March 17, 1959 J. F. MYERS 2,877,954

DRESSING OF ORE

Filed June 14, 1954

2 Sheets-Sheet 1

FIG. 1

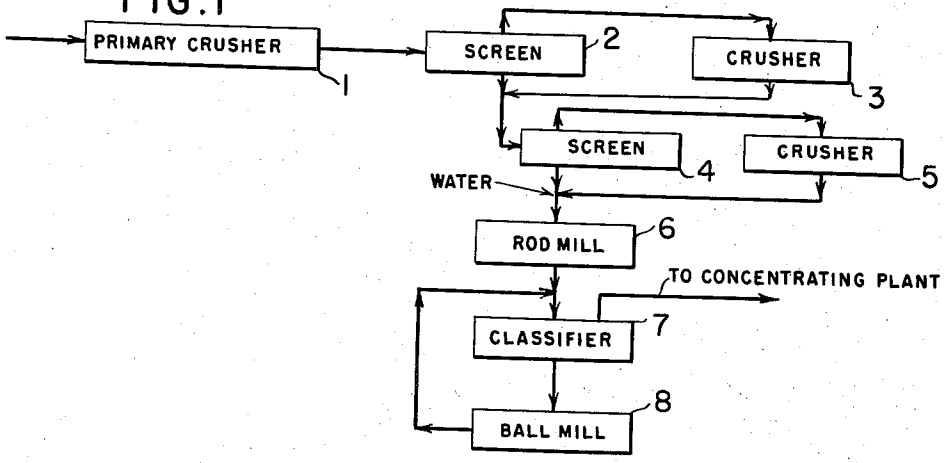
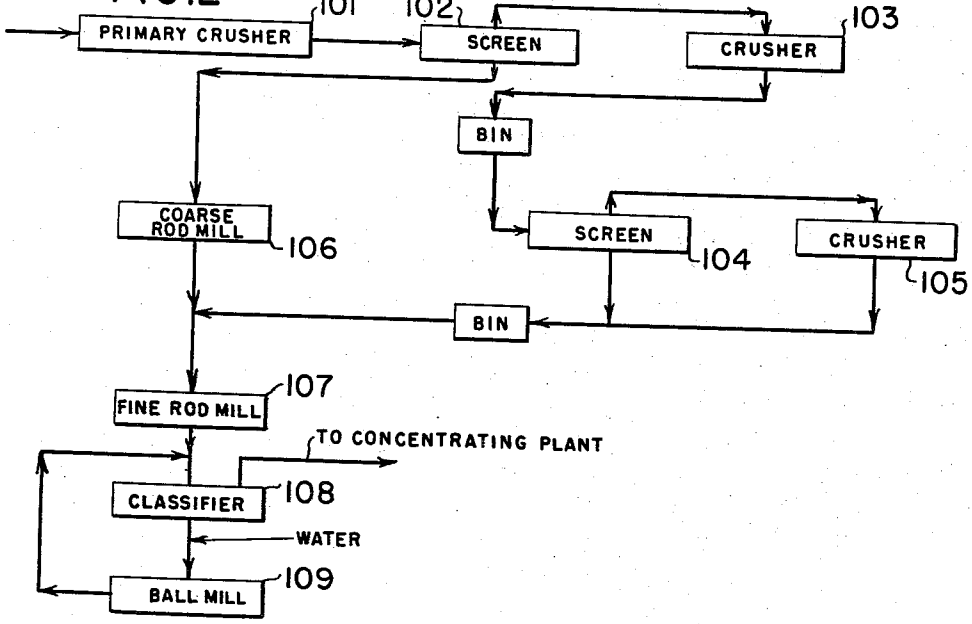


FIG. 2



John F. Myers
INVENTOR.

