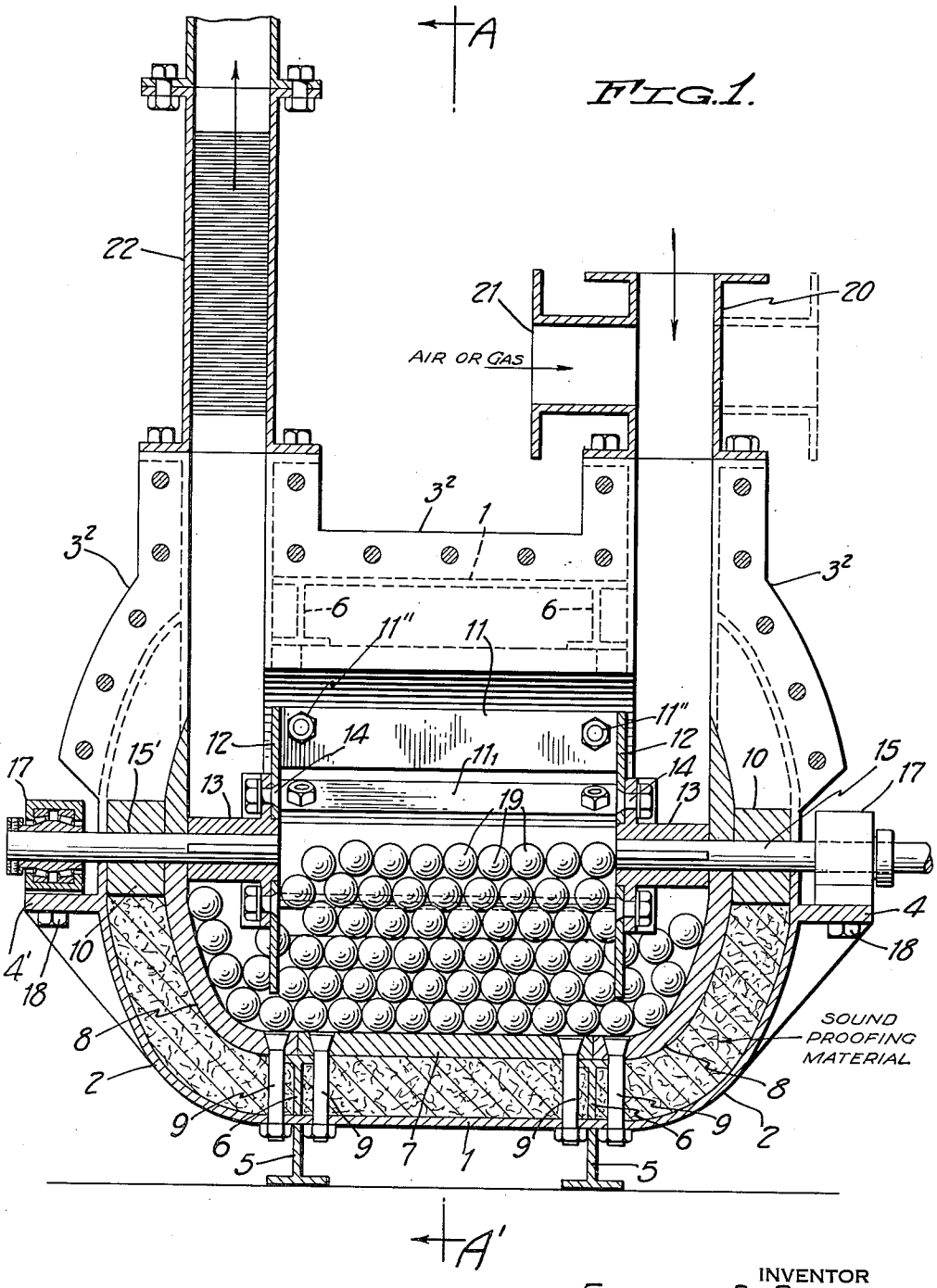
Dec. 16, 1952 E. D. PHILLIPS 2,621,859

FLUID SWEPT BALL MILL WITH BALL MOVING ROTOR AND STATIONARY DRUM

Filed Oct. 24, 1949 4 Sheets-Sheet 1

FIG. 1.



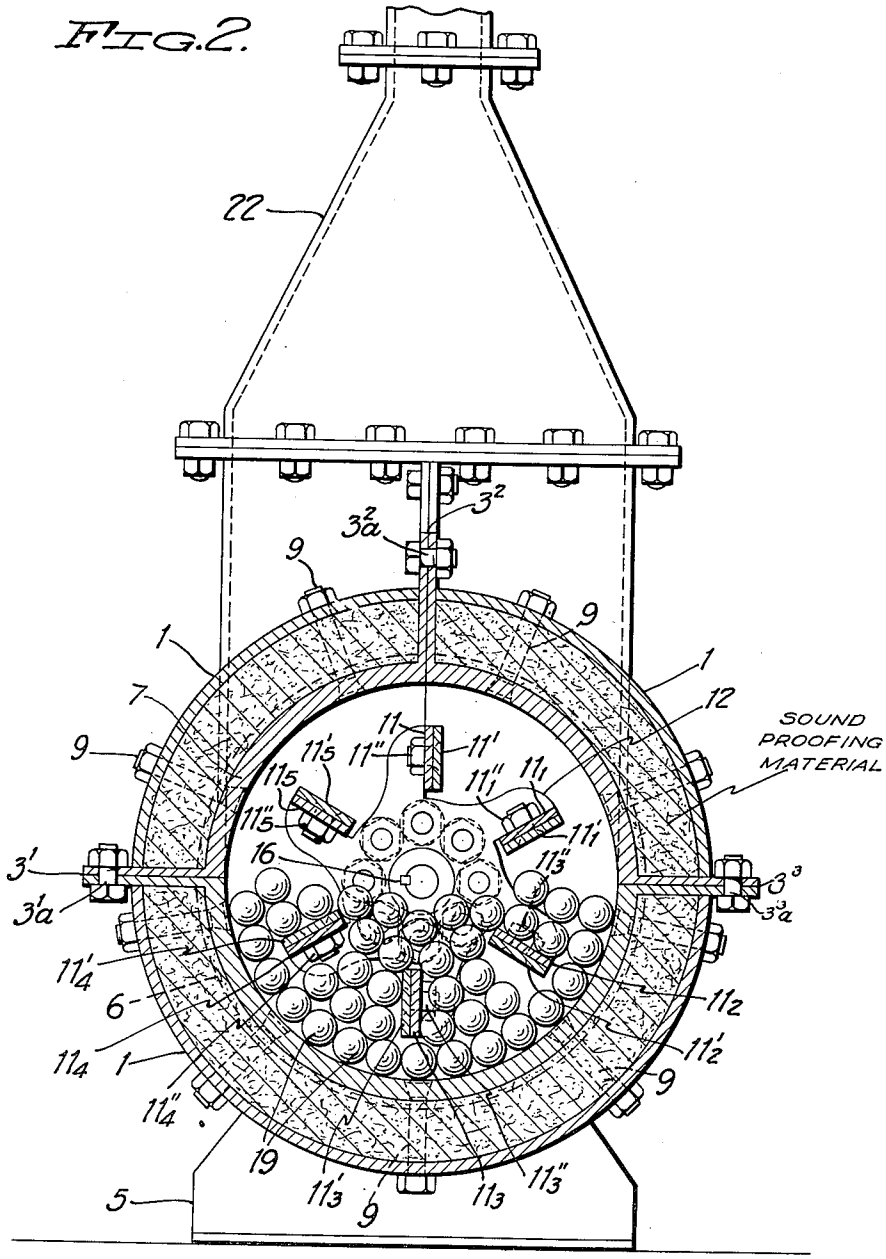
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FLUID SWEPT BALL MILL WITH BALL MOVING ROTOR AND STATIONARY DRUM

