May 6, 1941. LE ROY E. SCHIFFMAN ET AL 2,240,718

CONCENTRATION OF ORES

Filed Aug. 13, 1938 3 Sheets-Sheet 1

Fig. 1.

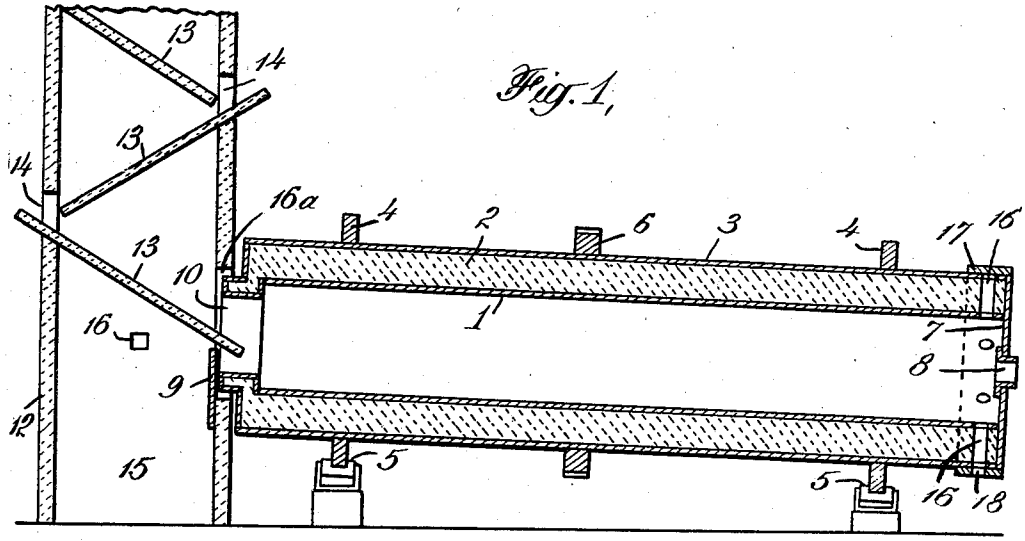
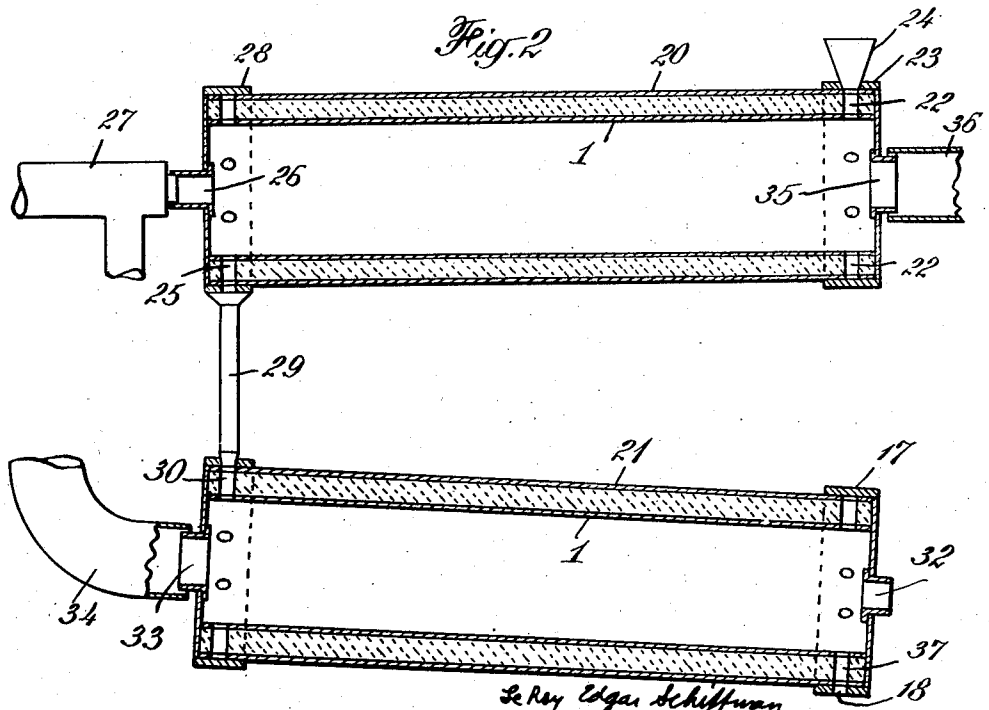



Fig. 2.




