Nov. 14, 1961 D. WESTON 3,008,656

GRINDING

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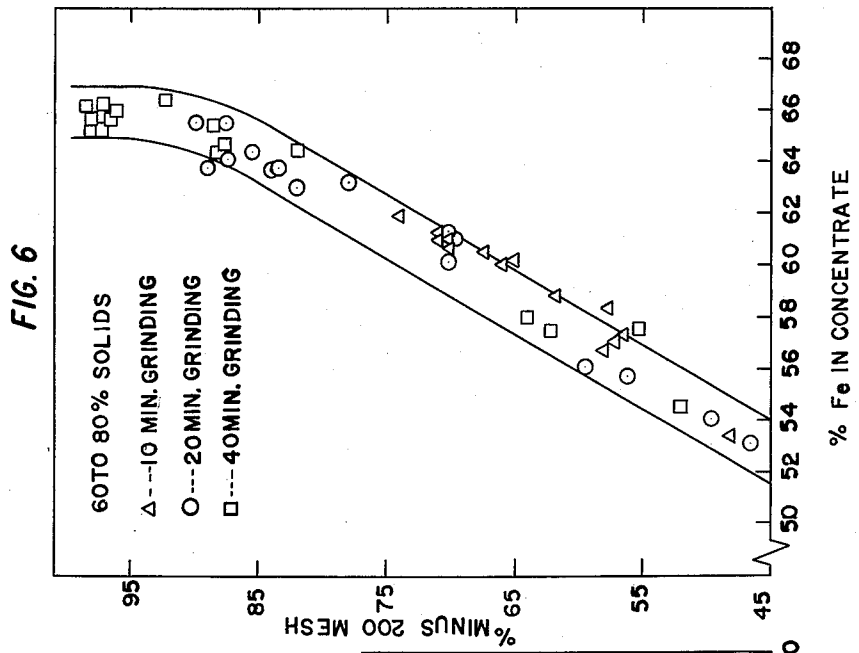