Filed Oct. 24, 1949 4 Sheets-Sheet 2

FIG. 2.



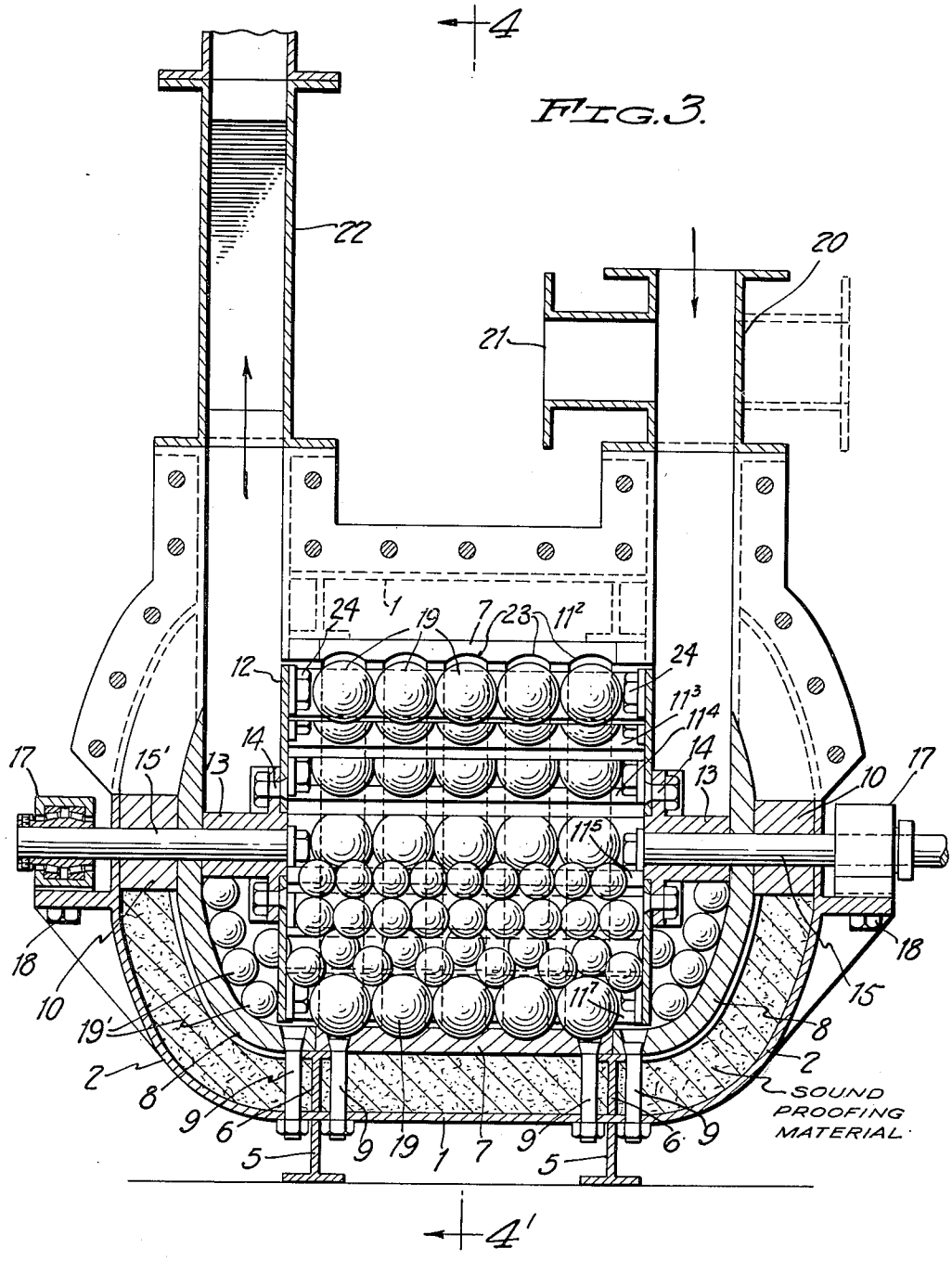
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FLUID SWEPT BALL MILL WITH BALL MOVING ROTOR AND STATIONARY DRUM

Filed Oct. 24, 1949 4 Sheets-Sheet 3

FIG. 3.