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CONCENTRATION OF ORES

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Fig. 3,

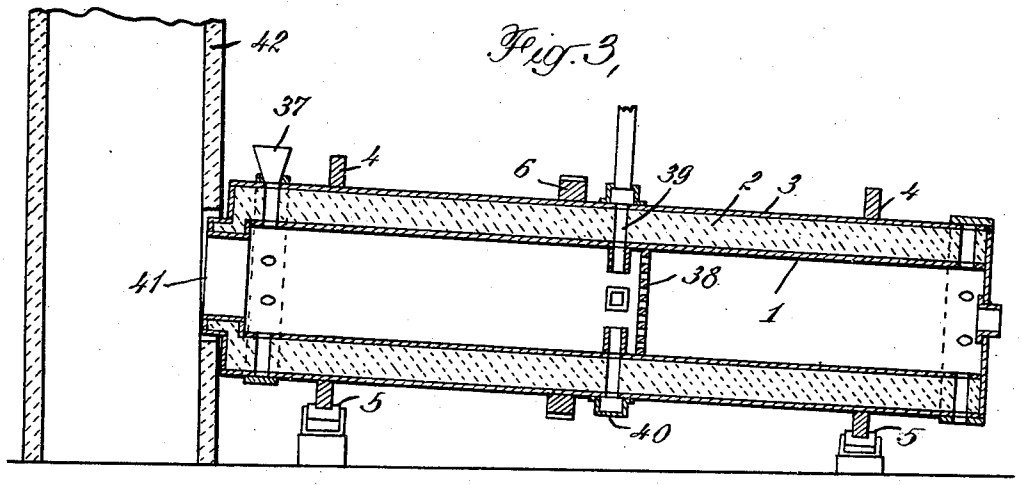
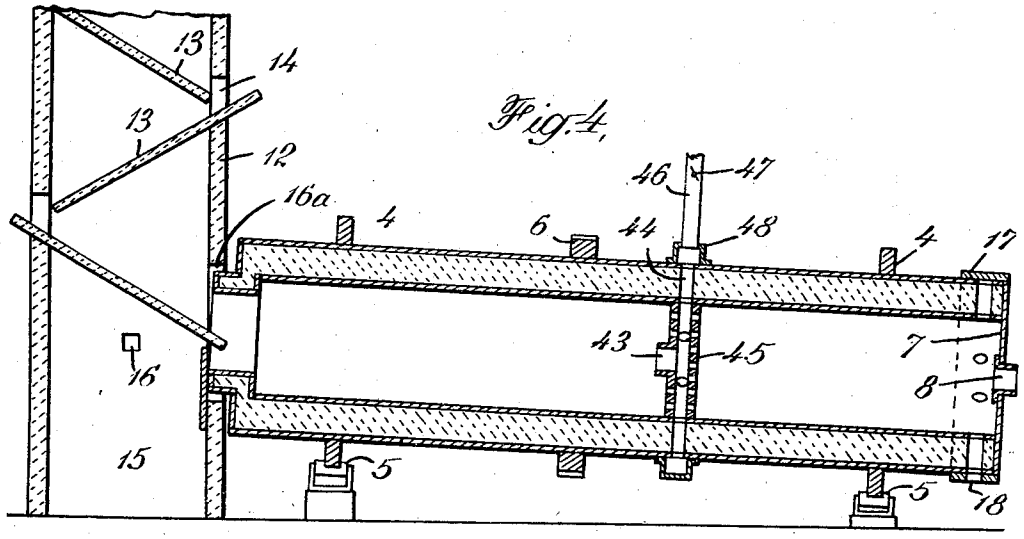



Fig. 4,




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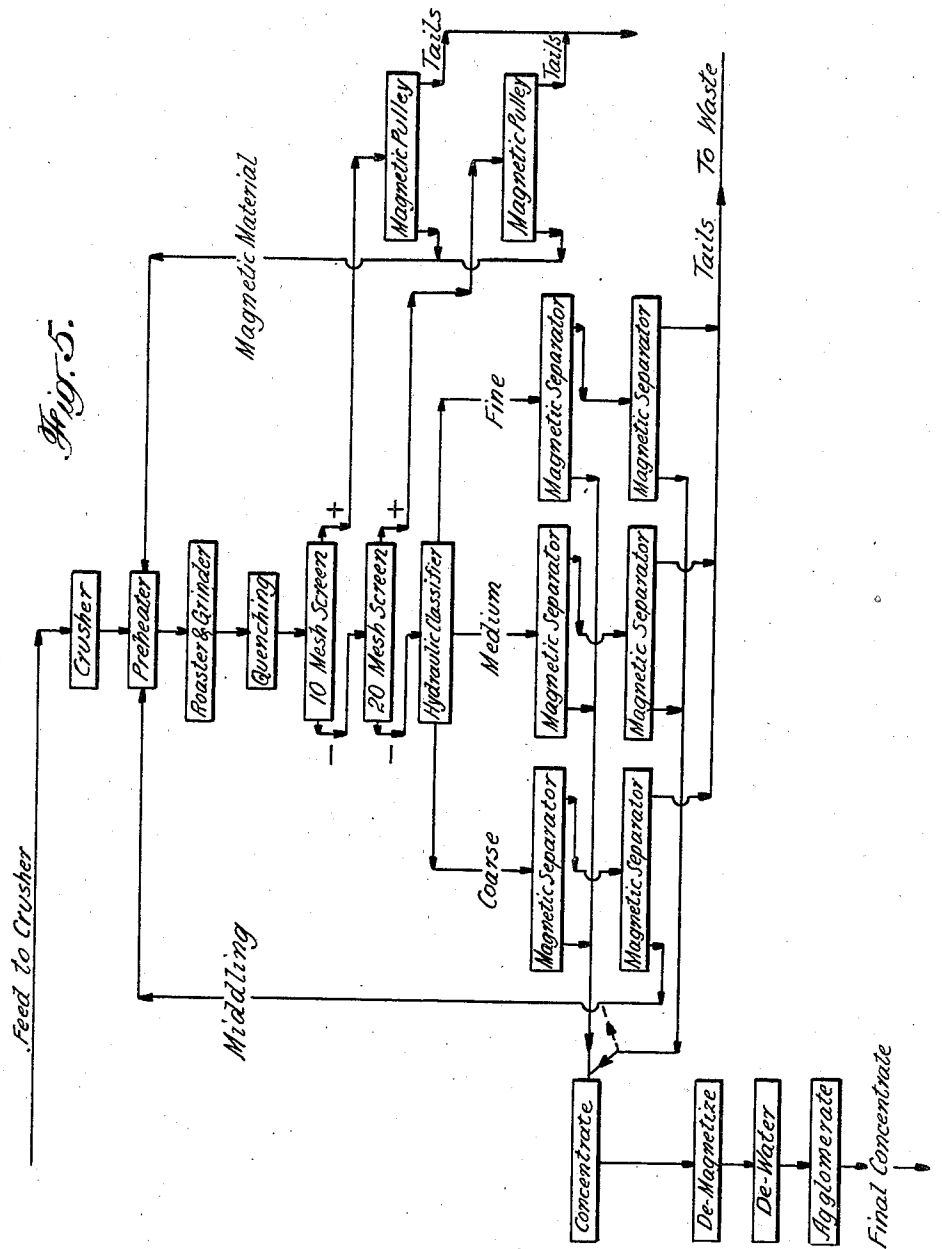
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May 6, 1941. LE ROY E. SCHIFFMAN ET AL 2,240,718

CONCENTRATION OF ORES

Filed Aug. 13, 1938 3 Sheets-Sheet 3

Fig. 5.




