at least 2200° F. but not more than about 2450° F. As the pellets are heated to this temperature range they are tumbled through the rotary kiln thus continually exposing new surface areas of the pellets to the hot gases within that zone and thereby producing a very uniformly burned pellet. During this stage of the heat treatment of the pellet, the tumbling pellets may pick up and forge onto the pellet dust or fines.

The final burning that takes place in the third zone 31 within the rotary kiln 32 produces a pellet shown in Fig. 6. This figure shows how grain growth and recrystallization has proceeded to a point where a continuous network of hematite crystals exists. This continuous network provides a pellet with greatly increased strength. This figure also shows a portion of silica embedded in the hematite network. The silica shown in this figure has not become slag but has remained as a dormant particle of silica within a surrounding body of hematite. If the temperature of the pellets in the third zone within the rotary kiln is permitted to get above about 2450° F. then hematite will begin to decompose back to magnetite. Magnetite at such a temperature range would then combine with available silica to form slag which would result as previously stated in a weaker pellet and an accretion build-up of a ring within the rotary kiln. Fig. 7 shows a portion of a pellet undergoing such reconversion from hematite to magnetite. In this photograph it can be seen that the gray areas of the individual grains which are magnetite are beginning to reappear. Continued exposure to temperature above approximately 2450° F. would complete the conversion of hematite back to magnetite and result in the magnetite combining with silica to form slag. With the process controlled so as to burn the pellets to a temperature of 2200 to approximately 2450° F. but not over approximately 2450° F. the pellet shown in Fig. 6 will be pro-

8

duced. This pellet has the desired strength to withstand handling, shipping and charging to a smelting furnace. This pellet has been subjected to the tumbling test previously referred to and it has been determined that this pellet will be so hard that it will not break as the result of the tumbling test and that fines produced by abrasion of one pellet on another will be reduced to the order of one to five percent or an improvement of from 2½ to 15 times that which is produced by burning on a traveling grate alone or in a shaft type kiln.

From the foregoing it will be apparent to those skilled in this art that the process described provides a new and improved way of producing pellets of concentrated iron ore for use in a blast furnace or other smelting apparatus and accordingly accomplishes the objects of this invention. On the other hand, it will also be obvious to those skilled in the art that the process may be varied or modified without necessarily departing from the spirit of the invention or sacrificing all of the advantages thereof. Accordingly, the disclosure herein is illustrative only and the invention is not limited thereto.

What is claimed is:

1. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of a preselected size out of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing at least first, second and third gas confining zones; conveying said body of pellets through said first and second zones at a first preselected rate; discharging said body from said third zone while simultaneously disrupting said body and imparting movement to said pellets relative to each other; tumbling said pellets through said third zone at a second preselected rate to maintain the movement of said pellets relative to each other; effecting a flow of highly heated gases containing a surplus of oxidant successively through said third zone countercurrently to said movement of said tumbling pellets therein, through said body in said second zone, and through said body in said first zone; and correlating the temperature of said heated gases simultaneously with said preselected pellet size and said first preselected rate to transform said individual green pellets into dry, preheated discrete pellets containing hematite (as evidenced by the growth of individual grains of hematite into bridging relationship with adjacent grains and a pellet strength capable of withstanding said tumbling) for discharge from said second zone to said third zone, and with said preselected pellet size and said second preselected rate to transform said dry, preheated discrete pellets containing hematite into hard, unsintered discrete pellets, each having a continuous network of bridged hematite there-through.

2. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of a preselected size out of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets stationary relative to each other within said body; establishing at least first, second and third gas confining zones; conveying said body of pellets through said first and second zones at a first preselected rate; discharging said body from said second zone to said third zone while simultaneously disrupting said body and imparting free movement to said pellets relative to each other; tumbling said pellets through said third zone at a second preselected rate to maintain the free movement of said pellets relative to each other; effecting a flow of highly heated oxidizing gases countercurrently to said movement of said pellets successively through said free moving pellets in said third zone, through said body of said relatively stationary pellets in said second zone, and through said body of said relatively stationary pellets in said first zone, and the temperature of said heated

oxidizing gases being correlated simultaneously with said preselected pellet size and said first preselected rate to transform said individual green pellets into dry, preheated discrete pellets containing hematite (as evidenced by the growth of individual grains of hematite into bridging relationship with adjacent grains and a pellet strength capable of withstanding said tumbling) for discharge from said second zone to said third zone, and with said preselected pellet size and said second preselected rate to transform said dry, preheated discrete pellets containing hematite into hard, unsintered discrete pellets, each having a continuous network of bridged hematite therethrough.

3. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of a preselected size out of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing at least first, second and third gas confining zones; conveying said body of pellets through said first and second zones at a first preselected rate; discharging said body from said second zone to said third zone while simultaneously disrupting said body and imparting movement to said pellets relative to each other; tumbling said pellets through said third zone at a second preselected rate to maintain the movement of said pellets relative to each other; burning fuel to provide a flame; supplying said flame with oxygen of 50 to 240 percent in excess of the oxygen required to support the combustion of said fuel to provide a supply of highly heated strongly oxidizing gases; effecting a flow of said highly heated strongly oxidizing gases from said supply successively through said third zone countercurrently to said movement of said tumbling pellets therein, through said body in said second zone, and through said body in said first zone, said gases being at a temperature with respect to said preselected pellet size and said first preselected rate to transform said individual green pellets into dry, preheated discrete pellets containing hematite (as evidenced by the growth of individual grains of hematite into bridging relationship with adjacent grains and a pellet strength capable of withstanding said tumbling) for discharge from said second zone to said third zone, and said gases being at a temperature with respect to said preselected pellet size and said second preselected rate to transform said dry, preheated discrete pellets containing hematite into hard, unsintered discrete pellets, each having a continuous network of bridged hematite therethrough.

4. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of a preselected size out of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing at least first, second and third gas confining zones; effecting a flow of highly heated oxidizing gases successively through said third, said second and said first zones; conveying said body of pellets through said first and second zones at a first preselected rate while simultaneously passing said heated gases through said body in said second and first zones until said individual green pellets are transformed into dry, preheated discrete pellets containing hematite (as evidenced by the growth of individual grains of hematite into bridging relationship with adjacent grains and a pellet strength capable of withstanding the forging action of impact during tumbling); discharging said body of dry, preheated discrete pellets from said second zone to said third zone while simultaneously disrupting said body into a plurality of discrete pellets and fines movable relative to each other and tumbling said pellets through said third zone at a second preselected rate to maintain the movement of said pellets and said fines relative to each other and to promote collision impact therebetween to forge said fines to said pellets while passing

said heated gases countercurrently to said movement of said tumbling forging pellets therein until said dry, preheated discrete pellets and fines containing hematite are transformed into hard, unsintered discrete pellets with substantially no fines, each of said pellets having a continuous network of bridged hematite therethrough.

5. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing first, second and third zones; conveying said body of pellets through said first and second zones; disrupting said body of pellets and tumbling said pellets through said third zone; effecting a flow of heated oxidizing gases successively through said third, second and first zones, the temperature in each of said zones being maintained below the sintering temperature of said ore; maintaining said body of pellets in said second zone until said pellets are dry, preheated, and have individual grains of hematite within each pellet, which have commenced to grow into bridging relationship with adjacent grains of hematite; then, before said grain growth becomes a continuous network therethrough, discharging said pellets into said third zone; and continuing said tumbling of said pellets in said third zone until said grain growth becomes a continuous completed network of bridged grains of hematite in each of said pellets.

6. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing first, second and third zones; conveying said body of pellets through said first and second zones; disrupting said body of pellets and tumbling said pellets through said third zone; effecting a flow of heated oxidizing gases successively through said pellets in said third zone and through said body in said second and first zones to heat said pellets and said body while maintaining their respective temperatures below the sintering temperature of said ore; maintaining said body of pellets in said second zone until said pellets are dry, preheated, and have individual grains of hematite within each pellet, which have commenced to grow into bridging relationship with adjacent grains of hematite; then, before said grain growth becomes a continuous network therethrough, discharging said pellets into said third zone; and continuing said tumbling of said pellets in said third zone to complete growth of hematite grains and recrystallization thereof until said grain growth becomes a continuous completed network of bridged hematite crystals throughout each of said pellets.

7. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing first, second and third zones; conveying said body of pellets through said first and second zones; disrupting said body of pellets and tumbling said pellets through said third zone; burning fuel to provide a flame; supplying oxygen to said flame in excess of requirements for combustion of said fuel to provide a supply of heated oxidizing gases; effecting a flow of said heated oxidizing gases successively through said third, second and first zones, the temperature in each of said zones being maintained below the sintering temperature of said ore; maintaining said body of pellets in said second zone until said pellets are dry, preheated, and have individual grains of hematite within each pellet, which have commenced to grow into bridging relationship with adjacent grains

of hematite; then, before said grain growth becomes a continuous network therethrough, discharging said pellets into said third zone; and continuing said tumbling of said pellets in said third zone until said grain growth becomes a continuous completed network of bridged grains of hematite in each of said pellets.

8. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore, the process comprising: making individual green pellets of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing first, second and third zones; conveying said body of pellets through said first and second zones; disrupting said body of pellets and tumbling said pellets through said third zone; effecting a flow of heated oxidizing gases successively through said third, second and first zones; maintaining said body of pellets in said second zone at a temperature of approximately 1600° F. to 1800° F. until said pellets are dry, preheated, and have individual grains of hematite within each pellet, which have commenced to grow into bridging relationship with adjacent grains of hematite; then, before said grain growth becomes a continuous network therethrough, discharging said pellets into said third zone; and continuing said tumbling of said pellets in said third zone at a temperature beneath the fusion temperature of said iron ore, said temperature being from about 2200° F. to about 2450° F., until said grain growth becomes a continuous completed network of bridged grains of hematite in each of said pellets.

9. A process for making hard, unsintered, separate pellets from finely divided magnetite iron ore, said process comprising the steps of making green pellets of said finely divided ore, forming said pellets into a movable body with individual pellets at rest within said body, drying said pellets in said body by heating them to drive off moisture, then preheating said pellets in said body and oxidizing said magnetite to hematite to cause individual grains of hematite to bridge together by grain growth but without slag formation; then, before said grain growth becomes a continuous network therethrough, tumbling and heating said tumbling pellets in an oxidizing atmosphere to complete growth of hematite grains and recrystallization thereof to provide a continuous network of bridged hematite crystals throughout each pellet without formation of slag while maintaining the temperature of said pellets below the sintering temperature of said ore.

10. A process for making hard, unsintered, separate pellets from finely divided magnetite iron ore, said process comprising the steps of making green pellets of said finely divided ore, forming said pellets into a movable body with individual pellets at rest within said body, drying said pellets by heating them to drive off moisture, then preheating said pellets in said body and

oxidizing said magnetite to hematite by raising the temperature of said pellets in a highly oxidizing atmosphere to 1600° to 1800° F. to cause individual grains of hematite to commence to grow into bridging relationship with adjacent grains of hematite; then, before said grain growth becomes a continuous network therethrough, tumbling and heating said tumbling pellets until said grain growth becomes a continuous network of bridged hematite crystals in each of said pellets without the formation of slag, said heating of said tumbling pellets being in an oxidizing atmosphere having a maximum temperature of 2200° F. to 2450° F.

11. For making hard, unsintered, dense, discrete hematite pellets from finely divided iron ore containing magnetite, the process comprising: making individual green pellets of said finely divided ore; forming said individual green pellets into a movable gas permeable body with said pellets at rest relative to each other within said body; establishing first, second and third zones; conveying said body of pellets through said first and second zones; disrupting said body of pellets and tumbling said pellets through said third zone; burning fuel to provide a flame; supplying oxygen to said flame in excess of requirements for combustion of said fuel to provide a supply of heated oxidizing gases; effecting a flow of said heated oxidizing gases successively through said pellets in said third zone and transversely through said body in said second and first zones; maintaining said body of pellets in said second zone at a temperature of approximately 1600° to 1800° F. until said pellets are dry, preheated, and have individual grains of hematite within each pellet, which have commenced to grow into bridging relationship with adjacent grains of hematite; then, before said grain growth becomes a continuous network therethrough, discharging said pellets into said third zone; and continuing said tumbling of said pellets in said third zone at a temperature beneath the fusion temperature of said iron ore, said temperature being from about 2200° F. to about 2450° F., until said grain growth becomes a continuous completed network of bridged grains of hematite in each of said pellets.

References Cited in the file of this patent

UNITED STATES PATENTS

1,153,203	Drefahl	Sept. 14, 1915
2,590,090	De Vaney	Mar. 25, 1952
2,750,272	Lellep	June 12, 1956
2,766,109	Komarek et al.	Oct. 9, 1956

OTHER REFERENCES

- Mining Engineer (1), December 1952, pp. 1223-1230.
 Mining Engineering (2), November 1952, pp. 1053-1058.
 Blast Furnace and Steel Plant, July 1955, pp. 745-752.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,925,336

February 16, 1960

William F. Stowasser, Jr.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 8, line 32, after "said", second occurrence, insert
-- second zone to said --; column 9, line 14, for "diided" read
-- divided --; column 10, line 13, for "zones:" read
-- zones; --.

Signed and sealed this 9th day of August 1960.

(SEAL)

Attest:

KARL H. AXLINE

Attesting Officer

ROBERT C. WATSON

Commissioner of Patents