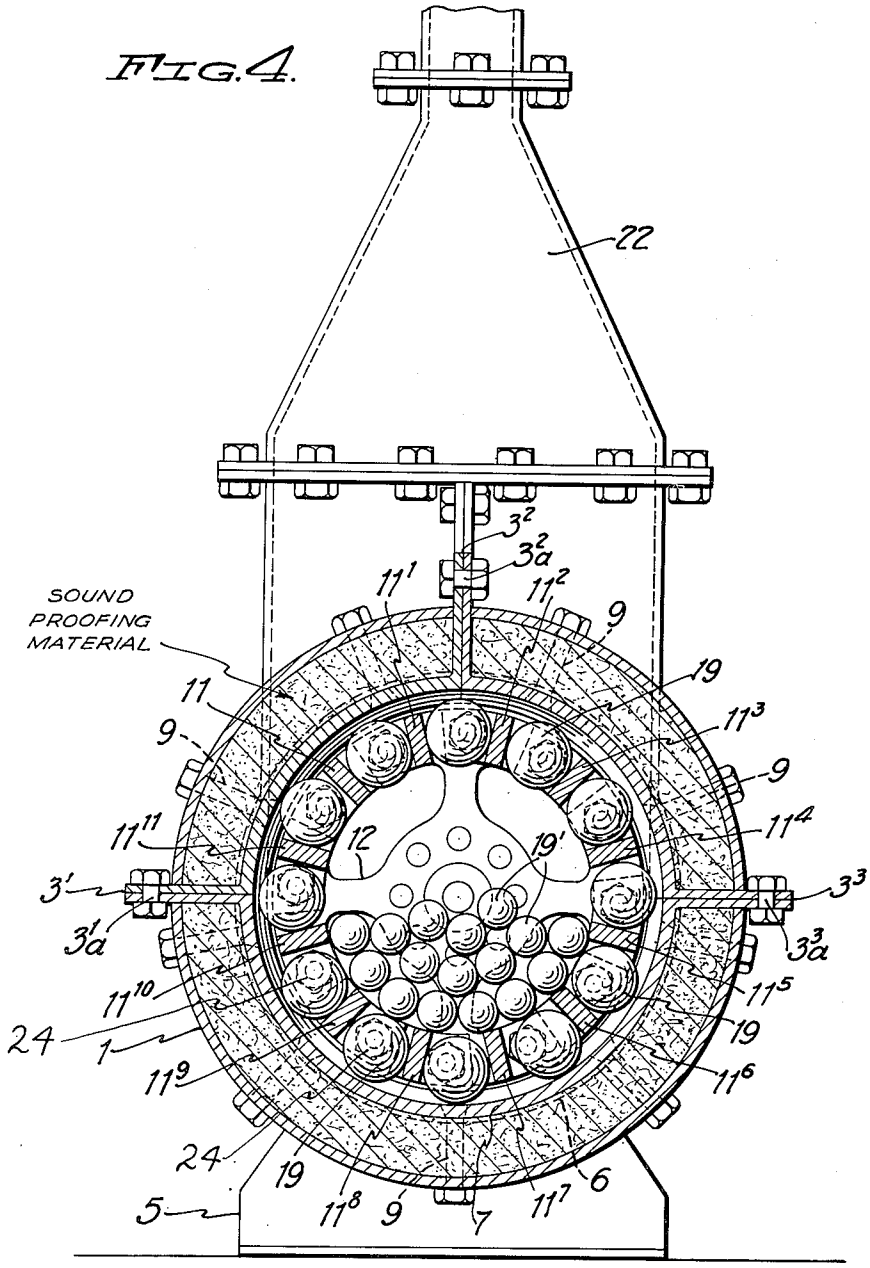
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FLUID SWEPT BALL MILL WITH BALL MOVING ROTOR AND STATIONARY DRUM

Filed Oct. 24, 1949 4 Sheets-Sheet 4

FIG. 4.



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Patented Dec. 16, 1952

2,621,859

UNITED STATES PATENT OFFICE

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FLUID SWEPT BALL MILL WITH BALL MOVING ROTOR AND STATIONARY DRUM

Everett D. Phillips, Saginaw, Mich.

Application October 24, 1949, Serial No. 123,245

11 Claims. (Cl. 241—47)

1

My present invention broadly relates to means, primarily mechanical, for reducing, even to superfine form, certain fragmentary materials such as coals (including extremely difficult to reduce anthracite), cement clinkers, iron pyrites, coke breezes, petroleum cokes, pigments, grains and many other vegetable matters. This application is a continuation-in-part of my co-pending application entitled "Ball Mill," Serial No. 531,951, filed April 20, 1944, now abandoned; and this application contains subject matter relating to Figures 3 and 4 not claimed herein but claimed in my continuation-in-part application No. 269,820, filed February 4, 1952.

An important object of my invention is to so design the particular arrangement of mechanical means that it is readily adaptable to having associated therewith an active fluid medium by which the reduced material can be most effectively collected and continuously removed from the region of the reducing means.

I am fully aware of the fact that numerous efforts have been made to create and design means having the same objectives as my invention. These designs have produced only moderate degrees of success. The general objective of my invention is to materially expand the success obtainable over anything heretofore accomplished in the particular field. In this connection, I cite in particular a number of fairly well-known so-called "drum and ball" or "ball mill" commercial products, also commonly termed "pulverizer." Each of these products, I know from first hand experience, have been criticized by commercial users and condemned by competition because of their relatively large power and space requirements. There are several major deficiencies contributing to the present inefficiency of the "drum and ball" type pulverizers.

First, and perhaps the greatest deficiency is the inability of these mills to separate the finely ground materials from the almost solid mass of material and balls rotating in the revolving drum before the reduction of these materials to a superfine product. This lack of separating capacity partially explains the relatively large power requirements of such mills. This excessive power requirement makes it difficult for this type of mill to successfully compete against high speed impact or hammer mill pulverizers, ball race type pulverizers, roller bearing mill type pulverizers and others whose power requirements are relatively lower but producing a coarsely ground product.

Second, an excessive amount of energy is expended in rotating the "drum" or its equivalent

2

element beyond that which is actually expended in reducing the material.

Third, all of these methods and machines employ excessive weights of machinery and occupy excessive mounting spaces with consequential high initial costs and inconveniences. Also, they require a large amount of plant space for dismantling and repairing.

All of the various types of pulverizers, both separately and as a group, because of the lack of control of the quality of their product, complicated operation, high power costs and over-all inefficiency are being displaced commercially by spreader stokers, particularly in the small and medium size installations. Until my invention, nothing was being done to eliminate these deficiencies of the "drum and ball" type mill, despite both the possibility and necessity for such improvement.

In the conventional "drum and ball" mill pulverizer, movement of the balls is dependent solely upon the balls being dragged into and maintained in action by the slight frictional and point contact existing between the balls and the wall of the rotating drum. This frictional contact is limited to those few of the balls that manage to make individual respective contact with the inner surface of the rotating drums. The total area of frictional contact is but a minute fraction of either the balls or the inner surface area of the drum. Thus, these conventional ball mills must be operated over a longer period of time to effect the same amount of reduction as will occur in a mill in which the movement of the balls is effected by positive engagement between the balls and their agitating means. Such increased operating time reduces efficiency and increases wear. This major handicap to effective reduction is one of the objectionable aspects of the said prior practices overcome by the instant invention. The greater quantity of power required to turn the rotor of my ball mill, due to the positive engagement with the balls, is offset by the elimination of the necessity for moving the mass and weight of the drum or grinding chamber shell. Thus, although the power consumption, per revolution, of my invention and of ball mills of conventional design are approximately equal, appreciable efficiency is obtained by my invention since the total reducing action obtained by each revolution of my invention is several times that of conventional ball mills. Further, since the balls in my invention are positively pushed and lifted into cascading position rather than raised into cascading position by a combination of frictional and centrifugal forces, my mill may be efficiently oper-

ated at less revolutions per minute. This speed reduction permits a power source of lesser horsepower to apply the same torque to the shaft driving the mill. These are but two of the ways in which my mill obtains a substantial increase in efficiency over ball mills of conventional design.

