

3,226,044

2 Sheets-Sheet 1

The diagram shows a vertical industrial machine, possibly a pump or a separator. It features a central shaft with a rotating element at the top. The main body is a vertical cylinder with internal components, including a series of diagonal blades or vanes (labeled 2, 2a, 3, 4). The machine has a hopper-like top (11, 10) and a conical bottom (14, 6). A pump or motor unit (12) is connected to the side via a pipe. Various dimensions and labels are indicated: D_0 and d_0 for diameters, H_0 and H for heights, and D_b for a base diameter. Arrows indicate the flow of material or fluid through the machine.

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YUKIO MATSUBAYASHI ETAL

3,226,044

GRINDING MILL

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2 Sheets-Sheet 2

Fig. 2.

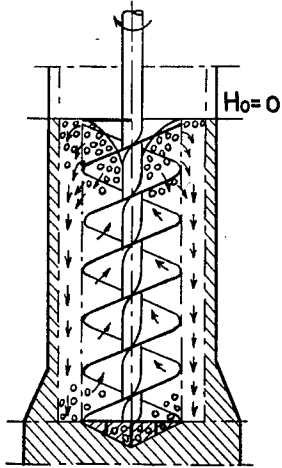


Fig. 3.

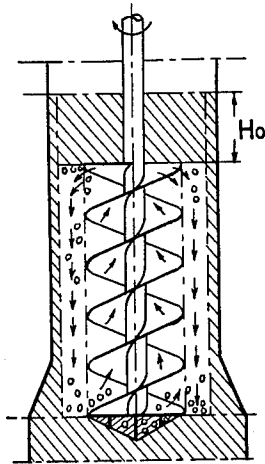


Fig. 4.

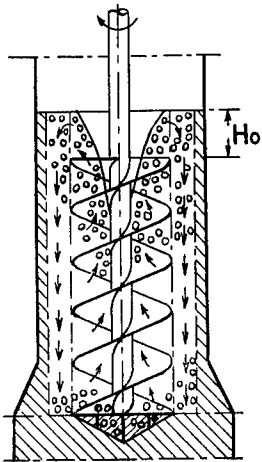
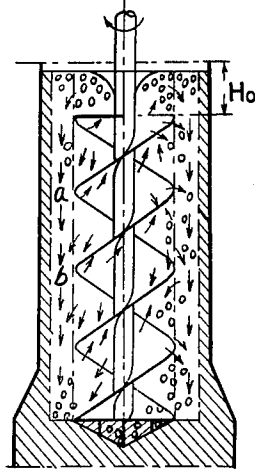


Fig. 5.



1

3,226,044

GRINDING MILL

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Claims priority, application Japan, Oct. 27, 1961, 36/38,517, 36/38,518, 36/38,519, 36/38,520

8 Claims. (Cl. 241-172)

The present invention relates to a continuous fine grinding mill and a method of grinding by this mill. It is well known to suspend a screw in a cylindrical shell, pack grinding media into the space between the shell and the screw and grind the material which is suspended in fluid, for example water or air, by abrasive action caused by rotating the screw. But in such a device the grinding media is always moved upward, downward and round repeatedly, which results in a severe contact of the grinding media or the material to be ground with the shell or the screw. Coating of wear-resistant materials such as rubber in order to prevent abrasion by said severe contact is already known. But rubber-coating is very expensive and if once a part of the coating is broken, this breakage extends without delay to other parts, which results in an exfoliation of the coating and therefore in a considerable decrease of the durable years of the device.

The inventors of this application have theoretically analyzed motions of grinding media within a grinding mill according to soil mechanics and found that said drawback is due to unreasonable motions of grinding media within the mill shell. Grinding action of this kind is namely effected in such manner that all of the individual of media make contact motions with one another under a packed condition and cause abrasions of material particles at contact points of the individuals. Therefore, the ideal grinding conditions should be such that voids of packed media are always filled up with suspension of material particles in a high density and the individuals of media make motions under a perfectly packed condition, that is to say, the individuals of media contact with each other in such a manner that the surface of each medium is covered with material particles. Under the above conditions in which the wear of media can be remarkably minimized, the abrasion of material particles becomes predominant and a greater part of power consumed in the motions of media can be efficiently utilized in abrading the material, a mill can perform much more effective fine grinding than a ball mill and so on. In this connection, the inventors have found that the grinding media can reasonably be removed and circulated in such fashion that they are conveyed upward through a spiral flowing path within the screw and moved downward through a vertical flowing path located around the screw under a perfectly packed condition by regulating packed volume of media, speed of rotation of the screw and pitch thereof.