BY Adams, Forward and McLean

ATTORNEYS

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FIG. 3A

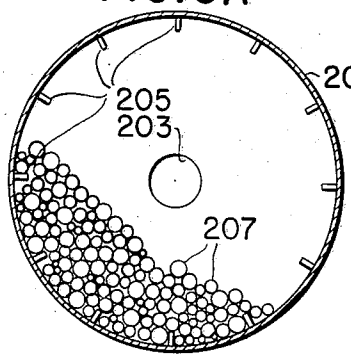
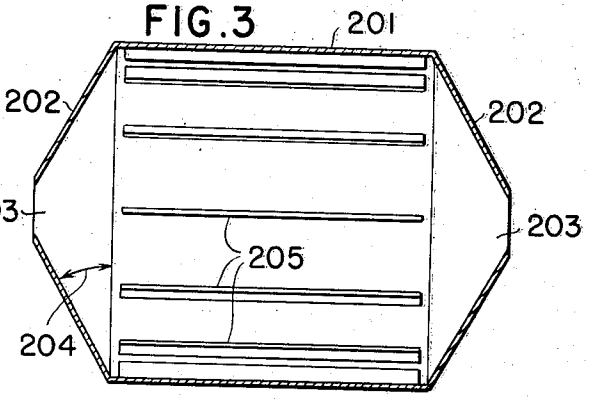


FIG. 3



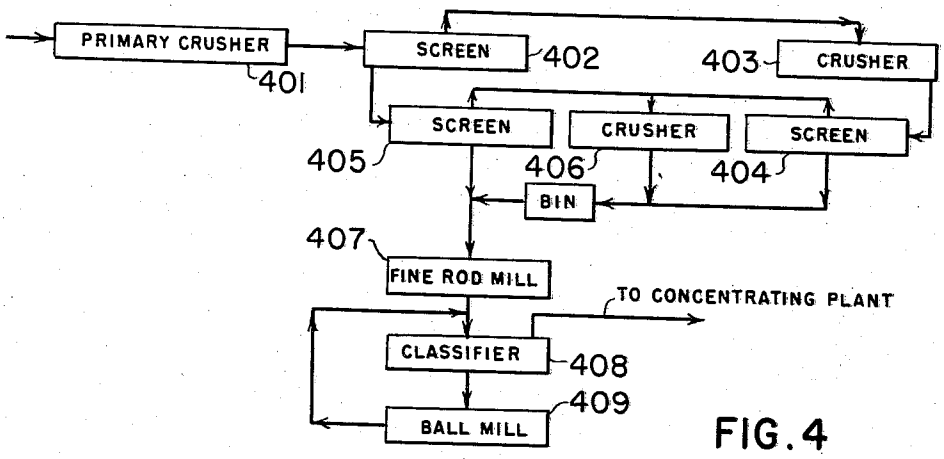
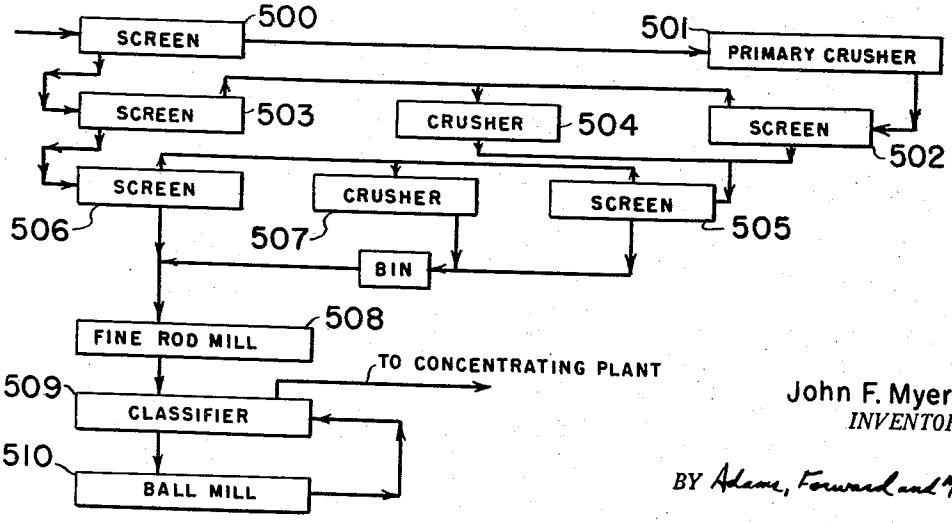


FIG. 4

FIG. 5



John F. Myers
INVENTOR.