Another excessively expensive, operational handicap in these prior products arises out of the weight distribution opposing rotation. The weight is normally concentrated at an unnecessarily excessive radial distance from the center of rotation without provision of any counterbalance means, thereby creating an excessive, counter to rotation, torque plus a decidedly lopsided wear and tear on the supporting journals and bearings. These objectionable factors are also overcome by the instant invention. By rotating only the rotor within the drum rather than the drum itself, the moment arm of the operating load is reduced, thus, reducing the torque necessary to operate the mill.

Another object of the instant invention is that of materially facilitating the making of repairs and the replacement of parts.

A further object of my invention is the elimination of certain of the operational hazards common to ball mills of conventional design. These hazards and their elimination are specifically brought out in connection with the description of the structure relating to them.

Other important objects of the instant invention will become readily apparent to those skilled in the particular art as its description in connection with the figures of the accompanying drawings is hereinafter carried out, which figures may be briefly identified as follows:

Figure 1 is a mid portion, cross-sectional side view elevation of one embodiment of the instant invention.

Figure 2 is a cross-sectional on line AA', right end view in elevation of Figure 1.

Figure 3 is a mid portion, cross-sectional side view elevation of a limited modified form of the instant invention.

Figure 4 is a cross-sectional on line 44', right end view elevation of Figure 3.

Like reference symbols in the same figure and in the various figures of the drawings represent like elements and parts in the same. Referring first to Figure 1, numeral 1 indicates a horizontally mounted, preferably metallic, cylinder, partially closed at each end by preferably metallic, ellipsoidal heads 2, bolted, as indicated, or welded to cylinder 1. The heads 2 are illustrated as ellipsoidal but may vary somewhat in shape without departing from the principle of my invention. The numerals 5 indicate suitable stationary mounting supports for the cylinder 1 and the elements associated therewith. The cylinder 1, as mounted on the supports 5, is stationary and cannot rotate.

The numeral 7 indicates a second cylinder or liner internally of, and more or less uniformly spaced from, cylinder 1 by spacing elements 6 and 10 and bolting elements 9. The linear 7 is partially closed at each end by ellipsoidal heads 8 bolted or welded to cylindrical liner 7. Like the heads 2, the heads 8 may vary in shape somewhat from that of an ellipsoid without departing from the principle of my invention. The second cylinder 7 together with the heads 8 define the grinding chamber which is also stationary and cannot rotate. The elements 15 and 15' indicate cylindrical stub shafts extending from outside internally of the said cylinders through close fitting openings centrally located in the respective heads 2 and 8. Each of the stub shafts 15 and 15' is supported in and by one of the roller bearing elements 17 mounted upon the brackets 4 and 4'. The brackets 4 and 4' are fixedly attached to the head elements 2. On the inner end of each of the stub shafts 15 and 15' a spider leg element 13 is securely mounted to rotate with its associated stub shaft. In some installations it may be preferable to make elements 13 and 15 and 13 and 15' in one piece. The spider leg elements are spaced apart the length of the second cylinder 7. The use of the stub shafts 15 and 15' leaves the major part of the internal, horizontal housing space unobstructed. The purpose of leaving the area between the spider leg elements 13 unobstructed will appear more fully hereinafter.

To each of the spider legs 13 (six being shown in Figure 2) is affixed, by bolts 14, a radially extending plate element 12. As shown in Figure 2, each of the plate elements 12 has, at its right hand side, a radially extending straight edge. The spider legs of the right and left elements 13 are so arranged that the straight edges of the corresponding right and left plate elements 12 are aligned in the same plane, which plane is parallel to the axis of the stub shafts 15 and 15'. Thus, the elongated pusher bars or rectangular plate elements 11 in Figure 1, and 11, 11_1, 11_2, 11_3, 11_4 and 11_5 in Figure 2, can have their end portions affixed, as by welding, to the respective straight edges of the plates 12. The plate elements, spider leg elements 13, and pusher bars 11 together form a six paddle cage or rotor occupying a major portion of the internal area of the second cylinder 7. The ends of the rotor may each be made as a single part, but such part should have openings or apertures to permit material to pass into the rotor. The rotor operates as an agitator for actuating the grinding balls.

A body of grinding balls 19 are placed in the grinding chamber. The diameter of the balls 19 is such that the layer of balls in contact with the inner surface of the second cylinder 7 will not be contacted by the pushers 11 of the rotor. The proportion of the total area of the inner surface of the second cylinder 7 which will be covered by the outer layer of balls will vary according to the size of the ball charge put in the mill. The protective layer of balls is neither stationary nor is it always made up of the same balls. The balls being positively moved by the pusher bars 11 frictionally engage those of the balls forming the protective layer. This frictional engagement causes the balls in the protective layer to be constantly agitated and moved in the same direction of the rotor, although at a slower speed. It is by this means that the protective layer is enabled to accomplish an appreciable amount of grinding. The movement of the protective layer in the direction of movement of the rotor causes some of the balls in the layer to be dislodged and removed where the pusher bars 11 emerge from the body of balls. These balls are replaced in the area where the pusher bars 11 enter the body of balls.

The minimum number of balls necessary to operate the mill is that quantity of balls which will form the outer protective layer plus additional balls for cascading action. The precise number of balls used will depend upon the type of material being reduced. The mill has been found to operate satisfactorily, with certain materials, with a ball charge occupying approxi-

mately one-third of the lower half of the grinding chamber. However, the mill is so constructed that it may be filled at least one-half full of balls when such is desired.

The material to be reduced in size or pulverized is introduced into the grinding chamber through the passage 20 indicated as entering into and at the right hand portion of the upper portion of the grinding chamber. The fines produced in the grinding chamber are removed through the passage 22 at the opposite end of the grinding chamber from the passage 20. Although the passages 20 and 22 are shown and described as at the extreme ends of the grinding chamber, a preferred arrangement, it is possible to relocate them closer together without departing from the principle of my invention.

As a result of the description of the mechanism up to this point, the reducing operation may be stated by way of illustration as follows: as is mechanically apparent, any suitable source of driving power, such as an electric motor, may be used to drive the rotor. Power may be delivered to the rotor by either or both of the stub shafts 15 and 15'.