FIG. 6

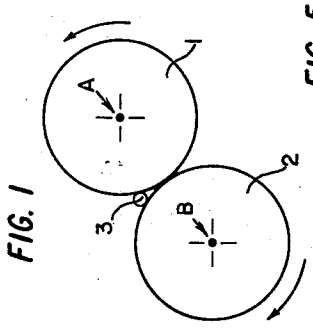


FIG. 1

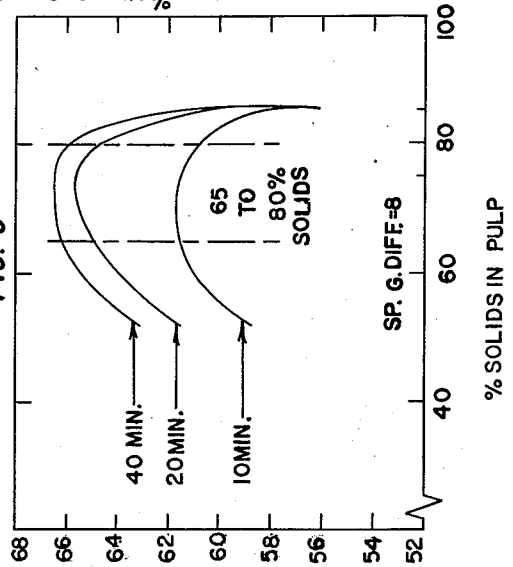


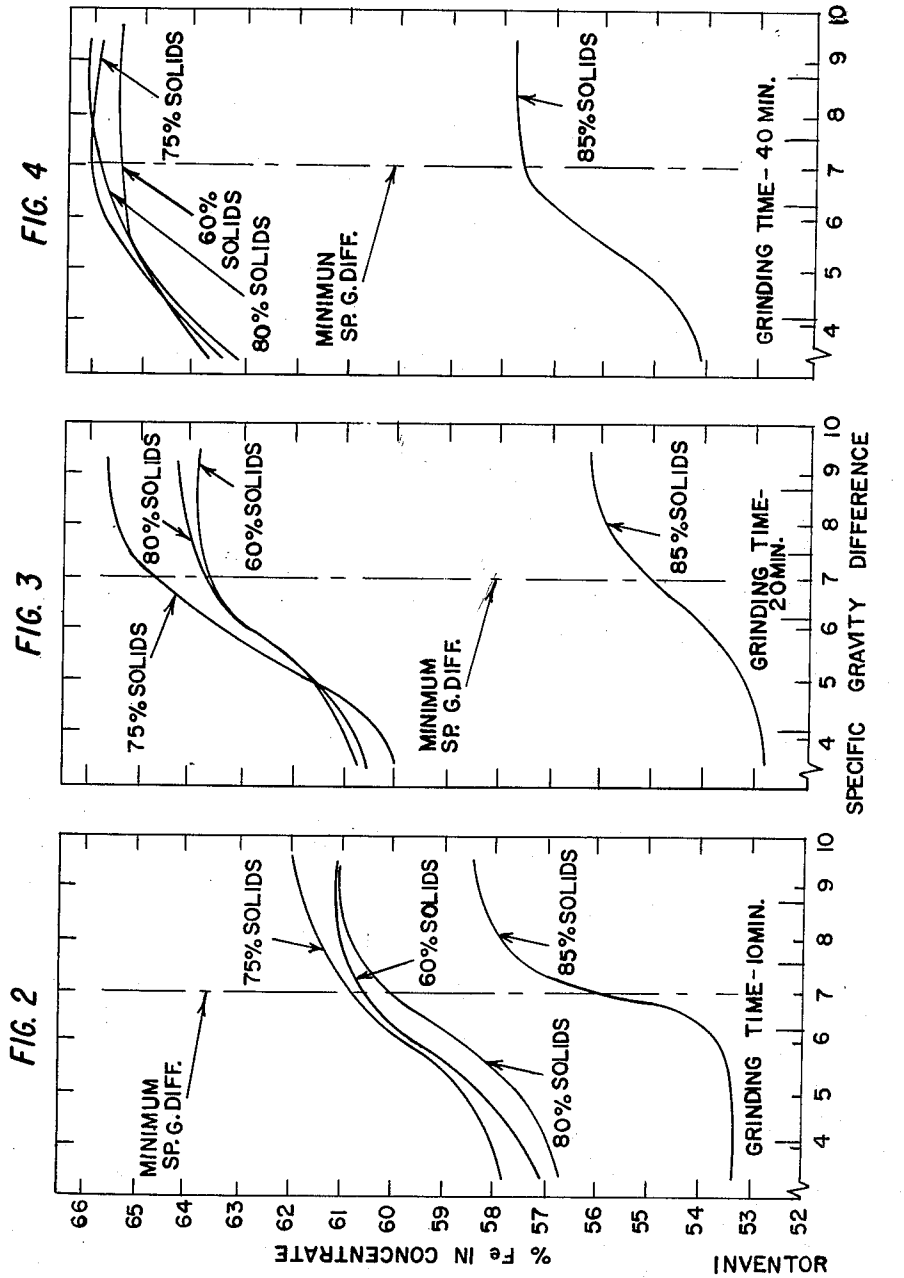
FIG. 5

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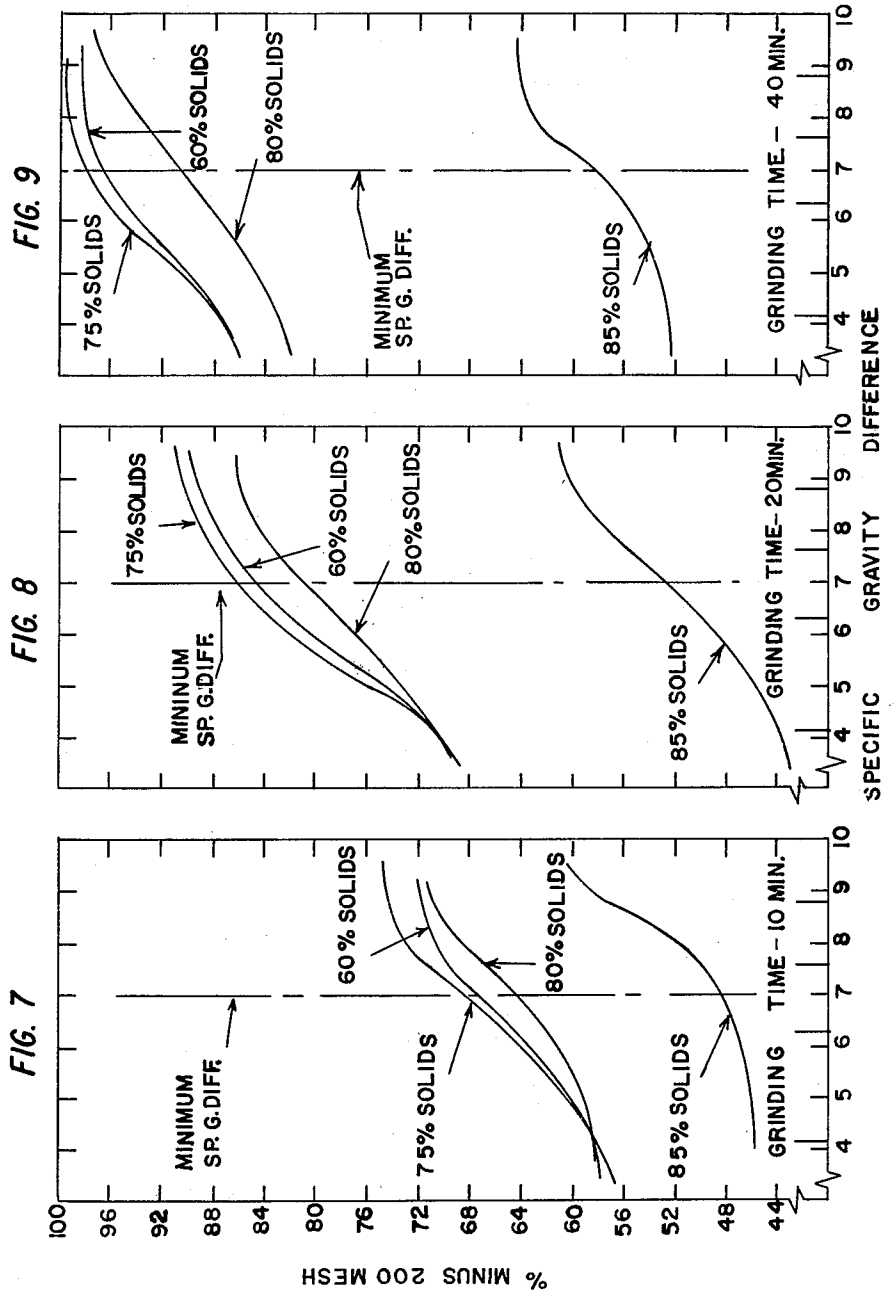