BY Adams, Forward and Khan

ATTORNEYS

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2,877,954

DRESSING OF ORE

John F. Myers, Greenwich, Conn., assignor to Taggart & Myers, Scarsdale, N. Y., a partnership composed of Arthur F. Taggart and John F. Myers

Application June 14, 1954, Serial No. 436,360

4 Claims. (Cl. 241—24)

My invention relates to a method for the crushing and grinding of ores and the like, particularly under conditions such that ice tends to form within masses of partially broken ore and also in and on machines in the plant in which the crushing and grinding are being carried on.

The fine concentration of ores in frigid regions gives rise to numerous operating difficulties which are brought about by frozen water. Important among these difficulties is ice formation on and in the apparatus utilized in the crushing plant. This is illustrated by the experiences which have been encountered in the new iron ore concentrating mills which were operated during the winter of 1953–4 for the first time in the Great Lakes region of the United States.

In the typical operation heretofore used, the ore is mined in open pits or quarries by setting off gigantic blasts which break the rock to a size that can be handled by large power shovels. The quantity of rock broken by one or a series of blasts is sufficient to run the crushing and grinding equipment for a period ranging from a few days to several weeks. During the interval between blasting and shoveling up, the blasted ore lies in the open exposed to the weather, and air and water penetrate the mass relatively freely. In frigid weather, the blasted ore becomes cooled to such an extent that temperature measurements of the interior of large lumps of ore have given readings as low as 30 degrees below zero Fahrenheit. Treatment preparatory to separation of the valuable from waste portions of the ores starts when the rock which has been blasted is shoveled up and sent to the crushing and grinding plant in railroad cars or large trucks. Referring specifically to Fig. 1, which describes a typical crushing and grinding method heretofore used, the ore from the railroad cars or trucks is dumped into a large primary crusher 1, from which the broken ore is transported by a conveyor belt to a screen 2, which removes as undersize material which will pass through about 2-inch openings. The oversize from screen 2 passes to a secondary crusher 3 which is set to break to about a 1½ inch maximum thickness. The crushed product from crusher 3 joins the undersize from screen 2 on another belt conveyor, and the combined streams are dumped into a distributing bin (not shown). From the distributing bin, the partially crushed material discharges to screen 4 which has about one-half inch apertures and separates a fine fraction and a coarse fraction. The coarse fraction from screen 4 discharges to a fine crusher 5, and the product of this crusher joins the undersize from screen 4 and passes to a storage and distributing bin (not shown). From this bin the finely crushed mixture is fed with the addition of liquid water to conventional rod mills 6 of the grinding plant. Rod mill product passes to mechanical classifiers 7, which overflow material to the concentrating plant. The coarse fraction from the classifiers passes to ball mills 8 for further grinding, whence it returns to classifiers 7 until eventually all escapes in the overflow to the concentrating plant. Tonnages treated in such plants range now, even in the pilot plant stage, from 1,500 to 10,000 long tons per day. Eventually, with the experience gained in the exploratory plants, it is expected that individual plants will be enlarged to treat as much as 100,000 long tons per day.

The normal operating crew for one of the larger pilot plants is about a dozen men. Yet during the cold weather of the winter of 1953–4 in one such plant a crew of 100 to 125 men was unable to keep the plant operating because of ice formation in and on belt conveyors, screens, crushers and bins. In the attempt the crew is reported to have done very extensive damage to equipment by poking, hammering, barring, blowtorching, and even dynamiting gently, in a frantic endeavor to combat rapidly forming ice.