Rotation of the stub shafts causes similar motion in the rotor forcing the pusher bars through the body of grinding balls 19. The inner shell 7 and outer shell 2, comprising the cylindrical drum remain stationary at all times, thus, all of the motion for generating the grinding or reducing action of my invention is imparted to the grinding balls 19 by the rotor. This design limits the energy requirements of my invention to that which is necessary to move the rotor against the resistance of the grinding balls and the charge of material being reduced. The energy requirements of previous devices of this type for moving the mass of the drum are eliminated.

As is readily apparent, the movement of the agitators or pusher bars 11, etc., the preferred direction of which is clockwise as viewed in Figure 2, will forcibly maintain all of the balls in action with respect to each other and all other surfaces contacted by these balls. The rotor is operated at a relatively low angular velocity. The exact revolutions per minute will vary according to that which will produce the most efficient results with the particular material and the size of the charge of grinding balls involved.

Those of the balls 19 in the paths of the rotating pusher bars 11 which do not escape from the pusher bars will be carried thereby into the upper region of the grinding chamber, free of the group of grinding balls in the lower portion of the grinding chamber from which point the raised grinding balls 19 will cascade downwardly with considerable impact momentum. The height to which these balls 19, raised by the pusher bars 11, will be elevated will depend, in part, upon the angular velocity of the rotor. By eliminating the central shaft through the rotor, the cascading balls are enabled to fall upon the material without interference. Thus, all of the velocity obtained by the falling balls is available for reducing the material. This feature alone adds materially to the efficiency of my invention. Those of the balls 19 adjacent to the path of the rotating pusher bars 11 will also be carried at least partially into the upper region of the grinding chamber.

All of the principles of reducing or pulverizing utilized in isolated cases, namely, crushing, impact and attrition, not heretofore combined in a single unit, are simultaneously and most effectively brought to bear in the instant invention. By way of explanation: reduction by crushing occurs between those of the balls adjacent the walls of the grinding chamber being forced to roll on surfaces with the material being crushed between the moving balls and the stationary wall surface; reduction by impact is effected by the cascading balls landing with appreciable impact on fragments of the material; and reduction by attrition occurs through the action of any two or more moving balls competing with each other in forcefully rubbing the same material.

Rotation of the pusher bars 11 not only elevates the balls 19 but also both the heavies and fines of the material being reduced. A stream of sweeping or transport fluid is passed through the grinding chamber by means of the passages 21 and 22. The fines of the material elevated by the rotor will be entrained by this fluid and removed from the grinding chamber through passage 22. The size of the fines which will be thus removed may be controlled by regulating the volume of fluid being passed through the grinding chamber. The fluid may be either forced through or sucked through the grinding chamber. By placing the input passage 21 and output passage 22 at the extreme opposite ends of the grinding chamber, sweeping of the entire grinding chamber by the fluid is assured.

As to refinements and special features, reference is made to Figures 1 and 2 jointly.

Element 16 indicates employing keys in keyways to lock each of the spider leg elements 13 to their respective shafts 15 and 15'.

To facilitate assembly, making repairs and replacing parts, the lower halves of cylinders 1 and 7, together with their corresponding heads 2 and 8, are indicated to be separate in construction from their respective upper halves. As more fully shown in Figure 2, the upper halves of these same cylinders and their respective heads are indicated to each be constructed in two equal quarter sections. The flanges 3^1, 3^2 and 3^3, together with the bolts and nuts $3a^1$, $3a^2$ and $3a^3$, respectively, are the means necessary for properly assembled external and internal containers and for securing them in place during operations.

In Figure 2 it is indicated that there are superimposed on the pusher bars 11, etc., facings 11_1, $11_1'$, $11_2'$, $11_3'$, $11_4'$ and $11_5'$, held in place by inset head bolts and nuts $11''$, $11_1''$, $11_2''$, $11_3''$, $11_4''$ and $11_5''$, respectively. Since it is elementary that the wear and tear on the parts of the mill involved in the actual reduction operation is bound to be severe even though these parts are made of materials selected for unusual durability, replacement of parts is a constant problem. My design makes it possible to minimize the cost of this replacement by simply renewing the facing 11, etc. Since this replacement can be accomplished by removing just one of the quarter sections of the cylinders or drum, there automatically results a substantial saving in time and labor.

Since it is also elementary that the wear and tear on the inner surface of the lower half of the cylinder 7 will likewise be severe, even though its material may be the most durable available and it is protected in part by the layer of balls contacting it, it stands to reason that the cost of renewing this part is greatly minimized by constructing it in the form of a separate, replaceable unit.

Of course, it is all important that the balls 19 should also be made of the most durable mate-

rial obtainable. The additional expense of such material will be more than recovered by the savings effected in replacement of time and labor.

By eliminating the necessity for rotating the entire cylinder portion or drum of the mechanism, it is possible to utilize insulation plus the inner and outer cylinder construction without increasing the power requirements of the mill. Such a construction, applied to conventional ball mill designs, would appreciably increase their power requirements. Thus, by my design, without increasing the cost of operation, the user can have the benefit of quieter operation by filling of the space intervening between the inner and outer cylinders, as indicated by the hatchings of this particular space in the drawings, with any one of the many sound proofing materials now available. Because of the high temperature prolonged reducing can create, which may be further increased by using a preheated gaseous medium for sweeping the grinding chamber, a sound proofing material composed primarily of asbestos would be among those preferable in such a case.

Where the matter of rotating a heavy cylinder and its contents is involved, as it is in all of the "drum and ball" reducing mills with which I am acquainted, the matter of wear of the journals and bearings becomes a very series problem due to the excessive weight supported by these elements. The problem of rapid wear is aggravated by the unbalanced torque loads generated by the mill, plus the exposure of the journals and bearings to the material being reduced and the frequently preheated, material saturated, pressurized, fluid for sweeping the grinding chamber. The arrangement of Figure 1 indicates that no such aggravated journal and bearing problem exists in the case of the instant invention. In my invention the cylinder or drum is stationary, thus, relieving the journals and bearings of this weight. The torque radius is reduced, and the design offsets, at least partially, the load attendant lifting the cascading balls by the weight of the balls acting downwardly on those of the pusher bars moving downwardly through the body of grinding balls in the lower portion of the grinding chamber. Furthermore, my design permits the journals and bearings to be completely isolated from the operating area of my mill. Since the drum or cylinder is stationary, the stub shafts **15** and **15'** may pass through the drum or cylinders without contact with any parts other than a dust and pressure seal. The bearings may be mounted outside the drum and sealed from the wear and corrosion promoting materials within the drum.