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Patented May 6, 1941 2,240,718

# UNITED STATES PATENT OFFICE

2,240,718

## CONCENTRATION OF ORES

Le Roy Edgar Schiffman, Claude Sims Lawson, and Joseph Thomas Blakemore, Birmingham, Ala.

Application August 13, 1938, Serial No. 224.694

15 Claims. (Cl. 209—6)

This invention relates to the concentration of low grade iron ores, such as low grade oxide and carbonate ores, etc., and comprises an improved method of treating such low grade iron ores by a combined roasting and grinding treatment, and particularly a combined reducing and grinding treatment, followed by separation of the treated ore, and particularly magnetic separation, to produce a high grade iron ore or concentrate. The invention includes various steps and features of the process, as well as combinations thereof, as will appear from the following more detailed description. The invention also includes an improved apparatus and equipment for use in carrying out the process.

The invention is of more or less general application to the treatment of low grade oxidized iron ores, such as oxide and carbonate ores, etc.

It is particularly applicable to the treatment of low grade iron oxide ores, for example, oolitic hematite ores, which are of too low grade to be used in their present state, in order to produce therefrom a higher grade ore or concentrate adapted for use in place of the present higher grades of ore, the supply of which is limited.

It has been proposed to roast low grade hematite ores in preparation for magnetic separation, but it has been found necessary to grind the ore, after roasting, to a point where the gangue material is freed from the mineral bearing portion of the ore in order to effect an efficient separation. With ores in which the mineral and the gangue are intimately mixed, this has heretofore required very fine grinding. Oolitic hematite ores, for example, ordinarily require grinding to at least minus 100 mesh and preferably minus 200 mesh for good separation.

We have found that by subjecting such low grade hematite ores to a combined roasting-grinding treatment, and particularly to a combined reducing-grinding treatment, an efficient separation can be effected without such fine grinding, and with other advantages, such as those hereafter pointed out. Using the combination roasting-grinding method of the present invention, we have made effective separation with 80% of the material plus 60 mesh in size. We have also taken that portion of the treated product that was minus 20 mesh and plus 40 mesh and obtained a better separation than we were able to obtain at minus 80 mesh with material separately roasted and ground before treatment.

According to the present invention, the low grade iron ore, after preliminary crushing, is subjected to roasting while grinding at a high temperature; and we find it of particular advantage to subject the ore to a reducing atmosphere while grinding at a high temperature. Apparently we secure a very desirable type of breakage and grinding by combining grinding with the roasting, or roasting and reducing, treatment. It is advantageous, in some cases, to subject the ore alternately to reduction and to oxidation while grinding at high temperature.

The combined grinding and roasting of the low grade ores presents various advantages, including the following: Due to the grinding action while the ore is hot, or while hot and while being subject to reduction, the desirable mineral bearing portion of the ore is better separated from the gangue and other desirable portions, the cleavage of the particles being broken apparently along the separating boundaries between the iron oxides and the siliceous matter; the desirable portion of the ore is better separated from the gangue and other undesirable portions so that subsequent separation, such as magnetic separation, can be more effectively made; the grinding appears to be selective, the impurities in general being less reduced in size than the desirable portion of the ore; effective magnetic separation can be made with larger size ore particles than by the prior methods; less grinding is required to effect separation with resulting economy in reduction of grinding costs and less need of agglomeration of the concentrate before further treatment; the magnetic portion of the material treated appears to be made more highly magnetic than in ordinary roasting; the need of less grinding allows retention of more lime in the concentrate when separating oolitic hematite ores so that these ores can be concentrated with less loss of lime than in other methods; and the concentration of low grade oolitic hematite ores, such as those of the Irondale Seam, can be made with rejection of a large proportion of the phosphorous obtained in the original low grade ore.

While we do not wish to limit ourselves by any theoretical explanation of the improved results obtained by the present process, we are led to believe that the following theoretical explanation applies: By grinding the ore while hot, the friability of the different materials constituting the ore is probably different from that in grinding cold material, probably causing a different type of breakage in the grinding process; some water of crystallization is driven off causing an internal force to act upon the material, or to weaken the

structure of the material, at the same time that it is being subjected to the external force of grinding; some carbon dioxide from carbonate material being driven off causes an internal force to act upon the material, or to weaken the structure of the material, at the same time that it is being subjected to the external force of grinding. By grinding the ore while hot and while subjected to a reducing atmosphere, additional influences are exerted in addition to those referred to in connection with grinding the ore while hot; the oxygen being taken from the mineral portion of the ore, due to the reducing atmosphere which converts hematite to magnetite, apparently either causing an internal force to act upon the material or to weaken the structure of the material, at the same time that it is being subjected to the external force of grinding. When the ore is ground hot and while subjected to alternately reducing and oxidizing atmospheres there is, in addition to the actions above mentioned, a further action, namely, during the subjection to an oxidizing atmosphere after a subjection to a reducing atmosphere oxygen is added to the mineral portion of the ore causing an internal force to act upon the material at the same time that it is being subjected to the external force of grinding. Whether these theoretical explanations furnish the real reason for the improved results obtained, we have nevertheless obtained improved results, of the character hereinbefore mentioned, by combining the grinding of the ore with the roasting, and other treatments.