The basic cause of this catastrophic ice formation was the contact of a slush or mud of fine ore and more or less liquefied snow and ice that had passed through the meshes of screen 2 and was returned to the stream and made contact with sub-zero surfaces of freshly broken pieces from crushers 1, 3 and 5 before those surfaces had been sufficiently warmed. As a result, the slushy mud was frozen onto the cold ore surfaces, or was supercooled to such an extent that it flash-froze onto any surface, such as the conveyor immediately following crusher 3, screen 4 or crusher 5 with which it came into contact. Or, escaping such contact until discharged into the bins following crusher 3 and crusher 5, it froze and cemented the masses therein and prevented normal withdrawal.

In accordance with my present invention, I have discovered a method whereby the aforementioned operating difficulties caused by freezing can be either largely or wholly eliminated.

The essence of my invention is early separation of the feed stream by screening into a coarse fraction containing the low-temperature material and a fine fraction that contains the bulk of the water in liquid and solid form together with ore particles which are at substantially surrounding atmospheric temperature, and subsequent handling of the two streams separately in such ways as not to bring the fine water-containing material into contact with sub-zero surfaces exposed by breakage of the particles of the coarse fraction until the conditions surrounding such intermingling are such that harmful freezing does not take place.

This can be effected in various ways. For example, I have discovered that by diverting the water-containing undersize from screen 2 of Fig. 1 into a coarse-crushing rod mill (or equivalent device) and therein crushing and grinding it in a particular way, and thereafter sending the product of this coarse-crushing rod mill to rejoin the main stream in rod mills 6 of Fig. 1, the aforementioned freezing difficulties are either substantially or totally eliminated. In operating in this manner and also in accordance with other embodiments of my process, water-containing material is kept away from sub-zero temperature surfaces that in the present operation freeze it, and is not rejoined with the main stream containing sub-zero surfaces until conditions are such that harmful freezing does not take place.

Fig. 2 represents in greater detail an operation falling within the scope of my invention. In Fig. 2, the ore from the railroad cars or trucks is dumped into a large, primary crusher 101, suitably a gyratory or jaw crusher, from which the broken ore is transported to a screen 102, which removes as undersize material which will pass through approximately 1½ to 2½ inch openings. The oversize from screen 102 passes to a secondary crusher 103, suitably a standard cone crusher, which is set to break to about a 1½ inch maximum thickness.

The crushed product from crusher **103** is dumped into a distributing bin, and from this bin this partially crushed material discharges in parallel streams to a battery of screens **104** of about ½ inch aperture which separate a fine fraction and a coarse fraction. The coarse fraction from screen **104** discharges to a fine crusher **105**, suitably a short head type gyrating cone, and the product of this crusher passes to a storage and distributing bin feeding fine rod mills.

The undersize from screen **102** passes to a coarse rod mill **106** which effects a size reduction to about ¾-inch maximum or less, say ⅜-inch, at which size the ore can be handled by conventional tumbling mills. As shown in Figures 3 and 3A, rod mill **106** comprises a cylindrical shell **201** with end closures **202** which are outwardly extending conical frusta having axial openings **203** for feed and discharge. The structure is conventionally mounted for rotation with its cylindrical axis horizontal. Its actual dimensions depend upon the capacity desired and the extent of reduction required. Normally the cylindrical portion will range between 6 and 12 feet in diameter, and the cylinder length is approximately equal to the cylinder diameter, say from 0.8 times to 1.25 times the cylinder diameter. The base angles **204** of the conical ends preferably lie between 20 and 30 degrees from the vertical. The interior of the cylindrical portion is fitted with heavy longitudinal ribs **205** which project substantially radially inward from the inner surface of the cylinder shell liner plates. The extent of the inward projection should be from not less than one-half to slightly more than 1½ times the diameter of the largest of the rods **207** in the mill charge. The mill should be charged to somewhat less than half, say from about 0.35 to about 0.45, its volumetric capacity with cylindrical steel rods normally of 3 to 5 inch diameter and of a length slightly shorter than that of the cylindrical section inside the liner plates, say from 1 to 6 inches shorter. Operating speed should be from 70 to 90 percent of critical, where critical speed in R. P. M. is defined by the equation:

$$N=\frac{54.19}{\sqrt{r}}$$

wherein N is R. P. M. and r is the interior radius of the cylindrical shell in feet.