All of the "drum and ball" mechanisms, with which I am acquainted, introduce the collection and removal fluid into the grinding chamber through an opening in the center of one end head and remove the fluid through a similar opening in the center of the other head. To avoid having balls enter these openings, the total number of grinding balls is chosen with a margin of safety to have a top level somewhat lower than the lowest points of these openings. Because of the circular nature of the conventional grinding chamber this necessarily limits the number of grinding balls to somewhat less than one-fourth of the number of balls the grinding chamber could hold if completely filled. The design of my invention makes feasible using enough balls to fill at least one-half of the available cylinder volume. Although such a quantity of grinding balls is frequently neither necessary nor desirable, the capacity is available when needed. Conventional ball mills are incapable of accomplishing this.

When it comes to reducing the harder materials that offer greater resistance thereto, as in the case of anthracite coals as compared to bituminous coals, it is elementary that more can be accomplished with such materials if greater reducing forces are employed. When mere frictional engagement between the grinding balls and the driving force is employed, as is the case in conventional "drum and ball" mechanisms, an inefficient reducing action results as compared to the position engagement between the grinding balls and the driving force characteristic of the instant invention. The positive engagement between the pusher bars **11** and the grinding balls **19** insures thorough and constant agitation of all of the grinding balls in the grinding chamber. It is clear that such a solution with respect to reducing the harder materials will automatically serve to accelerate reduction of the softer materials.

From the foregoing, in addition to it being readily apparent that the instant invention permits substantial power savings and a substantial increase in operating efficiency over conventional "drum and ball" mechanisms, it is equally apparent that substantial savings in weight of materials and mounting spaces are effected.

When it comes to efficiency in the matter of collection and removal of the reduced portion of the material involved, it is clear that the action of the pusher bars **11**, of the instant invention serves to expose all of the material charge to the grinding chamber sweeping fluid. In conventional ball mills much of the material charge remains submerged in the ball charge. Thus, efficiency, in this respect, is necessarily greatly in favor of the instant invention.

In conventionad "drum and ball" products, as well as in the instant invention, simplification of design calls for introducing the material to be reduced at one end of the cylinder or grinding chamber. Since operating speed or efficiency also depend, in part, upon having the material undergoing reduction equally distributed over the length of the reducing region, which region becomes quite large in some industrial requirements, the even distribution resulting from the extensive thorough agitation of the material by the pusher bars **11** in the instant invention, increases the efficiency of my invention.

The hazard arising from the operation of an exposed rotating cylinder or drum, common to conventional "drum and ball" practices is eliminated by the design of my invention. The danger of explosion attendant too small a charge, when the material charge is a combustible material, such as coal, is reduced by my invention since it permits, as a normal operating condition, a larger charge.

Example I

A ball mill substantially as shown in Figures 1 and 2 was operated to reduce coal. The condition of this coal as it was fed to the mill was:

Size, 1¼ to 2 inches with no fines.
Grindability index, 64 Hardgrove.

The analysis of the coal as used was:

Moisture	per cent	1.4
Volatile matter	do	36.2
Ash	do	5.6
Sulphur	do	0.6
B. t. u.'s	per pound	14,340

The specifications of the mill used were:

Inside length of grinding chamber—inches	48
Inside diameter of grinding chamber—do	30
Diameter of grinding balls—do	1¼
Total weight of grinding balls—pounds	1600
Total weight of grinding balls in protective layer—pounds	500

Power was supplied by a 40 horsepower D. C. motor through a gear reducer having approximately 80% efficiency. The mill was operated at 46 revolutions per minute.

Mild steel grinding balls were used and the charge of grinding balls occupied approximately one-third of the lower one-half of the grinding chamber. A charge of 300–400 pounds of coal was first placed in the mill, which charge became the circulating load of the mill. Then during a period of one hour 1040 pounds of coal were fed into the mill together with 1650 pounds of air at a pressure of 5.1 inches of water. The air supplied to the mill represented approximately 15% of the total air necessary for combustion. Total power consumption during the one hour operation was 13.5 kilowatts. The approximate power received by the mill was 10.44 kilowatts. This is a power requirement of 20.1 kilowatts per ton for pulverizing.

Quantities of pulverized coal were obtained by bleeding off a small part of the air passing through the mill together with the entrained fines and passing same through a 7 inch standard American Society of Mechanical Engineers cyclone which separated and collected the coal from the air. Samples of 25 grams each were taken from the cyclone, weighted and screened for 20 minutes. The efficiency of this cyclone was unknown but is not believed to be greater than 85 per cent. The analysis of these samples was not corrected for the cyclone efficiency. Analysis of these samples showed:

Screen	Percent Retained on Screen	Percent through Screen
100 mesh	2.45	97.55
150 mesh	6.53	91.02
200 mesh	12.65	78.37
325 mesh	23.7	54.67

The burning of this coal in a 20 year old furnace and boiler installation evaporated 11,450 pounds of water. The percentage of CO_2 in the flue gases was 12.64 giving it an efficiency of approximately 78%.

The power consumed in this operation was between one-half and one-third less than that which would have been consumed by a ball mill of conventional design to reduce the same quantity of similar coal to substantially the same degree of fineness.

Example II

A ball mill substantially as shown in Figures 1 and 2 was operated to reduce coal. The condition of this coal as it was fed into the mill was:

Size, 1½ to 2 inches with no fines.
Grindability index, 64 Hardgrove.

The specification of the mill, power supply and ball charged used were the same as those for the mill used in Example I. A charge of 300–400 pounds of coal was first placed in the mill, which charge became the circulating load of the mill. Then during a period of two hours 2314 pounds of coal at the rate 1157 pounds per hour was fed into the mill together with 1650 pounds of air per hour at a pressure of 5.1 inches of water.

The mill was operated at 50 revolutions per minute. Total power consumption during the two hour operation was 28.48 kilowatts. The approximate power received by the mill was 22.8 kilowatts during the two hours. This is a power requirement of approximately 19.7 kilowatts per ton for pulverizing.

Samples of the material treated by the mill were taken in the same manner as that for Example I. Analysis of these samples showed:

Screen	Percent Retained on Screen	Percent through Screen
100 mesh	2.02	97.98
150 mesh	4.97	93.06
200 mesh	11.18	81.88
325 mesh	22.36	59.52

The coal was burned in the same furnace and boiler used for Example I. A total of 24,700 pounds of water was evaporated. The percentage of CO_2 in the flue gases was 14.1, giving it an efficiency of approximately 80%.