In carrying out the present process the low grade ore is first crushed to a suitable size in a suitable crushing equipment, e. g., minus ¾ inch or minus ½ inch. The crushed ore can then be supplied to the apparatus by which the combined roasting and grinding is accomplished. The crushed ore is advantageously preheated before subjecting it to the combined roasting-grinding treatment. This results in conservation of fuel, enables the capacity of the roaster-grinder to be increased, and enables better control of the roaster temperature. Preheating may be carried out in separate equipment or in equipment combined with the roasting-grinding equipment. The temperature attained in the preheating treatment may approach that used in the roaster-grinder or may even exceed that in the roaster-grinder. The preheating can advantageously be accomplished with the use of the hot gases escaping from the roaster-grinder, for example, by combustion of the reducing gases escaping from the reducing-grinding operation, with additional fuel if required, for example, using additional fuel such as coal, coke, fuel oil, producer gas, coke oven gas, natural gas, or other similar combustible material.

The low grade ore, preliminarily crushed, and advantageously preheated, it is next subjected to the combination roasting and grinding operation. The essential function of this operation is to grind the material while hot, and advantageously while subjected to a reducing atmosphere, or to alternately oxidizing and reducing atmospheres. Any suitable means of grinding or crushing the ore may be used which is adapted to withstand the high temperatures and the controlled atmosphere, such as a ball mill, pebble mill, tube mill, rod mill, etc.

The temperature to which the ore is heated during the combined roasting-grinding treatment will vary somewhat with the ore and its composition. In general the temperatures will be above 500° and not above 2000° F. and more advantageously within the range of 900°–1500° F. with low grade iron ores of the character referred to. It is desirable to hold the temperature below that at which sintering takes place, which temperature will vary with different ores and with the character of the gangue present. With the oolitic hematite ores we have investigated, no appreciable sintering has occurred below 1500° F., and usually temperatures above 2000° F. were required to show any indication of sintering.

With such low grade iron ores good results have been obtained at temperatures somewhat below 1000° F. in the combined reducing-grinding operation but more prolonged exposure to the reducing atmosphere is required, and the type of breakage secured in this combined operation is apparently not as good as at somewhat higher temperatures. The use of higher temperatures reduces the time of exposure to the reducing atmosphere that is required and improves the type of grinding, but it is desirable, as above pointed out, to hold the temperature below the sintering point, and also to keep it low enough to protect the lining of the grinding mill and the grinding media. Temperatures within the range of 1000° F. to 1500° F. appear to be the most desirable.

The time required for the combined reducing-grinding operation will vary somewhat with the temperature and with the reducing medium used. When using a rotating ball mill with crushed ore preheated to about 1050° F. and with coke oven gas supplied as the reducing atmosphere, we have found a period of treatment of twenty-five minutes sufficient, with increase of temperature to about 1200° F.

The reducing medium or atmosphere for the combined reducing-grinding operation can be supplied in various ways. In general, a reducing atmosphere should be maintained, but a large excess of reducing gas does not appear necessary. We have obtained good results with a fully reducing atmosphere with but very little neutral gases present. We have obtained good results with the use of coke oven gas to furnish the reducing atmosphere but the reducing atmosphere may be otherwise obtained, for example, by the use of blast furnace gas, natural gas, vaporized oil, etc.

The heating of the ore during the combined roasting-grinding operation can be accomplished in various ways. The preheating of the crushed ore reduces the heat required during this combined operation. Electrical heating can be employed when available at a sufficiently low cost. The heating can be accomplished by burning fuel and using the products of combustion and this can be accomplished within the apparatus by incomplete combustion which gives a reducing atmosphere. Coal can be admixed with the ore in the roaster-grinder with resulting driving off of volatile material which furnishes a highly reducing gas, and by burning the coal with insufficient air heat is supplied together with reducing gases; or the heating and reducing gases may be separately supplied to the apparatus in which the combined roasting and grinding operation is carried out.

In some cases it is advantageous to subject the ore alternately to a reducing and to an oxidizing atmosphere, particularly in the case of refractory ores where a single reducing-grinding treatment does not sufficiently prepare the ore for further treatment. By following the reducing treatment with an oxidizing treatment, both

in combination with the grinding treatment, the ore will be first reduced and then oxidized, and these operations will be repeated, if necessary. The oxidizing atmosphere will re-oxidize the reduced ore and it may then be subjected to a further reducing-grinding treatment to accomplish further advantageous results from this combined operation and to leave the ore in a reduced state where, for example, a magnetic ore is desired for subsequent magnetic separation.

In order to avoid re-oxidizing of the ground and reduced ore, this ore should be protected from the atmosphere while hot. Cooling of the ore can readily be accomplished by a limited quenching with water in just sufficient quantity to quickly reduce the temperature to somewhat above atmospheric without saturating with water. If the treated ore is to be subjected to wet separation, the ore from the combined roasting-grinding treatment can be discharged into water at this point. The hot ore can also be cooled, without quenching, in apparatus in which it is protected from atmospheric oxidation.

The reduction treatment to which the low grade iron ores are subjected readily reduces the red iron oxide or hematite to magnetic iron oxide or magnetite; and the combined reducing and grinding treatment leaves the reduced ground material in a form particularly well adapted for subsequent treatment by magnetic separation, or by magnetic separation combined with sizing or screening and other separation treatment. Where the ore is to be subjected to magnetic separation, the reduced ores should be cooled in a manner such as to substantially prevent re-oxidation. Where wet separation, or separation other than magnetic separation, is to be used, this precaution may be unnecessary.

It is one of the advantages of the process of the present invention that fine grinding to a uniform small size is not necessary, and larger size particles can be effectively separated than where the grinding operation follows the roasting and cooling of the ore. In general it will be desirable to remove from the product particles larger than 20 mesh and to return them to the grinder for re-working; but we have secured a high grade concentrate with good iron recovery from the product of the combined reducing and grinding treatment by subjecting "run of mill" material to magnetic separation with no sizing or re-working of the material.