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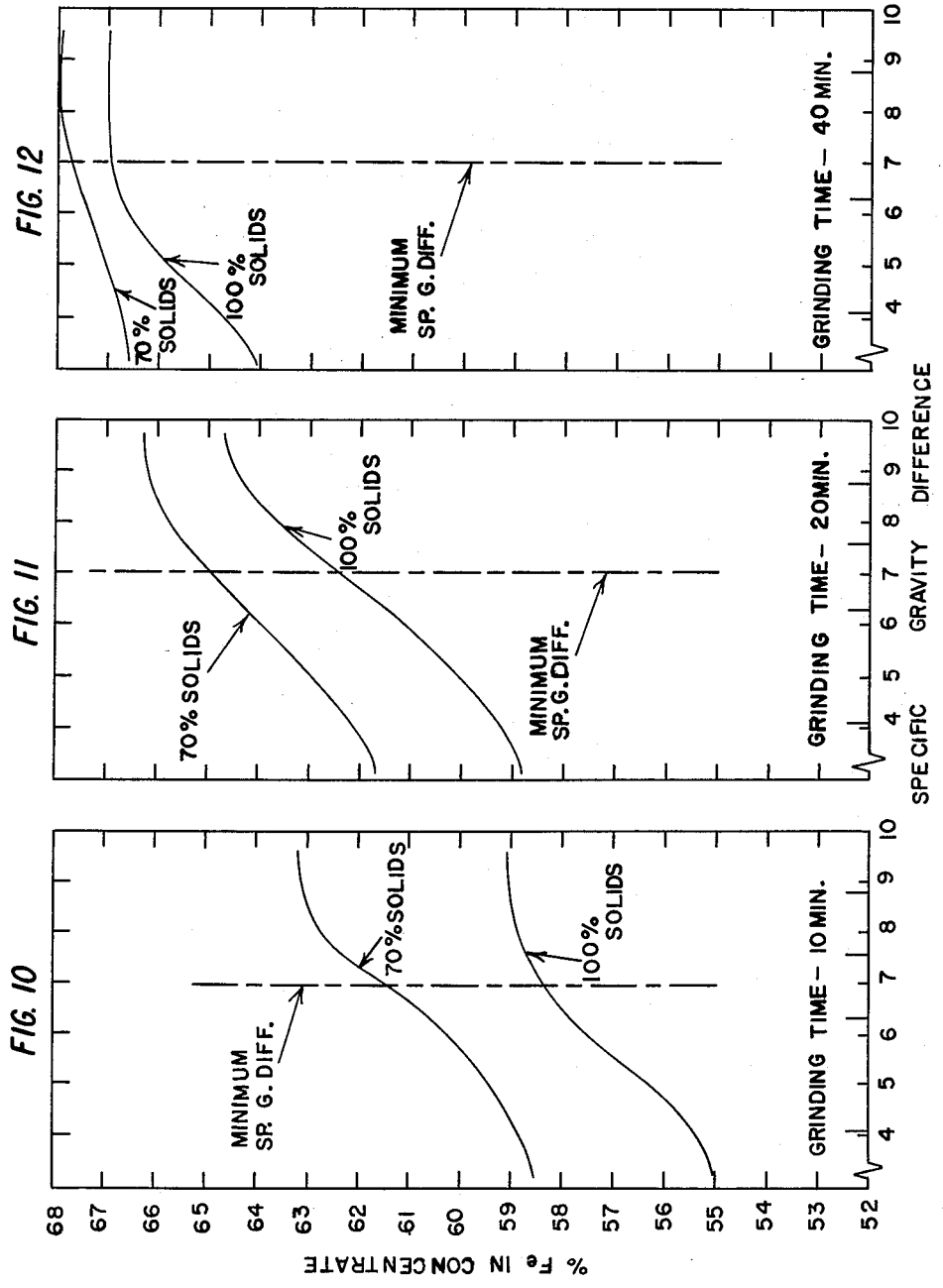
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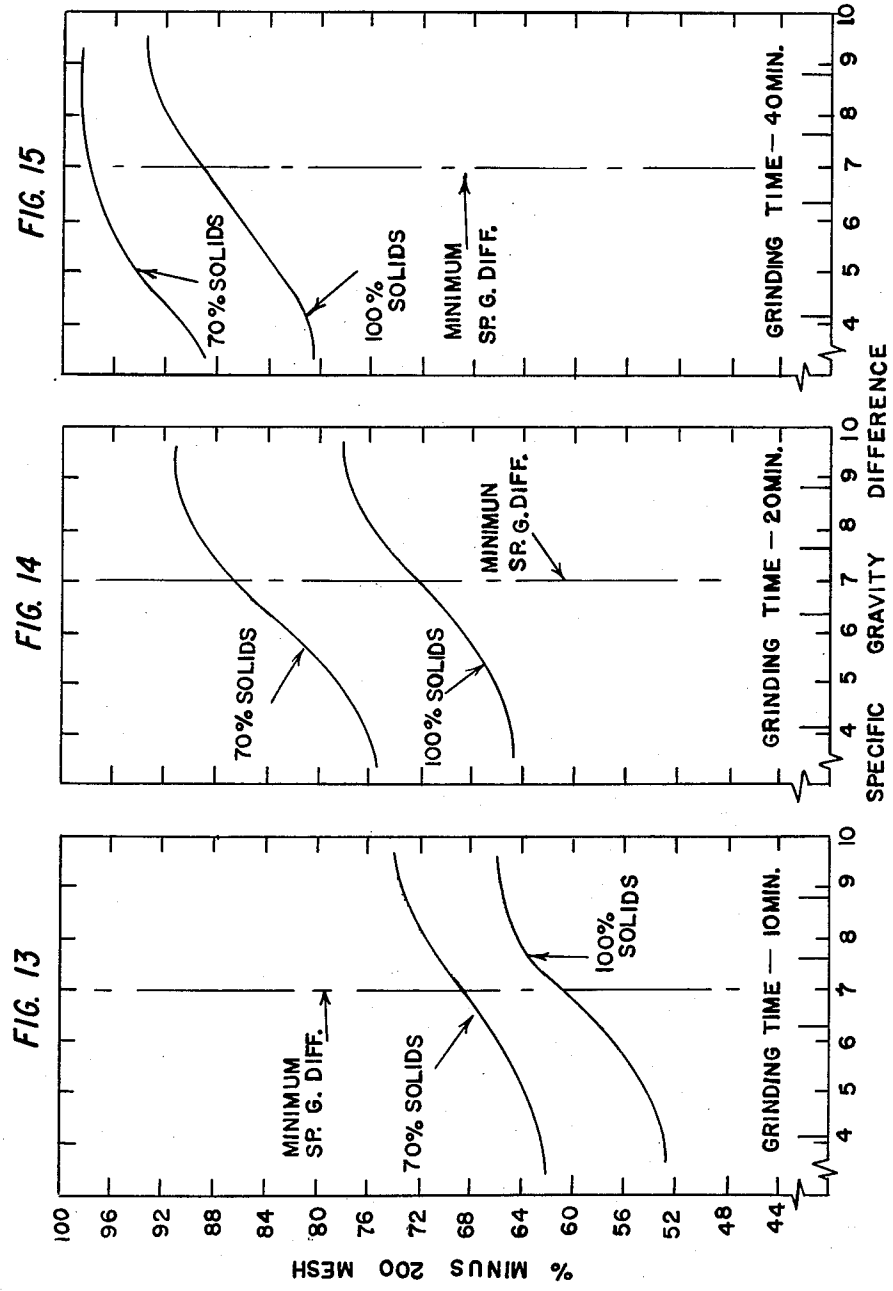