In order that the invention may be more readily understood, one embodiment will now be described with reference to the accompanying drawings, in which:

FIG. 1 is a vertical side-section of a preferred embodiment of a fine grinding mill according to the invention,

FIGS. 2-5 are schematic drawings illustrating undesirable movements of grinding media in a tower mill.

In the grinding mill illustrated in FIG. 1, a screw

2

formed with spiral wings 2a is suspended in a cylindrical shell 1. The inner space of the mill is packed up to a height which is located higher than the top end of the screw with grinding media such as iron balls, steel balls, corundum balls, etc., and granular or massive materials. When the screw 2 is rotated by a driving device provided with a continuous speed-controller, grinding media are conveyed upward by pushing up action of the screw and then moved downward, which is repeated continuously. According to the inventors' study, grinding media can be conveyed upward through the spiral flowing path within the screw and moved downward through the vertical ring-shaped flowing path located around the screw keeping a perfectly packed condition by regulating the dimensions and the operation conditions of the present device. But in this case the grinding media fall plumb down or effect circular motions along the internal surface of the shell, whereby this internal surface is subject to a serious rubbing with said media. According to the present invention, several circular horizontal ribs 3 and vertical ribs 4 are fixed on the internal surface of the shell and thereby a static layer of media is made along the internal surface even while the grinding media move within the shell. It results therefrom that the direct rubbing between the internal surface of the shell and the grinding media comes to a standstill and the internal surface can be perfectly free from wearing, so that the power consumed in said rubbing action can be converted to effective abrading energy. The mutual distances between the ribs depend on dimension and shape of the shell and the screw and the size of the grinding media. The ribs can be so arranged that its direction is somewhat inclined and the width of ribs in general should be two or three times the size of media. According to the invention it is not necessary for the internal surface of the shell to be made of or coated with special wear-resistant materials. If necessary, the coating can be done only on the edge of ribs in order to improve considerably the durability thereof. The construction of the screw will be then illustrated as follows:

As shown in FIG. 1, the screw has a special bottom construction which consists of a disc 14 fixed on the bottom of the screw 2 and radial ribs 5 fixed on the back of the disc 14. The radial ribs are fixed in such a way that the edges of them form geometrical generating lines of a conical surface. The bottom construction serves to prevent the local wear of the screw-end and due to this construction even the ends of the screw wings 2a serve to convey the grinding media.

When a screw without said bottom construction is rotated in the mill, the end-edges of spiral surfaces of the screw have to push through the packed bed of media against high grain pressure of packed media, and also severe rubbing action inevitably occurs between the back end-surfaces and the end-edges of spiral surfaces of the screw wings and the packed media. These phenomena result in an extremely rapid wear of the screw-end. The disc serves to prevent such a direct rubbing action and further for the purpose that also the end of the spiral surfaces of the screw wings causes the grinding media to effect the same soil mechanical motion as the upper spiral surfaces of the screw wings. By fixing only a disc at the end of a screw a direct rubbing action on the back plane of the disc with materials is unavoidable, which results in a rapid

wear of the disc. Radial ribs should be fixed to prevent the wear of back surface of the disc as they hold grinding media between the ribs and when the screw is rotated mutual friction of media occur on the inverted conical surface. In addition, material particles are forced to move toward outside of the conical surface by means of centrifugal force, thus the bottom construction serves to prevent the wear of the disc by material particles. In this case the abrasion of the disc occurs on its edge as well as that of the screw-wings and thereby the durability of the disc and the screw-wings become same. However, it is undoubtedly unavailable energy having no relation to the motion of media or grinding action that is consumed for rotating the inverted cone against friction force acting on the conical surface. This unavailable energy consumption can be decreased up to 5-8% of the total consumed energy by adopting a considerably high value of the ratio of the motion height of media to the effective diameter of the shell. One way to eliminate said unavailable energy is to arrange a bearing at the lower end of the screw, but the bearing in this case cannot be durable for a severe wear. According to the above-mentioned reasonable design condition, only a vertical force exerts on the screw shaft and therefore no lateral oscillation occurs, so that a lower bearing is not required.

Various screws for this invention can be formed. For example, a screw can be provided with screw-wings having a small diameter in order to maintain a high strength, the spiral surfaces of the screw being desirably divided into small and replaceable wing-pieces which have a prescribed radius and are made of wear-resistant material such as chilled cast iron, heat-treated special steel, tile, etc.