As to the modified form of the instant invention mentioned in connection with Figures 3 and 4, the modification is limited to the ball charge and the means for maintaining the same in action. Having fully described the instant invention in all other respects, for the sake of brevity, this part of the specification is limited to the particular modifying aspects.

Referring to Figure 3, the inner wall of the inner cylinder **7** is shown to be so constructed as to have a longitudinal series of closely spaced channels or grooves **23** therein each of which completely circles the said inner wall. The grooves are so shaped as to substantially fit that part of the arc of each of those ones of the larger balls **19** shown to be positioned therein. Referring to Figure 4, the larger balls **19** are also shown to be positioned in what may be termed pockets formed by the radially positioned pusher bars or partitions **11**, 11_1, 11_2, 11_3, 11_4, 11_5, 11_6, 11_7, 11_8, 11_9 and 11_{10}, which pockets so taper, radially inwardly, that the balls **19** cannot escape therefrom by way of the inner opening in each pocket. The balls in each pocket are as closely spaced as their size will permit.

Referring to Figure 3, the said pusher bars or partitions **11**, etc., are shown to extend between the two plates **12**. Each plate **12** is affixed to its corresponding spider leg of the respective elements **13**, as by being bolted thereto by the indicated multiplicity of bolts **14**. The end of each of the partitions **11** are bent at a right angle to the main body of the partition by which affixation to the respective plates **12** may be accomplished by installation of the bolts **24**. Although Figure 3 indicates bolted construction, they may be welded. Thus, when shafts **15** and **15'**, or either, are rotated, the elements **13**, affixed thereto, transmit the rotary motion to the balls **19** through the plates **12** and partitions **11**. The movement of the partitions **11** urges the balls **19** along in their respective grooves until cascading of the balls **19** takes place due to gravity overcoming their centrifugal force. The cascading action of the balls **19** is limited by the partitions **11** since the inward taper of the pockets between the partitions prevents inward escape of the balls **19**. The taper of the pockets also acts to increase the pressure applied by the balls to the material lodged in the grooves. This accelerates the reduction of the material.

In order to take advantage of the full reduction potential of my modified ball mill, a charge of smaller size balls indicated in part by the symbol 19', is used to fill what would otherwise be an idle, potential reduction area within the rotor. The larger balls, being exposed as they are to the activities of the smaller balls, receive from them supplementary power to act as crushers. The pockets between the partitions 11 act as channels for introducing the material to the grooves 23 after it has been subjected to preliminary reduction by the action of the smaller balls 19'. The material, once having entered the grooves 23 may be ground to a fine powder by the action of the larger balls 19. The pockets also serve effectively as elevators for raising the reduced material into the upper portion of the grinding chamber where the fines will be entrained by the sweeping fluid for removal.

Thinking in terms of long lives for the parts directly involved in the various reducing activities, it is important to use the most durable, suitable materials obtainable for these parts. Thus, the fact that the hatching used in the drawings with respect to these parts is that of the standard indication for steel (without qualification) is not to be taken as an intended limitation to steel per se.

In both of the described forms of my invention the life of the grinding chamber liner or inner cylinder is appreciably extended by the use of the layer of balls constantly in contact with the walls of the lower portion of the grinding chamber. This layer of balls absorbs the impact of the cascading balls, protecting the walls of the grinding chamber against the wear incident to the constant blows occurring in ball mills of conventional design. The convex shape of the heads used on my grinding chamber contribute to both the safety and efficiency of my invention. These heads are so shaped that the charge of free or cascading balls, balls 19 and 19' in Figures 2 and 4, respectively, cannot become jammed between the heads and the rotor. The heads, as they extend outwardly from the straight portion of the grinding chamber, are designed to curve on a radius at least equal to the radius of the balls with which the mill is charged. Preferably, this radius is greater than that of the balls. The curvature of the heads is designed to become tangent to the straight portion of the inner cylinder at a point sufficiently outwardly from the ends of the rotor to permit the griding balls free travel between the rotor and the heads. By elimnating all sharp corners and permitting the grinding balls freedom of travel throughout the entire area of the grinding chamber the formation of pockets of material is avoided. These pockets, when the material is combustible, create a serious explosion hazard and their elimination is an appreciable improvement in safety.

My invention has heretofore been described as primarily used for grinding dry, solid fuel. Because of its positive and continuous agitation of both the material being processed and the balls and its adaptability to operation with a pressurized sweeping fluid, it is capable of handling fuels containing high percentages of total moisture. The construction of existing mills of this type has prevented their use with high moisture content materials. For fuels containing inherent moisture only, preheated sweeping fluids are not required for satisfactory operation of my pulverizer. Since a high percentage of surface moisture is acquired in the transportation of solid fuels between the mines and their ultimate point of use, it is necessary to preheat the sweeping fluid to a high enough temperature to vaporize the moisture and dry the fuel as it is pulverized. The design of my invention, permitting the grinding chamber to be insulated and the bearings to be isolated from the grinding chamber, ideally adapts my invention to the use of a heated sweeping medium.

The pulverizer mill described as used in Examples I and II has successfully pulverized and delivered to a burner coals having total moisture contents between 7 and 12 percent without employing a preheated sweeping fluid. Although this type of operation is not desirable from the standpoint of furnace efficiency, it illustrates the capacity of my mill.

My invention will operate with either the dry or wet process and for that reason is readily adaptable and suitable for efficienctly grinding and dispersing other materials requiring the wet process such as pigments, for example.

Since my invention, by its design and construction, is suitable to fabrication from steel plate rather than the conventional cast iron castings, an expensive type of fabrication at best, it is structurally suitable for safe operation under pressures of 100 pounds per square inch or more.

The recent development of gas turbines, at present in the experimental stage, requires pulverizers capable of operation under pressures as high as 75 pounds per square inch. Gas turbines require pulverizers capable of continuous and consistent superfine pulverization at low cost. The circumstances of installation of many gas turbines, such as locomotives, make a compact pulverizer an absolute essential. Conventional pulverizer designs, whether or not they are the "drum and ball" type, are incapable of meeting the specifications of gas turbines. My invention fulfills and meets these requirements.

Numerous modifications of my invention may be made without departing from the principle of my invention. Each of these modifications are to be considered as included in the hereinafter appended claims unless the claims by their language expressly provide otherwise.

I claim:

1. A ball mill comprising a stationary horizontal drum provided with a smooth inner cylindrical surface and with heads closing the ends of said drum, said drum having therein a body of grinding balls for cascading movement therein, said drum having an inlet at one end for a carrying fluid and having an outlet at the other end thereof for said fluid whereby to carry ground material out of said mill, a drum-shaped cage within and extending substantially the full length of said drum, said cage having supporting ends and having elongated pusher bars supported thereby, said cage having a stud shaft at each end thereof and extending from said ends axially of said cylindrical surface and rotatably carried by the heads of said drum, said pusher bars being positioned radially of said surface with their edges which are adjacent to said surface parallel thereto and spaced therefrom a distance more than the diameter of said balls and less than twice the diameter of said balls, whereby rotation of said cage cascades said balls with a layer of balls in contact with said surface.