This rod mill differs from the conventional rod mill both in its function and in its combination of structural features and operating conditions. Its general function is to reduce maximum particle size of a relatively coarse feed through a relatively short range (3 or 4 to 1), at high capacity. Its specific function is to provide a crushing zone capable of fracturing ice and ice-coated particles without interruption with the action normal to it under ice-free conditions and additionally to crush moist mixtures of such coarse material with muddy slush which congeals when passed through the typical crushing plant in the presence of sub-zero rock. This ability is obtained by the combination of substantially equal diameter and cylindrical length, coned ends, high speed of rotation, the high lifter bars, and preferably the addition of water in an amount to comprise 25 to 35% total water in the pulp. The effect of this combination of shell dimensions, lifter bars and high speed is to throw the rods from a position high on the upcoming side of the cylindrical section into a jackstraw-like jumble in the diametrically opposite lower part of the shell and continuously to bundle the lower part of this ever-building heap into parallel by rapid, sudden slaps of the downcoming inwardly projecting ribs. In thus bundling the rods, all particles adjacent to a given contacting pair of crossed rods and/or to the pushing rib are subject to suddenly applied hammer-like and scissor-like forces which shatter and slice slippery particles as well as normal particles without permitting them to slide away. Powerful rolling and sliding in the rod mass on the upcoming side prevents congelation and the considerable quantities of heat evolved in the crushing operation pass in large part into the pulp. The added liquid water not only contributes further heat, but also aids in absorbing and distributing the heat of crushing throughout the mass.

Selection of a suitable coarse grinding rod mill for the purpose of my invention requires modification of conventional rod mill design constants to allow for the higher operating speeds and the high lifter bars previously described. An example of such design follows:

Referring to Fig. 2 with the primary crusher set to five inches open setting and receiving 500 tons of taconite per hour approximately 300 tons per hour pass a rod-deck screen with apertures 2-inches wide. The work index W_i (see F. C. Bond, Mining Engineering, May 5, 1952) for the rock rod milled to ½-inch product size is 20.2 from which the required work input W by the Bond equation is:

$$W=W_i\left(\frac{\sqrt{R}-1}{\sqrt{R}}\right)\sqrt{\frac{100}{P}}=$$

$$20.2\left(\frac{\sqrt{4}-1}{\sqrt{4}}\right)\sqrt{\frac{100}{12{,}700}}=0.89 \text{ kw. hour per ton}$$

wherein R, the reduction ratio, contemplates 2 inches as the 80% size of the feed and ½-inch as the 80% size of the product, and P is the micron equivalent of the ½-inch product. The total work input required for reduction of 300 tons per hour is, therefore,

$$300\times0.89=267 \text{ kwh.}$$

The power draft per ton of rods at conventional speeds (65 to 70 percent of critical) averages about 5.8 kw. Power draft at higher speeds is greater in substantial proportion to the higher speed. At 90 percent of critical the draft per ton of rods is about

$$\frac{90}{67.5}\times5.8=7.8 \text{ kw}$$

High ribbing reduces the input in the proportion of lifter projection to mill radius inside the shell. With 4 inches projection and a preliminary estimate of 50 inches radius inside liners the reduction in draft is

$$\frac{4}{50}=8\%$$

Whence the power draft per ton of rods is

$$0.92\times7.8=7.2 \text{ kw.}$$

The rod charge required is, therefore,

$$\frac{267}{7.2}=37 \text{ tons}$$

Taking rod weight at 330 pounds per cubic foot of struck volume $(37\times2000)/330=224$ cubic feet rod filled volume is provided. The mill volume necessary for 224 cubic feet to comprise 45 percent of mill volume is $224/0.45=500$ cubic feet inside liner plates. A mill of this interior volume, with diameter equal to cylinder length, has a diameter

$$d=\sqrt[3]{4\times500}/\pi=8.75 \text{ feet}$$

Allowing three inches for thickness of liner plates requires a mill 9 feet 3 inches inside diameter of shell and 8 feet 9 inches long. A 9 by 9 foot mill provided with conical ends having base angles of about 25°, provided with 4-inch ribs and filled to about 45% of its volumetric capacity with 4-inch rods about 3 inches shorter than the horizontal length of the mill fulfills the requirements when rotated at about 90% of critical speed.