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GRINDING

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4 Claims. (Cl. 241—30)

This invention relates to fine grinding of particulate materials, and more particularly to an improved method of fine grinding wherein a ball mill containing a charge of balls of less than 1" in diameter is used to reduce particulate material from a particular size range predominantly in the 10 to 200 mesh size range and down to the —325 mesh size range and lower.

Fine grinding ball mills may be either wet or dry depending upon the material which is being reduced. The widest application of fine grinding in the dry state is in clinker mills in the production of cement. There are many applications of fine grinding in the wet state which may be exemplified mainly by the regrinding of metallic ores of which examples are copper and iron.

As fine grinding in most cases is a secondary operation which follows the primary production milling units in the plant and as the material which is fine ground represents only a fraction of the tonnage treated by the primary units, less attention has been paid to accomplishing efficiency of grinding in fine grinding equipment than has been paid to the achievement of efficiency in primary grinding units. In general, the current theory of grinding has been developed essentially in accordance with the conditions prevailing in primary ball mills and other primary milling units whose efficiency of operation directly affects the capacity of the milling plant as a whole.

It has, however, been generally recognized that to maintain reasonable efficiency in secondary or wet ball mills, it is necessary to operate at a lower pulp density than is the case with primary ball mills. At the same time, based on experience obtained in pebble mills on the one hand, and ball mills on the other, the theory has evolved that the useful work input to the material is a linear function of the difference in specific gravity between the grinding medium and the feed material. Thus, it has already been proposed to increase the productive capacity of primary ball mills by using a reduction medium or high specific gravity, and I am aware that heavy grinding media such as steel balls having a lead core and balls consisting of compacted tungsten carbide of high specific gravity have been proposed for this purpose. Despite such proposals, the use of heavy reduction media has not had any wire acceptance mainly because the increases in efficiency obtainable as compared with the use of steel balls has not been sufficient to offset the comparatively large additional capital cost of charges of special heavy reduction media.