2. A ball mill as defined in claim 1, in which the inner surface of the drum is curved at the ends of the cylindrical surface on a radius of curvature greater than the radius of said balls,

whereby to avoid lodging of material to be crushed at that point.

3. A ball mill comprising a stationary horizontal drum provided with a smooth inner cylindrical surface, a drum head closing each end of said drum, whereby, said drum and said drum heads provide a shell, said shell having an inlet and an outlet into and out of said shell located at the ends of said drum whereby to provide for the flow of fluid through said drum, a body of grinding balls within said drum, a pair of plates within said shell positioned perpendicularly to the axis of said cylindrical surface, said plates defining a plurality of openings therethrough of substantial size, a plurality of pusher bars interconnecting said plates and positioned radially of said cylindrical surface, said plates and said pusher bars constituting a rotatable agitator, a stud shaft extending from each of said plates and journalled in said drum heads axially of said cylindrical surface, and extending through at least one of said drum heads to provide power receiving means for rotating said agitator with the edges of said pusher bars adjacent to said cylindrical surface parallel to said axis, said edges being spaced from said surface a distance greater than the diameter of said balls and a distance less than twice the diameter of said balls, whereby the agitator moves the plurality of balls upon rotation of said agitator together with any occluded material being ground, the layer of balls in contact with said cylindrical surface rolling thereon, and whereby said balls and occluded material are elevated and dropped, with finely ground material being removed by a stream of fluid flowing through said drum during the dropping of said ground material.

4. A ball mill comprising: a stationary, horizontal drum provided with a smooth inner cylindrical surface and with heads closing the ends of said drum, said drum having therein a body of grinding balls; conduits communicating with the interior of said drum whereby a carrying fluid may flow through said drum for removing ground material from said drum; a cylindrical cage within and extending substantially the full length of said drum, said cage having supporting ends and pusher bars supported thereby; said cage having a stud shaft at each end thereof and extending from said ends axially of said cylindrical surface and rotatably carried by the heads of said drum, said pusher bars being positioned radially of said surface with their edges which are adjacent to said surface parallel thereto and spaced therefrom a distance more than the diameter of said balls and less than twice the diameter of said balls, whereby rotation of said cage cascades said balls with a layer of balls in contact with said surface and between said surface and said cascading balls.

5. A ball mill, the improvement therein comprising: a stationary, horizontal drum closed on each of its ends; a rotatable drum-shaped cage within and extending substantially the full length of said drum having supporting ends and elongated pusher bars supported thereby, said cage having a stud shaft at each end thereof and extending from said ends axially of said drum and rotatably carried by the closed ends of said drum; said drum having a smooth inner surface in the direction of rotation of said cage; said drum having therein a body of grinding balls; a layer of balls between said cage and the lower portion of said drum, said layer of balls being between said drum and the cascading balls of said body of balls; said drum having a carrying fluid inlet at one end and a carrying fluid outlet at the other end whereby a fluid may flow through said drum for removing ground material.

6. A ball mill as described in claim 5 wherein said closed ends of said drum are convex and said cage is co-extensive with the straight portion of said drum.

7. A ball mill as described in claim 5 wherein said closed ends of said drum are convex and said cage is co-extensive with the straight portion of said drum; the inner surface of the drum being curved at the ends of the cylindrical surface on a radius of curvature greater than the radius of said balls, whereby lodging, adjacent said ends, of material to be crushed may be avoided.

8. A ball mill, the improvement therein comprising: a stationary, horizontal, cylindrical drum having convex ellipsoidal closing means on each of its ends; a pair of spiders having pusher bars therebetween for forming a rotatable, hollow, cylindrical cage within and extending substantially the full length of the cylindrical drum; a stud shaft mounted to each of said spiders and rotatably carried by said closing means; said drum having a smooth inner surface in the direction of rotation of said cage; a body of grinding balls within said drum; a layer of balls between said cage and the lower portion of said drum said layer of balls being between said drum and the cascading balls of said body of balls; said drum having a carrying fluid inlet at one end and a carrying fluid outlet at the other end whereby a fluid may flow through said drum for removing ground material.

9. A ball mill comprising: a stationary, horizontal drum having a smooth inner surface; heads for closing the ends of said drum; said drum and said heads defining a grinding chamber; a body of grinding balls within said grinding chamber; a pair of stud shafts, one rotatably mounted in each of said heads concentrically of said grinding chamber; a journal exterior of said drum for supporting each of said stud shafts; a rotor, including a plurality of pusher bars, mounted within said grinding chamber, the periphery of said rotor spaced from the inner surface of said grinding chamber a distance greater than the diameter of one of said balls of said body of grinding balls and less than twice the diameter of one of said balls of said body of grinding balls; power means for driving said rotor; conduits communicating with said grinding chamber whereby a carrying fluid may flow through said grinding chamber for removing ground material from said grinding chamber.

10. A ball mill comprising: a stationary, horizontal drum closed on each of its ends, said drum having therein a body of grinding balls for cascading movement, said drum having means for passing a ground material entraining fluid therethrough, a drum shaped cage within and extending substantially the full length of said drum, said cage having supporting ends and having elongated pusher bars supported thereby, said cage having a stud shaft at each end thereof and extending from said supporting ends axially of said cylindrical surface and rotatably carried by the heads of said drum, said pusher bars being positioned radially of said surface with their edges which are adjacent to said surface parallel thereto and spaced therefrom a distance more

than the diameter of said balls and less than twice the diameter of said balls, whereby the rotation of said cage cascades said balls with a layer of balls in contact with said surface, said drum provided with a smooth inner cylindrical surface in the direction of rotation of said cage.

11. A ball mill, the improvement therein comprising: a stationary, horizontal drum closed on each of its ends; a rotatable drum shaped cage within and extending substantially the full length of said drum having supporting ends and elongated pusher bars supported thereby, said cage having a stud shaft at each end thereof and extending from said ends axially of said drum and rotatably supported by the closed ends of said drum; said drum having a smooth, inner surface in the direction of rotation of said cage; said drum having therein a body of grinding balls; a layer of balls between said cage and the lower portion of said drum, said layer of balls being between said drum and the cascading balls of said body of balls; means for passing a ground material entraining fluid through said drum.

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