The enlarged part 6 of the shell 1 is provided for the purpose of preventing local wear of the disc 14 which would be caused by rapid flow of the suspension having material particles suspended due to the fact that the vertical flowing cross-sectional area around the screw is reduced by the disc. According to the invention, the relation between the effective inside diameters D_0 , D_b of the shell and the enlarged part thereof and the diameters d_2 , d_1 of the screw-wings and the screw shaft should be chosen as follows:

$$D_b = \sqrt{D_0^2 - d_1^2 + d_2^2}$$

The bottom of said enlarged part of the shell has an inverted cone-like construction as shown in FIG. 1. The angle of inclination of the inverted conical surface should be a little larger than the angle of repose of material particles to prevent precipitation of these particles. Media located under the disc, forming a completely static packed column and having no relation to grinding action, can be substituted for other substances. In selecting the substances, it is only necessary that static packed columns of them have high fractional void volumes and have enough strength to support load of the packed column of moving media. This packed column can be supported by a grid plate through which the material particles can pass. In addition the disc of the screw can be supported directly from below by a slide mechanism, which is so arranged that the material cannot enter said slide mechanisms by forcing high pressure fluid into said mechanisms. The suspension of material particles so small as to pass freely through voids of packed column of media is fed into the shell from above, flows down through the shell to the lower outlet 7 and is conveyed circularly by a pump 12 from the outlet to the upper part of the shell. The newly supplied material and fluid enter the classification device 8, 11 through a flow-in funnel 10 together with the circulated suspension. In the classification vessel 8, the fine particles which require no further grinding are suspended in the upward current of fluid caused by continuous flowing-in of the fluid, and are overflowed from the whole edge of the vessel 8 into the flow-out through 9. 11 denotes the size-controller, which can be raised and lowered automatically or by hand by an elevating mechanism 13.

Sectional area for classifying action being reduced by lowering the position of 13, the overflowing speed becomes larger and therefore coarser particles can be overflowed, while being enlarged by raising it, finer particles are overflowed. By thus controlling the position of the size-controller, the fixed size of ground product can be attained also in case of fluctuations of feed quantity or the size of ground product can be controlled. In addition, construction of the shell, flowing system of suspend and classification means can be subject to some modifications. For example, the internal surface of the shell can be provided with coating of rubber, the suspension can be flowed out from the circumference of the enlarged part of the shell, the classification device can be arranged separately or the suspension of the material particles and the circulated fluid can be conveyed upward to the upper part of the packed column through pipes extended along the shell wall. Further, in case of preventing iron oxide from mixing in ground product or in case of using corrosive fluid grinding media containing no iron should be used and (or) the internal surface of the shell and the outer surface of the screw should be coated with plastics and so on. In case of using gas as suspension cyclone and the like can be used as classification device.

The constructional characteristics of the grinding mill according to the present invention have stated above and the determination of the main dimensions and the operational method of said grinding mill will be explained as follows:

In the embodiment of this invention shown in FIG. 1 the screw should be regarded as a "screw conveyor" with diameter d_2 . When the screw is rotated to the arrow direction in FIG. 1 by a driving device provided with a continuous speed-controller, grinding media are conveyed upward within the screw and then moved downward between the shell and the screw, thus doing a circular motion upward and downward, and in this case the height of packed column has a great influence on the motion of the grinding media. For example, when the packed grinding media are too little in quantity and the upper end of the packed layer has the same level as that of the screw-wings, as is shown in FIG. 2, the first one pitch of the screw cannot serve to convey up media and the media here cannot but slide down to the outside of d_2 -cylinder, which results in a local wear of the first one pitch of the screw. In FIGS. 2-5 the hatching parts show static medium layers and the arrow directions the motional directions of the grinding media. Moreover, as said pitch of the screw cannot serve to convey up media, the grinding capacity of the mill cannot be fully applied.