It is more advantageous, however, because of the varying sizes of the particles, to subject the product from the roaster-grinder to a sizing treatment, after it has been cooled or quenched, for example, to sizing by screens or by hydraulic classifiers or both, to obtain products of various sizes which can be separately subjected to magnetic separation. The concentrate product from the larger sizes may, in some cases, be advantageously returned to the roaster-grinder for re-working, if desired, or may be treated as a final concentrate, while the rejected material is discarded.

We have found that by sizing the material before separation, a more efficient separation can be obtained on the sized material, and better efficiency secured from each separator by presenting to it a more uniformly sized product.

We have also found it of advantage to use magnetic separators with the magnet strength so adjusted as to remove that portion of the material which it is desired to remove allowing the less magnetic material to be discarded, or subsequently treated. In this way the more strongly magnetic material can be separated as the concentrate from the less strongly magnetic and non-magnetic material. The concentrate from the smaller sizes may go direct to the final concentrate while the rejected material may be sent to a second set of separators to lessen the loss in the tailings. The concentrate from the second set of separators may either be sent direct to the final concentrate or treated as middlings for further re-working, while discarding the rejected material.

The invention will be further illustrated and described in connection with the accompanying drawings which are somewhat diagrammatic in character and illustrate apparatus adapted for carrying out the roasting-grinding operation in various ways, and a flow sheet showing the combination of the various steps of the process including magnetic separation. While the product of the roasting grinding treatment is amenable to other methods of separation, the invention will be more particularly described in combination with magnetic separation, with indication of the advantages thereby obtainable.

In the accompanying drawings:

Fig. 1 shows one form of apparatus including the preheater and combined roaster-grinder;

Fig. 2 shows a modified construction and arrangement of the preheater and combined roaster-grinder;

Fig. 3 shows a further modified form of apparatus;

Fig. 4 shows another modified form of apparatus; and

Fig. 5 shows a flow sheet of the complete opation from the crushing of the ore to the final magnetic separation for the production of final concentrate.

The apparatus of Figs. 1 to 4 includes preheating ararngements of different kinds and somewhat different types of constructions and arrangements of the roaster-grinder. In Figs. 1, 2 and 4 the preheater is separate from the roaster-grinder, while in Fig. 3 the preheater is a part of the same equipment.

In Fig. 1 the roaster-grinder consists of a cylindrical cast iron lining or shell 1 surrounded by insulation 2 and an outer jacket or shell 3. The cylinder is slightly inclined from the horizontal, has flanges 4 mounted on rollers 5 and is arranged to be rotated by means of the gear 6. Grinding media (not shown) such, for example, as iron balls, are to be used in this rotating cylinder. One end of the cylinder is shown as closed by a plate 7 with an opening 8 in it for a gas burner (not shown). The other end is partly closed by plate 9 to retain the grinding media and having an opening 10 above it to permit the introduction of ore and the escape of gases. This end is inserted into a brick preheater 12 which contains sloping shelves 13 over which the ore is fed and with openings 14 which in operation will be closed except for the insertion of mechanical devices for insuring the feed of the ore or mechanically driven rams (not shown) for aiding in the regulated feed of the ore.

At the bottom of the preheater is a chamber 15 which may serve as a supplementary combustion chamber for supplying additional heat. An airport 16 permits fresh air to be introduced, for example, for the combustion of reducing gases coming from the roaster-grinder and to provide additional heat for the preheating operation; and

air may also enter at 16a between the cylinder and preheater.

The burner end of the cylinder has openings 16 around its circumference to permit discharge of the roasted ore, a stationary ring 17 being shown for closing the outer openings except at the bottom where openings 18 are provided to permit escape of the ore therethrough. Discharge pipes or receptacle (not shown) will be arranged to receive the discharged ore and for protecting it against re-oxidation until cooled or quenched.

The apparatus of Fig. 2 has a separate preheater 20 and roaster-grinder 21, both being rotatable cylinders, slightly inclined, and the construction of which is generally similar to that of the cylinder of Fig. 1. The cylinder 20 has a series of inlet openings 22 near one end, with a stationary ring 23 closing the openings, except at the top where ore is introduced through the hopper 24. A similar means for discharging ore is provided at the other end of the cylinder through openings 25. The discharge end of the cylinder is shown as provided with an opening 26 connected with flues 27 leading from a combustion chamber for introducing hot gases, or combustible gases and air, for preheating the ore. The other end of the preheater has an opening 35 connected with a pipe 36 leading, e, g., to a cyclone dust connector (not shown) and thence to a stack.

The preheated ore is discharged through the openings 25 and openings in the ring 28 into the hopper 29 and thence through similar openings 30 into the roaster-grinder cylinder 21. The outlet end of this cylinder has similar discharge openings 31 to the openings 16 shown in Fig. 1. An inlet 32 near the discharge end of the cylinder provides for introducing reducing gases, or of products of combustion with excess of reducing gases, and the other end of the cylinder has an outlet opening 33 for the gases connected with the pipe 34 leading, e. g., to a cyclone dust collector (not shown). It will be understood that the cylinders 20 and 21 are rotatable, for example, in a manner similar to the rotation of the roaster-grinder cylinder of Fig. 1, and that the roaster-grinder 21 will contain balls or other grinding elements.