The discharge of rod mill **106**, in admixture with undersize from screen **104** and crushed material from crusher **105**, passes to the conventional fine crushing rod

mill 107, and thence to a classifier-ball mill circuit including classifier 108 and ball mill 109 wherein more water is added and more heat is generated and absorbed into the pulp. If desired, coarse rod mill 106 can be replaced by an equivalent intermediate crushing mill, for example, a tumbling device, such as a ball mill, or a hammer mill (preferably of the grateless type) if the ore is relatively friable and not too abrasive, and if desired the fine rod mill 107 can be replaced by an equivalent tumbling device, such as a ball mill. Further, if desired, the material passing from fine rod mill 107, instead of being passed to a conventional ball mill-classifier circuit, can be handled as described in application Serial No. 389,273, filed October 30, 1953, now Patent 2,791,382. Thus, the effluent from rod mill 107 can be introduced into a ball mill constructed and operated as described in said patent so as to effect simultaneous wet-grinding and classification, and the resulting ground and classified material can then be transferred to the concentrating plant.

It is also possible to practice the process of my invention without any further crushing or grinding or the like intermediate the first screening, in which the bulk of the water in liquid and solid form together with ore particles which are at substantially surrounding atmospheric temperature and the coarse fraction containing the low-temperature material are separated, and the milling in the fine rod mill (107 of Fig. 2) or equivalent prior to the classifier-ball mill system. Fig. 4 and Fig. 5 set forth in diagrammatic form operations of this type.

Referring specifically to Fig. 4, the ore from the mine is supplied to a primary crusher 401 having a 5 to 6 inch closed size setting. The crushed ore from primary crusher 401 passes to a conventional double deck screen 402 having 5 inch and 2 inch apertures. The oversize from both screens passes to crusher 403 having a 1½ inch closed size setting. From crusher 403, crushed ore passes to screen 404. Undersize from screen 402 passes to screen 405, this screen as well as screen 404 being a conventional single deck half-inch aperture screen. Oversize from screens 404 and 405 is fed to crusher 406 which is set to a ½-inch closed size setting. Thereafter, the operation is similar to that set forth in Fig. 1, undersize from screen 404 and the ore crushed in crusher 406 passing to a storage bin, and ore from that bin as well as undersize from screen 405 passing to fine rod mill 407 and thence to a conventional classifier-ball mill circuit including classifier 408 and ball mill 409. Overflow from the classifier-ball mill circuit flows to the concentrating plant. Here again, if desired, as in the operation set forth in Fig. 2, the fine rod mill 407 can be replaced by an equivalent tumbling device, such as a ball mill. If desired, the classifier-ball mill circuit can be replaced by the type of operation described in my application referred to above.

Referring specifically to Fig. 5, the ore from the mine is initially fed to screen 500 having apertures of about 4 to 6 inches, suitably a grizzly. Oversize from screen 500 passes to primary crusher 501 having about a 5 inch closed size setting. The crushed ore from the primary crusher 501 then passes to screen 502 having about a 2 inch aperture. Undersize from screen 500 passes to screen 503, which likewise has about a 2 inch aperture. Oversize from both of screens 502 and 503 are transported to crusher 504 having a closed size setting of about 2 inches. Undersize from screen 502 and the ore crushed in crusher 504 are fed to screen 505 having an aperture of about ½-inch. Likewise, undersize from screen 503 is passed to screen 506, which also has an aperture of about ½ inch. Oversize from both of screens 505 and 506 is fed to crusher 507 which has a closed size setting of about ½ inch. From this point on, the embodiment set forth in Fig. 5 is similar to that set forth in Fig. 4. Thus, ore crushed in crusher 507 and undersize from screen 505 are passed to a storage bin, from which the mixture passes to fine rod mill 508, which also receives the undersize from screen 506. From the fine rod mill 508, the ore is fed to a conventional ball mill classifier system including classifier 509 and ball mill 510. As was the case in the operation described in Fig. 4, fine rod mill 508 can be replaced by an equivalent tumbling device, such as a ball mill, and the operation carried out in classifier 509 and ball mill 510 can be performed using the method described in my aforementioned prior application.