I have now found that whereas the above-mentioned current theory of work input in relation to the difference in specific gravity between the grinding media and the feed material holds true for primary ball mills and the like, the most surprising additional increases in efficiency are made possible by the correct use of heavy grinding media in fine grinding mills. Such increases in efficiency are completely unforeseen in view of the above expressed current theory, and enable not only most surprising increases in productive capacity and efficiency, but also enable the production of fine grains resulting in greater mineral liberation or surface area than is possible in similar equipment using conventional steel balls.

I have found, contrary to existing knowledge, that the increase in capacity and surface area is not linearly correlated to the difference in density between the material and the grinding media but that there is a critical minimum density difference, below which there is a marked

falling off in efficiency and above which substantially high efficiency and capacity can be maintained.

It is therefore the object of the present invention to provide a method of fine grinding characterized by high mineral recovery and improved capacity.

Another object is to provide a method of fine grinding whereby increased grinding capacity is achieved with concomitant increase in surface area of the resultant product.

A further object is to provide a grinding system with the aim of fulfilling the foregoing objectives.

These and other objects will more clearly appear from the following description taken in conjunction with the accompanying drawings wherein:

FIGURE 1 illustrates diagrammatically two adjacent balls within an operating fine grinding mill;

FIGURES 2 to 4 depict the results obtained in the recovery of iron from a taconite ore by using grinding media of various specific gravities below and above the critical minimum;

FIGURE 5 shows the effect of pulp density and time on the recovery of iron from a taconite ore at a specified specific gravity above the critical minimum;

FIGURE 6 depicts the relation between the mesh size of the finally ground product and the iron content of the concentrate produced from said final product;

FIGURES 7 to 9 show the affect of grinding media of specific gravity below and above the critical minimum on the amount of minus 200 mesh obtained in the final product;

FIGURES 10 to 15 are illustrative of similar grinding data obtained on dry feed as compared to results obtained on pulp containing 70% solids.

According to the method of my invention, a fine grinding ball mill is charged with balls of preferably less than 1" diameter of specific gravity at least seven specific gravity points higher than the material making up the charge. In this connection, I use the word "charge" to include the material worked on whether in the dry or wet state. When the material is mentioned as having a certain specific gravity, reference is had to the absolute specific gravity of the material itself and it is this specific gravity which is used for reference purposes with that of the grinding media. The term "specific gravity points" is used herein in the relative sense and means the difference in the number of specific gravity units between the absolute specific gravity of the grinding balls and the specific gravity of the particulate material to be ground. While it is difficult to attribute the surprising results of the invention to any particular theory, it is believed the results can be rationalized if regard is had to the comminuting forces at work within a fine grinding mill system and the effect which the viscosity of the charge may be considered to have upon these forces.

To assist in this consideration, reference will be had to FIGURE 1 which illustrates diagrammatically two adjacent balls within an operating fine grinding ball mill. As is well known, during operation each ball within a ball charge (e.g. balls 1 and 2) tends to rotate upon an axis (e.g. axes A and B) parallel to that of the mill, and it is the rotation of the balls which is considered to have the principal grinding effect upon the particles of material (e.g. particle 3) which are nipped between adjacent ball surfaces. The grinding force applied between the two adjacent ball surfaces varies with the weight of the balls. In addition to the aforesaid forces, an inertia effect is created when the balls cascade and particles are reduced by the crushing effect of two balls being brought together in this manner. In a fine grinding mill, due to the relatively high surface area of the material undergoing comminution, the viscosity of the material is substantially higher than that in a primary ball mill, and such viscosity with its attendant "stickiness" tends to increase as the

surface area of the feed material is increased due to the action of the mill. At the same time, the diameter of the balls in a fine grinding mill is much less than that of balls in a primary mill, and consequently the ball charge per unit volume has a much greater surface area. As a result of this, the drag opposing rotation of the balls which is caused by the viscosity of the pulp is very much greater than is the case in a primary mill with the result that the free rotation of the balls which produces the principal comminution action in the mill is substantially retarded. Secondly, as particles of feed material become smaller in size, they become truly suspended and form a heavy medium producing a substantial flotation action on the balls, thus effectively reducing the force with which the balls by reason of their weight can grind against each other. Furthermore, this flotation action hinders the normal circulation of the balls and the material, further adversely affecting the efficiency of grinding.

I believe that, when in accordance with my present invention, the specific gravity of the balls is maintained at at least seven specific gravity points above that of the material, such resistance produced by the viscosity is overcome. It will be observed that the theory above expressed applies equally well to dry ball mills as to wet ball mills inasmuch as an agitated mass of very finely divided dry solids acts in many respects like a fluid when in a state of agitation such as exists within a mill, and I believe that the phenomena both of flotation and resistance to movement are present in very finely divided dry solids in a mill as well as in a pulp formed from suspending such fine solids in a liquid.

For the purposes of illustrating the surprising advantages which may be achieved in accordance with the present invention, the following examples are provided. It is to be understood that the examples are illustrative only, and are not intended to be construed as a limitation upon the scope of the invention as it will be obvious that the invention may be applied otherwise than as specifically set forth.