The grinding mill according to the invention is packed with media up to the total height H which consists of the effective length of the screw and the height H_0 as shown in FIG. 1, when H_0 is called "height of the additional packed bed of media." When the mill is packed with media beyond the fixed height H_0 , motion of grinding media in the height H_0 becomes more and more inactive with increasing the height, until the movement of media located in the height H_0 comes to a stop as shown in FIG. 3. Under such a condition, the edges of upper end of the screw are directly rubbed by the static media layer and their rapid wear occurs. In addition, the grinding media located in the height H_0 cannot serve to grind the material. The inventors have found that the height of the additional packed bed of media H_0 can be obtained from the following formula:

$$\frac{D_0 - d_2}{4H_0 \tan \varphi} \left(1 - e^{-\frac{4H_0 K \tan \varphi}{D_0 - d_2}} \right) \geq \tan^2 \left(\frac{\pi - \varphi}{4} \right)$$

where $D_0 - d_2$: double distance between the ribs of the shell and the screw-wings

φ : angle of internal friction of media

K : earth pressure coefficient for a vertical break surface

When thus a suitable additional packed bed of media is formed according to the invention, the grinding media

located in d_2 -cylinder are subject to a horizontal packing-pressure from the outer side of d_2 -cylinder and thereby soil-mechanical break surfaces occur in the medium layer between the screw-wings, the media in d_2 -cylinder are conveyed upward in a definite angle in which a slip occurs most easily. In addition, the grinding media located above the screw-surfaces are in the same active motion as that within the screw and also above the screw-wings the media are conveyed upward, which results in the same wear of the first one pitch as that of the other pitches of the screw. The additional packed bed of media serves to increase "medium-pressure" in the mill. Thus the whole length of the screw contributes to conveying action of media and the local wear of the screw-end is completely prevented.

Further, the motion of the grinding media is closely related with the speed of rotation of the screw. When the screw is rotating, centrifugal force acting on each individual particle of media in the d_2 -cylinder generates a horizontal medium-pressure which acts outward on the inner surface of d_2 -cylinder. This centrifugal medium-pressure is balanced to the external medium-pressure which acts inward on the outer surface of d_2 -cylinder. In the higher level of the packed column a pot-shaped cavity is formed around the screw shaft as shown in FIGS. 2, 4 and 5, because the external medium-pressure is lower. A cavity in which material particles are only passing by serves nothing for grinding action and its formation is nothing but consuming unavailable power and causes also the wear of the screw-wings. However, so long as the screw is rotated, the formation of a cavity is unavoidable so that it is desirable to restrict the cavity formation within the additional packed layer with the height H_0 . For this purpose, the angular velocity ω (rod/sec.) of the screw should be chosen as follows:

$$\omega = \frac{3gd_2(D_0 - d_2)}{d_2^2 - d_1^2} \left(1 - e^{-\frac{4K \tan \varphi}{D_0 - d_2} H_0} \right)$$

where g : acceleration of gravity

d_2 : diameter of the screw-wings

d_1 : diameter of the screw shaft

D_0 : effective inner diameter of the shell

Further, according to the inventors' studies the screw-pitch has an influence upon the motion of the grinding media.

In case of a suitable pitch direct contacts of media with the wing surfaces of the screw do not occur and the grinding media are pushed up most easily along break surfaces. If the pitch is too large an unreasonable motion of media is made in the mill as shown in FIG. 5. Considering a bed of media held in any one pitch ab of the screw, the value of "static medium-pressure" must be zero at a and increases toward b in proportion to the depth of packed media. Therefore, in the upper part of the bed, where static medium-pressure is very low, media can be pushed up by external medium-pressure acting on the outer surface of d_2 -cylinder, in the lower part, sliding action of media is caused by considerably high static medium-pressure. In this case, only incomplete conveying action can be done in the mill and the spiral surfaces of the screw are directly rubbed by sliding media. And as the angle of internal friction of coarse media is larger in general than that of fine media, the coarse media gather at the upper part of the bed and the fine media at the lower part, which results in a decrease of grinding action. In order to prevent such a disadvantage, the screw-pitch p must be within such an adequate range given by the following formula:

$$\frac{D_0 - d_2}{4p \tan \varphi} \left\{ 1 - e^{-\frac{4K(H_0 + p) \tan \varphi}{D_0 - d_2}} \right\} \geq \tan^2 \left(\frac{\pi}{4} - \frac{\varphi}{2} \right)$$

Thus according to the invention, the reasonable motion of media can be facilitated or ensured by satisfying one or all of the conditions for packing height of grinding media, speed of rotation of the screw and the screw-pitch

and consequently the durable years of the screw can be considerably lengthened. As under such a motion condition the vertical media layer around the screw has the highest packing pressure and a part of media located between the screw-wings moves outward into said vertical media layer through the voids of media due to centrifugal force, the screw-wings are subject to about a uniform wear from their outer-edges to the inner sides over the total length. In this case the screw surfaces are free from wearing and hence do not need any coating of wear-resistant materials over their total length, so only wear at the edge of the screw surfaces must be considered. When the screw-wings subject to wear and their radii become smaller, the motion of grinding media would become inactive naturally and the grinding capacity of the mill would be reduced. But the mill according to the invention can be operated under a definite grinding capacity while the wear of the screw-wings is within an allowable limit, and that in such a manner that the speed of rotation of the screw becomes so large with decreasing the radii of the screw-wings by means of the continuous speed-controller that the required power for rotating the screw is always kept constant.