I claim:

1. In a process of dressing water-containing ore under freezing conditions to a size appropriate to be fed to a classifying operation, the steps of screening lumps of ore into coarse fraction containing low temperature material and fine fraction containing the bulk of the water in liquid and solid form together with ore particles which are at substantially surrounding atmospheric temperature; size-reducing coarse fraction and at least the larger particles contained in the fine fraction; combining size-reduced coarse fraction, such particles contained in the fine fraction as have been size-reduced and such particles in the fine fraction as have not been size-reduced and size reducing the resultant mixture in a fine-crushing tumbling mill to a size appropriate to be fed to a classifying system, with the proviso that particles of size-reduced coarse fraction are admixtured with such particles of the fine fraction as have not been size-reduced only when they are introduced in admixture with each other into the tumbling mill and with the further proviso that when the entire fine fraction undergoes size reduction before said combining such reduction is carried out in an intermediate crushing mill to provide a size-reduced mixture which is then admixed with size-reduced coarse fraction and the admixture is introduced into the tumbling mill.

2. In a process of dressing water-containing ore under freezing conditions in which the ore is crushed to a size appropriate for screening on a screen having effective openings of approximately 1½ inches to 2½ inches, in which the crushed ore is screened on such a screen and in which the oversize from the screen is further crushed and finally milled in a fine-crushing tumbling mill to a size appropriate to be fed to a classifying operation, the step of rod milling the undersize from the screen in a coarse-crushing rod mill separate from the oversize crushing step and passing the discharge thereof to the fine-crushing tumbling mill and therein crushing the ore to a size appropriate to be fed to a classifying system, said coarse-crushing rod mill having a cylindrical shell of substantially equal length and diameter provided with outwardly extending conical ends sloping at an angle of approximately 20 to 30 degrees from the vertical, the interior of the cylindrical shell containing a mass of rods and being provided with ribs projecting inwardly not less than ½ to slightly more than 1½ times the diameter of the rods and being rotated in revolutions per minute at from 70 to 90 percent of $54.19\sqrt{r}$ where r is the interior radius of the lined cylindrical shell in feet.

3. In a process of dressing water-containing ore under freezing conditions to a size appropriate to be fed to a classifying operation, the steps of successively screening lumps of ore to provide as oversize coarse particles containing low temperature material and as an undersize a fine fraction containing the bulk of the water in liquid and solid form together with ore particles which are at substantially surrounding atmospheric temperature; size-reducing the oversize; and size-reducing the size-reduced oversize and the aforementioned fine fraction in a fine-crushing tumbling mill to a size appropriate to be fed to a classifying operation with the proviso that particles or size-reduced oversize are admixed with the fine fraction only when they are introduced into the tumbling mill and at such a time as freezing does not occur when they are mixed.

4. In a process of dressing water-containing ore under freezing conditions to a size appropriate to be fed to a classifying operation, the step of initially screening lumps or ore into coarse fraction containing low temperature material and fine fraction containing the bulk of the water and further size-reducing the coarse fraction to a size appropriate to be fed to a classifying operation and admixing the size-reduced coarse fraction and the fine fraction containing the bulk of the water at a time when said coarse fraction has been sufficiently warmed in the size reduction operation so that freezing does not occur when the size-reduced coarse fraction and fine fraction are admixed.

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