EXAMPLE 1

Fine wet grinding tests were conducted on a Minnesota taconite which had already been subjected to primary grinding followed by magnetic concentration. The concentrate which exhibited a head assay of 43.73% iron had the following screen (Tyler Standard) analysis:

Mesh size	Percent by weight	Mesh size	Percent by weight
+14	3.3	+65	7.0
+20	7.5	+100	7.6
+28	8.4	+150	5.1
+35	9.0	+200	10.5
+48	7.9	−200	33.7

Using the foregoing concentrate, a series of ore charges was made up comprising mixing 2000 grams of the concentrate with sufficient water to produce pulp densities of 60, 75, 80 and 85 percent solids by weight. Each of these charges was subjected to fine grinding in a batch type ball mill having an internal diameter of 7.5 inches and a total volume of about 275 cubic inches (mill manufactured by Abbe). The mill in each case contained 500 grinding balls of a specified density and having an average diameter of about one-half inch. The details concerning the types of balls employed in the tests are as follows:

Type	Weight, grams (500 balls)	Specific gravity
Steel [1]	7,710	7.8
30% tungsten [2]	9,945	10.0
50% tungsten [2]	11,202	11.3
70% tungsten [2]	12,358	12.5

[1] These balls are made of cast steel.
[2] These balls were made of tungsten-iron alloy.

The grinding characteristics for each type of ball charge was determined for each pulp density at times of 10, 20, and 40 minutes. The mill was operated at 73 r.p.m. or 75% of critical speed. After completion of each grind, the reground concentrate was removed from the mill and reconcentrated in a wet magnetic concentrator to produce a final concentrate which was then analyzed for iron content. The increase in the iron content of the concentrate was taken as indicative of the increased efficiency in grinding in liberating the metal values from the ore. Similarly, the increase in minus 200 mesh product was taken as indicative of the increase in surface area. The particulars of each test and the results are tabulated as follows:

Table 1

Ball charge spec. grav.	Percent solids by weight	Time mins.	Percent minus 200 mesh	Conc. percent Fe	Conc. percent total Fe
7.8	85	10	47.9	53.4	92.6
10.0	85	10	44.5	53.5	93.2
11.3	85	10	49.8	57.5	93.1
12.5	85	10	57.2	58.3	91.0
7.8	80	10	58.1	56.9	90.7
10.0	80	10	61.9	59.1	90.2
11.3	80	10	67.1	60.7	89.3
12.5	80	10	70.5	60.9	88.4
7.8	75	10	57.3	57.1	90.3
10.0	75	10	65.0	60.3	89.5
11.3	75	10	71.3	61.0	89.2
12.5	75	10	74.2	61.9	87.9
7.8	60	10	56.6	57.4	90.0
10.0	60	10	65.3	60.1	89.6
11.3	60	10	69.8	61.0	88.9
12.5	60	10	70.9	60.9	88.8

Table 2

Ball charge spec. grav.	Percent solids by weight	Time mins.	Percent minus 200 mesh	Conc. percent Fe	Conc. percent total Fe
7.8	85	20	45.6	53.0	93.3
10.0	85	20	49.5	54.1	92.0
11.3	85	20	55.5	55.9	91.3
12.5	85	20	59.4	56.1	90.6
7.8	80	20	70.2	60.9	89.8
10.0	80	20	78.3	63.4	88.0
11.3	80	20	83.3	63.9	88.0
12.5	80	20	85.4	64.4	87.2
7.8	75	20	70.2	60.4	89.4
10.0	75	20	83.9	63.8	87.8
11.3	75	20	87.5	65.6	87.8
12.5	75	20	90.2	65.4	88.0
7.8	60	20	69.5	61.4	88.4
10.0	60	20	81.9	63.2	88.1
11.3	60	20	87.6	64.0	87.1
12.5	60	20	89.1	63.8	87.9

Table 3

Ball charge spec. grav.	Percent solids by weight	Time mins.	Percent minus 200 mesh	Conc. percent Fe	Conc. percent total Fe
7.8	85	40	52.2	54.5	92.1
10.0	85	40	54.9	57.6	90.9
11.3	85	40	63.9	58.0	89.8
12.5	85	40	62.8	57.6	90.3
7.8	80	40	82.6	64.5	87.8
10.0	80	40	88.6	65.5	87.7
11.3	80	40	92.6	66.6	88.4
12.5	80	40	96.1	66.0	87.3
7.8	75	40	87.3	64.7	88.2
10.0	75	40	97.0	66.2	87.7
11.3	75	40	98.6	65.9	87.2
12.5	75	40	98.4	66.1	87.2
7.8	60	40	88.3	64.4	87.5
10.0	60	40	96.1	65.8	87.3
11.3	60	40	97.4	65.4	87.0
12.5	60	40	98.2	65.5	86.9

It will be noted from the data of Tables 1 to 3 that concentrates of markedly improved iron content of over 60% are obtained more easily at the higher range of the specific gravities of the grinding medium. This will be more clearly evident by referring to FIGURES 2 to 4 which show the effect of the difference in specific gravity between the material being ground and the grinding medium on the yield of concentrate. Taking 3.7 as the specific gravity of the taconite concentrate, the difference

between the value for taconite and that of the various grinding media results in specific gravity differences of 4.1 (steel), 6.3 (30% W), 7.6 (50% W) and 8.8 (70% W). It is thus apparent the aforementioned data that while the specific gravity differences between the ore and the grinding media should be at least about 7 integers, it may range up to about 9 integers (for example, about 8.8).