Further, to adjust the grinding capacity is important for carrying out the present invention and also a characteristic thereof. In general the smallest wear of the grinding media and the greatest grinding capacity can be obtained only when the highest suspension density of material particles exists around the grinding media under the perfectly packed condition. When the pulp density in the mill is dilute, wear of the grinding media and waste of power occur due to mutual abrasion of media. In order to prevent such a drawback, the speed of rotation of the screw should be adjusted so that the density of material particles in the circulated fluid is kept constant at a maximum allowable value which still permits free-flowing of the material particles, by measuring the pulp density. Namely, the grinding capacity should be reduced by decreasing the speed of rotation of the screw with lowering the pulp density and the grinding capacity should be promoted by increasing the speed of rotation with raising the pulp density, whereby an unavailing waste of power and wear of the grinding media can be prevented.

Then the flow of material particles in the mill will be mentioned below.

The suspension of such small material particles as to pass freely through voids of packed column of media is supplied through the classification device 11, as shown in FIG. 1, and the liquid level of the classification device is always kept constant by overflowing over its total circumference, so that there is no deflection in the supplied liquid into the shell and its flow-in speed can be easily regulated by adjusting the flowing section of the lower outlet. In addition, the suspension is supplied into the shell and moved downward therein at such a velocity that the superficial mean velocity of the suspension based on empty column cross section (namely the velocity when supposing that there is no grinding media in the shell and the suspension flows downward uniformly) is approximately equal to the settling velocity of the grinding media in the concerned static liquid. By selecting such a velocity the material particles circulate through the shell together with the grinding media without being deposited on the grinding media layer or at the bottom of the shell. When the velocity is too rapid, the material particles flow down mainly through the outside of d_2 -cylinder, which results in a lowering of the grinding action of the mill. On the other hand, when said velocity is too late, precipitation of material particles is caused mainly at the bottom of the mill, an irregular flow occurs and the grinding media are pushed up. It results therefrom that the lower end of the screw is subject to wearing and, moreover, the grinding action is lowered. The material particles flows through the

voids of the grinding media together with the fluid and, in this case, the direction and the speed of said flow are in accordance with that of the motion of the grinding media layer in a regular state. The fluid having material particles suspended fills the voids of media in a perfectly packed condition and covers the surface of each medium with suspended particles. Keeping such a condition the fluid is moved upward with the grinding media through the spiral flowing path within the screw and conveyed downward through the vertical ring-shaped flowing path around the screw, because the flow resistance of viscous pulp is so high in the packed column that the motion of media, that is, the motion of voids causes the carrying action of pulp filling the voids in the same direction and speed. Thus the material particles are ground by the grinding media.

According to the invention, the fluid flows out through the outlet 7 due to its static pressure, as the fluid is moved downward in the shell. In this case, the capacity of the pump 12 can be determined so as to let the pulp flow at a sufficient velocity for preventing sedimentation only in considering the difference between the maximum height of the pipe supplying the circulated fluid and the liquid level in the classification vessel 8, which results in a very small required power of the pump.

As is already above-mentioned, the size of ground product can be controlled by regulating the position of the size-controller. In this case, the classification device can be advantageously provided with such a curved surface that the overflowing sectional area changes lineally depending on the displacement distance of the size controller. Further, when the inclination of the classification device is so sharp that it is larger than the angle of repose of the material particles and there is no possibility of precipitation of the material particles on the surface of the classification device, the internal surface of the classification device can be substituted for the flow-in funnel, which therefore can be omitted.

It is very difficult in general grinding mills to keep ground product always in a definite size also when the feed rate of material is changed. But in case of using the classification device constructed according to the invention the definite size of ground product can easily be obtained. When a fixed volume of material and liquid is supplied fixing a position of the classification device, the fixed size of ground product is obtained naturally, so long as the speed of rotation of the screw and the feed ratio of material and fluid are fixed. But coarser particles are overflowed when the supplied volume is increased, while finer particles are overflowed when the supplied volume is reduced. When the supplied volume is fixed, the size of ground product can be controlled by regulating the sectional area of the overflowing level which can be performed by displacing the classification device, as is already above-mentioned.