The apparatus of Fig. 3 shows a single cylinder having a preheating section and a roaster-grinder section. In general construction it is similar to the cylinder of Fig. 1 and corresponding parts are indicated by the same reference numerals, and provision is made for feeding the ore to the preheater through a hopper 37 arranged similar to the hopper 24 of Fig. 2. Centrally arranged in the cylinder is a perforated cast iron plate 38 having openings to permit the ore to pass therethrough but for preventing the balls or grinding media from passing therethrough. This cylinder also has a series of airports 39 surrounded by stationary air pipe 40 through which supplementary air can be introduced for combustion of the reducing gases coming from the roaster-grinder section to aid in preheating the ore. These air inlet ports 39 extend a sufficient distance into the cylinder to prevent ore from entering them from the cylinder. Similar ports (not shown) can be used for supplying additional fuel or additional hot gases and a surrounding hollow stationary ring closely fitting the shell. The end of the preheater section of the cylinder has an opening 41 extending into the stack 42.

The apparatus of Fig. 4 corresponds for the most part to the construction of the apparatus of Figs. 1 and 3 and corresponding parts are indicated by the same reference numerals. In addition the apparatus of Fig. 4 has supplementary means for introducing air at an intermediate portion of the cylinder thru an airport 43 connected with air pipes 44 in a perforated cast iron plate 45 which has openings to permit ore to pass therethrough. The air is supplied through an air supply pipe 46 having damper 47 therein to a stationary ring 48 closely fitting the shell and connecting with the air pipes 44. This arrangement serves for introducing air to obtain an oxidizing atmosphere, and by cutting off the air to permit the reducing gases to act on the ore.

In the operation of the different types of apparatus described, the ore, after crushing, e. g., to minus ½ or ¾ inch, is fed to the preheater section of the apparatus and is there preheated by hot products of combustion which may be separately introduced, as in Fig. 2, or which may be heated by combustion of the reducing gases coming from the roaster-grinder, with supplemental combustion thereof by the separately introduced air, as in Figs. 1, 3 and 4. The preheated ore enters the roaster-grinder section of the apparatus and is there subjected to a combined grinding and reducing treatment by the simultaneous action of the grinding media and of the reducing gases. The preheated ore may be further heated by incomplete combustion in the roaster-grinder section of the apparatus. In Fig. 4 the introduction of air intermittently into a part of the roaster-grinder permits of obtaining oxidizing conditions and reducing conditions alternately and intermittently during part of the grinding operation, and subsequently obtaining reducing conditions during the final stage of the grinding operation.

In the operation of all of the different arrangements of apparatus illustrated provision is made for preheating the ore before it is subjected to the roasting-grinding operation, and the preheated ore is then subjected to a combined roasting and grinding operation which includes, in all of the instances illustrated, a combined reducing and grinding treatment, and which may be combined, as in Fig. 4, with a preceding alternate oxidizing and reducing treatment during part of the grinding operation.

In the operation of all of these forms of apparatus the ore discharged will be quenched or cooled where re-oxidation is to be prevented, this subsequent part of the apparatus for this quenching or cooling treatment not being illustrated in the drawing.

It will be evident that the rate at which the ore is fed to the apparatus and is passed therethrough can be regulated, depending upon the size of the cylinder, its dimensions, the rate of rotation, etc. to obtain the desired degree of grinding combined with reduction, these operations taking place simultaneously. A preferred speed of rotation of the cylinders is that ordinarily used in mill practice where the balls, pebbles, or rods are made to cascade or fall onto the ore. The grinding of the ore and the agitation of the ore by the rotation of the cylinder continually subjects fresh portions of the ore to the grinding and reducing treatment. The preferred temperature range at which the roasting and grinding is carried out is around 1000 to 1500° F. and we have obtained good results at temperatures

around 1050 to 1250° F. with oolitic hematite ores.

In Fig. 5 is shown, by way of illustration, a flow sheet of the various operations including the preliminary crushing, preheating, roaster-grinder treatment, quenching, sizing and magnetic separation. The sizing operation illustrated includes screening and hydraulic classification.

According to the operations illustrated in the flow sheet the material is fed to the crusher of gyratory or other type for crushing the ore, e. g., to minus ½ inch. The crushed ore then passes through the preheater which may, for example, be a preheater such as illustrated in Figs. 1 to 4. Provision is made for returning certain of the materials from subsequent magnetic separation for further treatment.

From the preheater the material passes to the combined roaster and grinder where it is subjected to simultaneous grinding and roasting. In the apparatus of Fig. 4, by admitting or shutting off air at the intermediate stage of the roaster-grinder, the atmosphere in a portion of the cylinder can be made oxidizing, and by closing off the gases the atmosphere can be made reducing, thus providing for one or more alternate oxidizing and reducing treatments when desired. The final portion of the grinding operation in the apparatus of Fig. 4, as well as the grinding operations in the apparatus of Figs. 1 to 3, is made under reducing conditions so that the final reduced product discharged will be magnetic.

In the flow sheet the material from the roaster-grinder is subjected to quenching, e. g., with a limited amount of water or by cooling under non-oxidizing conditions, and is then passed through 10 mesh and 20 mesh screens. The plus 10 mesh material goes through a magnetic pulley type or dry type separator and the material going through the 10 mesh screen and plus 20 mesh goes through a separate magnetic pulley separator. The tails from these two magnetic separations go to waste and the concentrates are shown as being returned to the preheater for further roasting-grinding treatment. The material passing through the 20 mesh screen is shown as going through a hydraulic classifier and as there being separated into coarse, medium and fine sizes which go separately to wet magnetic separators. The heads of these three magnetic separators form part of the concentrate. The tails are subjected to further magnetic separation in each case and the tails from these further magnetic separations go to waste. The heads from these further magnetic separators may be returned as middlings for treatment in the roaster-grinder or may be combined as part of the concentrate.

It may or may not be necessary to de-magnetize the concentrate. If de-magnetization is desired a suitable de-magnetization treatment may be used, e. g., an alternating current coil. Any suitable method of de-watering may be used if necessary. With some separators de-watering is not necessary. If the final concentrate is desired to be coarser than minus 40 mesh, some means of agglomeration can be used, such as sintering or briquetting, to give the final concentrate an agglomerated form for further treatment.