Since the main purpose of the grinding treatment is to achieve maximum liberation of the valuable mineral from the chert or silica, then the amount of iron in the concentrate will be indicative of the improvement achieved in grinding. Thus, it will be noted in FIGURE 2 that for a pulp grinding time of 10 minutes, a marked recovery of iron is effected when the difference in specific gravity between the ore and the grinding media is maintained at or above seven points, the optimum concentration (i.e. over 60% iron in concentrate) being achieved at pulp densites in the range of 65 to 80%, preferably at pulp densities of 65%to 75% (note FIGURE 4). While an improvement is effected in the grinding of material of 85% pulp density, it is apparent from the recovery curve that the somewhat viscous character of this high pulp density with its attendant "stickiness" prevents full utilization of the inventive concept as compared to the recovery curves for material of 75 and 80% pulp density.

At the grinding time of 20 minutes, still better results were obtained (note FIGURE 3) at or above the specific gravity difference minium of seven, the iron in the concentrate being raised as high as about 65.5%. At 40 minutes grinding time, except for the pulp containing 85% solids, the specific gravity difference does not appear to be as effective as at lower grinding times. In other words, if one grinds long enough, the material will eventually grind down to the desired size.

It is apparent from FIGURES 2 to 4 that increasing the specific gravity of the grinding media to at least seven points above that for the ore greatly decreases the grinding time required to achieve the desired end product with a net increase in grinding efficiency. Putting it another way, increasing the specific gravity of the grinding media above a critical minimum markedly increases the grinding capacity of the ball mill.

The foregoing will clearly appear from the following illustration:

In order to produce a concentrate containing between 64 and 65% iron using steel balls (specific gravity difference of 4.1), FIGURE 4 indicates that a grinding time of 40 minutes is required. Yet, according to FIGURE 3, this concentrate can be obtained in half the time by maintaining a specific gravity difference between ore and grinding balls of 7 or above, which would be equivalent to doubling grinding capacity.

Depending upon the metallurgical requirements, it may be more economical to produce a concentrate containing from 60 to 62% iron, particularly where high tonnage rates is an important consideration. A sacrifice of only several points in the iron content of the concentrate would be more than compensated for by a three- or four-fold increase in grinding capacity. To illustrate the foregoing, suppose 100 lbs. of ore concentrate containing 43.7% Fe is processed by fine grinding for 40 minutes as in Figure 4 with heavy grinding media to produce a 65% concentrate with an indicated overall recovery of 87.5% Fe. The ultimate yield of iron would be $100 \times .437 \times .875$ or 38.24 pounds, assuming no loss in the subsequent metallurgical treatment. On the other hand, if the same ore concentrate is processed by fine grinding with heavy media to produce a 61% iron concentrate with an indicated overall recovery of 89% iron as in FIGURE 2, a total of 400 pounds of ore would be processed in 40 minutes to produce a concentrate of approximately 61% iron content. The ultimate iron yield in this case would be about $400 \times .437 \times .89$ or 156 pounds or about 4 times more than when a richer concentrate is produced. By controlling the wet grinding over narrow limits of pulp densities (e.g. 65 to 80%) as shown in FIGURE 5, together with the specific gravity of the heavy media, high yields can be maintained. Consistently higher yields are indicated for a pulp density of about 70% solids as shown in Table 4 and FIGURES 11 to 12.

Concomitant with the improvement in grinding capacity and efficiency, a marked increase in surface area is indicated in the final product when the specific gravity of the grinding balls is maintained at least seven points above that for the material being ground. This is clearly shown in FIGURES 7 to 9 which correlate the amount of −200 mesh material produced with the specific gravity of the grinding media. It will be noted that the family of grinding curves are very similar to those based on iron recovery in FIGURES 2 to 4. In other words, the greater the surface area per unit weight of final product, the greater will be the amount of iron liberated in the concentrate produced from the finally ground product. By plotting all the values of Tables 1 to 3 as shown in FIGURE 6 (percent minus 200 mesh vs. percent Fe in the concentrate) an almost direct proportionality is indicated up to about 65% iron and when up to about 90% of the ground material passes 200 mesh. However, as the amount of minus 200 mesh increases to about 98%, the iron in the concentrate appears to approach approximately 67% as an asymptotic limit. This is a very rich concentrate considering that pure magnetite contains slightly over 71% iron and considering that originally the taconite ore as mined contained about 21% iron, before being subjected to primary grinding followed by the controlled fine grinding of the invention.

While fine grinding is an important consideration in reaching the critical crystal size of the mineral in the ore and thereby effect its liberation, it is also very important in the dry grinding of cement clinker where optimum surface area is an essential requirement in the end use of the product.