While the invention has been described in detail with respect to a preferred embodiment, it will be understood by those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention, and it is intended to cover all such changes and modifications in the appended claims.

We claim:

1. A grinding mill comprising an outer shell having ribs extending inwardly about its internal surface a screw mounted for rotation within said shell, grinding media packed tightly into said shell, said grinding media being composed of particles sufficiently small to lodge between said ribs and to pass downwardly between said ribs and the outer extremities of said screw.

2. A tower mill comprising a vertical screw having spiral screw wings, a shell surrounding said screw, said shell having various ribs extending inwardly about its inner surface, a disk mounted horizontally at the lower

end of said screw, said disk being of equal diameter to, and forming a termination for, the wings of said screw, and grinding media packed tightly within said shell and around said screw and disk, said grinding media being composed of particles sufficiently small to lodge between said ribs and to pass downwardly between said ribs and the outer extremities of said screw.

3. A tower mill as in claim 2 wherein the lower end of said outer shell flares outwardly in the vicinity of said disk.

4. A tower mill as defined in claim 3 wherein said disk has formed along its undersurface, ribs whose extremities generate an inverted cone depending from said disk as said disk rotates.

5. Apparatus for grinding material by abrasive action, said apparatus comprising a vertically suspended screw, an outer shell surrounding said screw, said outer shell having horizontal and vertical ribs formed about its internal surface, grinding media packed tightly into said shell, said grinding media being composed of particles sufficiently small to lodge between said ribs and to pass downwardly between the inner extremities of said ribs and the outer extremities of said screw, said grinding media being packed within said shell and around said screw to a height above the top of said screw below a height which would be sufficient to prevent upward movement of material within said shell upon rotation of said screw and below a height sufficient to develop a static layer of grinding material above said screw said height being determined by the formula

$$\frac{D_0 - d_2}{4H_0 \tan \phi} \left(1 - e^{-\frac{4H_0 K \tan \phi}{D_0 - d_2}} \right) = \tan^2 \left(\frac{\pi - \phi}{4} \right)$$

where $D_0 - d_2$ is twice the distance between the ribs of the shell and the screw wings, ϕ is the angle of internal friction of the media within the device, and K is the earth pressure coefficient for a vertical break surface.

6. Apparatus for grinding material by abrasive action, said apparatus comprising a vertically suspended screw, an outer shell surrounding said screw, said outer shell being provided along its internal surface with horizontally and vertically extending ribs, grinding media packed tightly into said shell, said grinding media being composed of particles sufficiently small to lodge between said ribs and to pass downwardly between the ribs and the outer extremities of said screw, said grinding material being packed tightly into said shell to a height above the top of said screw such that centrifugal action produced by rotation of said particles by said screw media is insufficient to produce voids of grinding material among the wings of the upper portion of said screw, said height of grinding media above the top of said screw also being insufficient to prevent upward movement of material by rotation of said screw and further being insufficient to develop a static layer of grinding material above the screw said height being determined by the formula

$$\frac{D_0 - d_2}{4H_0 \tan \phi} \left(1 - e^{-\frac{4H_0 K \tan \phi}{D_0 - d_2}} \right) = \tan^2 \left(\frac{\pi - \phi}{4} \right)$$

where $D_0 - d_2$ is twice the distance between the ribs of the shell and the screw wings, ϕ is the angle of internal friction of the media within the device, and K is the earth pressure coefficient for a vertical break surface.

7. Apparatus for grinding material by abrasive action, said apparatus comprising a vertically suspended screw, an outer shell surrounding said screw, said outer shell having horizontal and vertical ribs disposed about its internal surface, grinding media packed tightly into said shell, said grinding media being composed of particles sufficiently small to lodge between said ribs and to pass downwardly between the inner extremities of said ribs and the outer extremities of said screw, said screw having wings arranged at a pitch such as to produce complete upward movement of all grinding media among said wings upon rotation of said screw.

8. A tower mill comprising a vertical screw having spiral wings, a shell surrounding said screw, said shell having various ribs extending inwardly about its inner surface, a disk mounted horizontally at the lower end of said screw, said disk being of equal diameter to, and 5 forming a termination for, the wings of said screw, grinding media packed tightly within said shell and around said screw and disk, said grinding media being composed of particles sufficiently small to lodge between said ribs and 10 to pass downwardly between said ribs and the outer extremities of said screw, a centrifugal hydraulic classification device mounted above said column of grinding material and means for transferring particles having passed

down between said screw and said ribs up to said hydraulic classification device.

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