The 10 and 20 mesh screens shown in the flow sheet may be of suitable construction, e. g., vibratory screens, or screens of other types. The particular mesh is shown by way of illustration and screens of other desirable mesh can be used. The magnetic separators shown for the larger sizes of dry material are of the magnetic pulley or dry type; while the other magnetic separators shown, applied to the wet material after hydraulic classification, are wet types of separators. Where hydraulic classification is not used, and only dry screening is used for classification and sizing of the ore, dry types of magnetic separators can be employed.

The hydraulic classifier shown may be of any suitable type which will separate the material into a number of sizes, using either "free settling" or "hindered settling" classifications. The ores may thus be separated, e. g., into a coarser size which is minus 20 and plus 40, a medium size which is minus 20 and plus 60 and a finer size which is minus 60.

The process is not dependent on the use of any one type of magnetic separator but advantageously makes use of a suitable field strength which will pick up the more magnetic portion and reject portions somewhat less magnetic. A second magnetic separation of the rejected portion of the first may or may not be desirable or necessary, depending upon the results obtained and the efficiency of the first separation. In the flow sheet the concentrate from the second magnetic separator of the coarse material from the hydraulic classifier is shown as returning as middling to the preheater. The concentrate from the second magnetic separators for the medium and fine material may either go to the concentrate or be returned, as indicated in dotted lines, as middlings to the preheater.

It will be noted that the particular number of sizes into which the ore is separated and the particular nature and number of magnetic separation treatments can be varied to take full advantage of the different sizes of material, including both coarser and finer sizes, present in the ore after the combined roaster-grinder treatment.

While the flow sheet shows the combined operations with magnetic separation, for which the material after the combined reducing and grinding treatment is particularly adapted, other types of separation, such as wet methods or tabling methods, may be used.

The results obtained by the combined roasting and grinding treatment of the present invention will be illustrated by the following example of the treatment of a low grade oolitic hematite ore from the Irondale Seam near Birmingham, Alabama.

The ore treated contained 34.5% iron and 27% insoluble. It contained 9.5% calcium oxide, 0.34% phosphorous and 0.17% manganese. It was crushed to minus ¼ inch, preheated to about 1050° F. and subjected to a combined reducing and grinding treatment in a ball mill type of apparatus with increase in temperature to about 1200° F. and using coke oven gas as the reducing atmosphere, the time of treatment being about 25 minutes. The material lost about 7% in weight and showed 37.0% iron, 29% insoluble. This material was cooled to atmospheric temperature in a reducing atmosphere and was then separated by screening using 10, 20, 40, 60 and 80 mesh screens.

The plus 10 and plus 20 sizes were subjected to dry magnetic separation and the middlings obtained were reground to minus 60 mesh and subjected to wet magnetic separation. The finer sizes were subjected separately to wet magnetic

separation. The final concentrate obtained represented 62.4% of the roasted ore and contained 53.1% iron, 9.7% calcium oxide, 0.31% phosphorous, 0.08% manganese and 13.6% insoluble. The tails obtained represented 34.7% of the weight of the roasted ore and contained 11.7% iron and 48.3% insoluble.

While the invention has been described more particularly in connection with the treatment of low grade oolitic hematite ores, to which it is particularly applicable, the invention in its broader aspects includes the treatment of other low grade oxidized ores such as other low grade oxide and carbonate ores, etc. With carbonate ores the combined roasting and grinding treatment results in decomposition of the carbonates with elimination of carbon dioxide and conversion of the carbonate to oxide; and, with a regulated reducing treatment combined with the grinding operation, the carbonate ore is readily converted into a magnetic condition well adapted for subsequent separation of magnetic separation.

We claim:

1. The method of concentrating low grade oxidized iron ores which comprises subjecting the ore while at a temperature varying from 900° F. to 1500° F. to a combined roasting and grinding treatment to effect grinding and separation of the metal bearing material and gangue, said grinding being effected by breaking the ore under the impact of a hard body to such fineness that it will substantially all pass through a 10-mesh screen, said roasting and temperature conditions being such as to cause the ore to break more effectively when subjected to impact at the time of roasting, and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom.

2. The method of concentrating low grade oxidized irons ores which comprises subjecting the ore to a combined reducing and grinding treatment at a temperature of about 900 to 1500° F. to effect grinding and separation of the metal bearing material and gangue while hot and subjected to reducing conditions, the ore being ground to such fineness that it will substantially all pass through a 10-mesh screen and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom.

3. The method of concentrating low grade oxidized iron ores which comprises subjecting the ore to a grinding treatment and alternately subjecting the ore to reducing and oxidizing conditions during such grinding treatment to effect separation of the metal bearing material and gangue, said grinding, oxidizing and roasting being carried out at from 900 to 1500° F. to effect a change in the structure of the ore causing it to break easily under the impact of a hard body, and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom.

4. The method of concentrating low grade oxidized iron ores which comprises subjecting the ore to a combined reducing and grinding treatment at a temperature varying from 900 to 1500° F. to effect grinding and separation of the metal bearing material and gangue while hot and subjected to reducing conditions, the ore being ground to such fineness that it will substantially all pass through a 10-mesh screen and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom, said separation treatment including magnetic separation.

5. The method of concentrating low grade oxidized iron ore which comprises subjecting a preheated ore in such state of subdivision that it will substantially all pass through a ¾ inch opening to a combined roasting and grinding treatment at a temperature within the range of 900° F. to 1500° F to effect grinding and separation of the metal bearing material and gangue, said grinding being effected by breaking the particles of ore under the impact of a hard body, and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom.