To determine whether the criticality as to specific gravity also obtains for dry grinding, tests were also conducted in the same ball mill using the same ball charge. The weight of material used in the dry run was 2,000 grams. A comparison test was run on a pulp of the material containing 70% solids. The material tested was not the same taconite concentrate used in the earlier examples. The results obtained are tabulated in Table 4 below and illustrated in FIGURES 10 to 15.

Table 4

Ball charge spec. grav.	Percent solids by weight	Time mins.	Percent minus 200 mesh	Conc. percent Fe	Conc. percent total Fe
7.8	100	10	52.8	55.4	96.0
10.0	100	10	57.6	57.86	97.0
11.3	100	10	65.3	58.35	95.5
12.5	100	10	63.0	59.05	95.2
7.8	100	20	64.6	59.24	95.0
10.0	100	20	69.5	61.4	94.5
11.3	100	20	74.7	63.2	93.6
12.5	100	20	77.2	64.4	93.4
7.8	100	40	80.7	64.9	94.0
10.0	100	40	87.4	66.91	94.2
11.3	100	40	92.1	66.8	92.8
12.5	100	40	95.0	66.6	91.6
7.8	70	10	62.2	58.9	96.2
10.0	70	10	66.4	60.4	96.5
11.3	70	10	70.4	62.5	95.1
12.5	70	10	73.5	62.8	95.0
7.8	70	20	76.0	62.1	95.0
10.0	70	20	83.5	64.5	93.6
11.3	70	20	89.5	65.5	93.1
12.5	70	20	90.5	66.0	92.1
7.8	70	40	94.1	66.7	94.0
10.0	70	40	97.2	67.5	91.8
11.3	70	40	98.5	68.0	90.4
12.5	70	40	98.7	67.8	90.0

It will be noted that the curves obtained for dry grinding bear the same family resemblance to those obtained for wet grinding whether based on surface area of the final product (i.e. amount of minus 200 mesh) or iron content in the concentrate produced from the product.

It is particularly significant that the results obtained by dry grinding, while varying below those obtained at pulp densities between 60 to 80% solids, are markedly superior to the results obtained for pulp containing 85% solids. For optimum dry grinding results, it is preferred that the grinding media have a specific gravity of at least about 8 points higher than the material to be ground.

In applying the inventive concept to the fine grinding of ores in a ball mill, it is to be understood that the usual ball milling practice will prevail as to ranges in charge volume of the material, whether wet or dry, and as to ranges in charge volume of the grinding balls used. In other words, whatever is deemed good practice in the conventional use of a ball mill will apply to the carrying out of the invention. For example, according to the art the ball charge volume may range from about 35% to as high as 50% of the mill volume including voids, the capacity of the mill generally increasing proportionately with the increase in volume of the ball charge up to the latter figure. Likewise, usual mill practice will prevail as to the speed of rotation of the mill. In normal practice, as pointed out in Taggart's Handbook of Mineral Ore Dressing at page 5-08 (3rd ed. 1948), the mills are run at about 50% to 90% of critical speed.

According to current practice in dry grinding, the normal total volume occupied by the material undergoing comminution and the ball charge is of the order of about 45 to about 50% of mill volume. The ideal charge is one that completely occupies the voids between the balls, a slight excess being desired in order to assure all voids are occupied by the material.

In current practice, the angle of "nip" between two balls basically determines the size of feed particle which will be efficiently reduced and thus the size of the balls required to give efficient results will normally be determined by the particle size of the feed. Thus, in the fine grinding of feed having particle sizes predominantly within the range of 10 down to 200 mesh or lower, it is preferred the size of balls used not exceed substantially one inch in diameter. The comminution of materials employing conventional practice is described in some detail by Taggart (Handbook of Mineral Dressing, 3rd ed., 1948).

While the present invention has been described with respect to the fine grinding of taconite ore concentrate, it is also applicable to the fine grinding of any materials requiring fine comminution for metallurgical or large surface area purposes, such as for instance cement clinker and talc, and as mentioned hereinbefore cement clinker.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

What I claim as my invention is:

1. A method of fine grinding particulate feed material of taconite of particle size predominantly between the range of 10 mesh and 200 mesh in a ball mill which comprises maintaining a ball charge of maximum diameter not exceeding about one inch and of specific gravity ranging from about seven to about 9 integers higher than the specific gravity of the material to be ground, said ball charge constituting about 35% to about 50% of the mill volume including voids, forming a mill charge of said material and said balls, and subjecting the charge to the action of said ball mill at a speed of rotation within the range of about 50% to 90% of the critical speed of the mill.

2. The method of claim 1 wherein the particulate feed material is ground in the dry state.

3. The method of claim 1 wherein the partticulate feed material is ground in the wet state and has a pulp density of about 65% to 80% solids.

4. A method of fine grinding particulate feed material of particle size predominantly between the range of 10 mesh to 200 mesh in a ball mill which comprises maintaining a ball charge of maximum diameter not exceeding about one inch and of specific gravity at least seven integers higher than the specific gravity of the material to be ground, said ball charge constituting a substantial portion of the mill charge, forming the mill charge of said material and said balls, and subjecting the charge to the action of said ball mill.

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