6. The method of concentrating low grade oxidized iron ore which comprises preheating the crushed ore, subjecting the preheated ore to a combined reducing and grinding treatment at a temperature at about 900 to 1500° F. to effect grinding and separation of the metal bearing material and gangue while hot and subjected to reducing condition, the ore being ground to such fineness that it will substantially all pass through a 10-mesh screen, and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom.

7. The method of concentrating low grade oxidized iron ores which comprises subjecting the same to a combined roasting and grinding treatment while at a temperature within the range of 900° F. to 1500° F. to effect grinding of the ore and to effect separation of metal bearing material and gangue to produce a product having particles of varying sizes, said grinding being effected by breaking the particles under the impact of a hard body and continuing the treatment until a substantial portion of the particles are in a pulverulent state, subjecting the resulting ore to a sizing treatment to separate particles of different sizes and separately subjecting the sized fractions of the ore to a separation treatment to concentrate the ore and separate the gangue therefrom.

8. The method of concentrating low grade hematite ores which comprises subjecting the ore in such state of subdivision that it will substantially all pass through a ¾ inch opening to a combined reducing and grinding treatment at a temperature varying from 900 to 1500° F. to effect grinding of the ore while hot and under reducing conditions and to produce a magnetic iron ore having particles of varying sizes, the ore being ground to such fineness that it will substantially all pass through a 10-mesh screen, subjecting the resulting ore to a sizing treatment to separate particles of different sizes, and separately subjecting the sized fractions of the ore to a separation treatment to concentrate the ore and separate the gangue therefrom, said separation treatment including magnetic separation.

9. The method of concentrating low grade oxidized iron ores which comprises subjecting the ore to a preliminary crushing treatment to reduce the particles to such fineness that the ore will substantially all pass through a ¾ inch opening, preheating the crushed ore, subjecting the preheated ore to a combined reducing and grinding treatment at a temperature of about 1000° to 1500° F. by passing reducing gases into contact therewith while subjecting the ore to grinding by breaking the ore under the impact of a hard body to such fineness that a substan-

tial portion thereof is in a pulverulent state, cooling the ground ore under conditions to prevent oxidation, and subjecting the reduced ore to a separation treatment to concentrate the ore and remove gangue therefrom.

10. The method of concentrating low grade oolitic hematite ores which comprises subjecting the crushed ore to a preheating treatment, subjecting the preheated ore to a combined reducing and grinding treatment at a temperature of about 1000° to 1500° F. by passing reducing gases into contact therewith while subjecting the ore to grinding and to produce a magnetic iron ore product having particles of varying sizes, the particles being sufficiently fine that substantially all of the ore will pass through a 10-mesh screen, cooling the resulting ore under conditions to prevent oxidation, subjecting the resulting ore to a sizing treatment to separate fractions of different sizes, and separately subjecting the size fractions to a separation treatment to concentrate the ore and separate the gangue therefrom, said separation treatment including magnetic separation.

11. The method of concentrating low grade oxidized iron ores which comprises subjecting the ore to a combined reducing and grinding treatment to effect grinding and separation of the metal bearing material and gangue while at a temperature varying from 900 to 1500° F. and subjected to reducing conditions, said grinding being effected by breaking the ore under the impact of a hard body to such fineness that it will substantially all pass through a 10-mesh screen, and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom, said separation treatment including a magnetic separation with the magnet strength so adjusted as to effect separation of the more magnetic material from the less magnetic material.

12. The method of concentrating low grade oxidized iron ores which comprises subjecting the ore to a combined reducing and grinding treatment to effect grinding and separation of the metal bearing material and gangue while at a temperature varying from 900 to 1500° F. and subjected to reducing conditions, said grinding being effected by breaking the ore under the impact of a hard body to such fineness that it will substantially all pass through a 10-mesh screen, and subsequently subjecting the ore to a separation treatment to effect concentration of the ore and separation of gangue therefrom, said separation treatment including a series of magnetic separations of adjusted magnet strength to effect separation of the more magnetic and less magnetic materials from each other and from the non-magnetic material.

13. The method of concentrating low grade oxidized iron ores which comprises subjecting the same to a combined reducing and grinding treatment to effect grinding of the ore while at a temperature varying from 900 to 1500° F. and to effect separation of metal bearing material and gangue to produce a product having particles of varying sizes, said grinding being effected by breaking the ore under the impact of a hard body to such fineness that it will substantially all pass through a 10-mesh screen, subjecting the resulting ore to a sizing treatment to separate particles of different sizes, and separately subjecting the sized fractions of the ore to magnetic separation of adjusted magnet strength to effect separation of the more magnetic and less magnetic materials.

14. The method of concentrating low grade oxidized iron ores which comprises subjecting the same to a combined reducing and grinding treatment to effect grinding of the ore while at a temperature varying from 900 to 1500° F. and to effect separation of metal bearing material and gangue to produce a product having particles of varying sizes, said grinding being effected by breaking the ore under the impact of a hard body to such fineness that it will substantially all pass through a 10-mesh screen, subjecting the resulting ore to a sizing treatment to separate particles of different sizes, said sizing treatment including a dry screening separation of sized fractions of the ore, and separately subjecting the resulting sized fractions to dry magnetic separation.

15. The method of concentrating low grade oxidized iron ores which comprises subjecting the same to a combined reducing and grinding treatment to effect grinding of the ore while at a temperature varying from 900 to 1500° F. and to effect separation of metal bearing material and gangue to produce a product having particles of varying sizes, said grinding being effected by breaking the ore under the impact of a hard body to such finess that it will substantially all pass through a 10-mesh screen, subjecting the resulting ore to a sizing treatment to separate particles of different sizes, said sizing treatment including a wet classification separation of sized fractions of the ore, and separately subjecting the resulting sized fractions to wet magnetic separation.

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