United States Patent

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[54] **APPARATUS FOR AND METHOD OF COMMINUTING SOLID MATERIALS**
10 Claims, 14 Drawing Figs.

[52] **U.S. Cl.** **241/5**
[51] **Int. Cl.** **B02c 19/06**
[50] **Field of Search** 241/5, 39

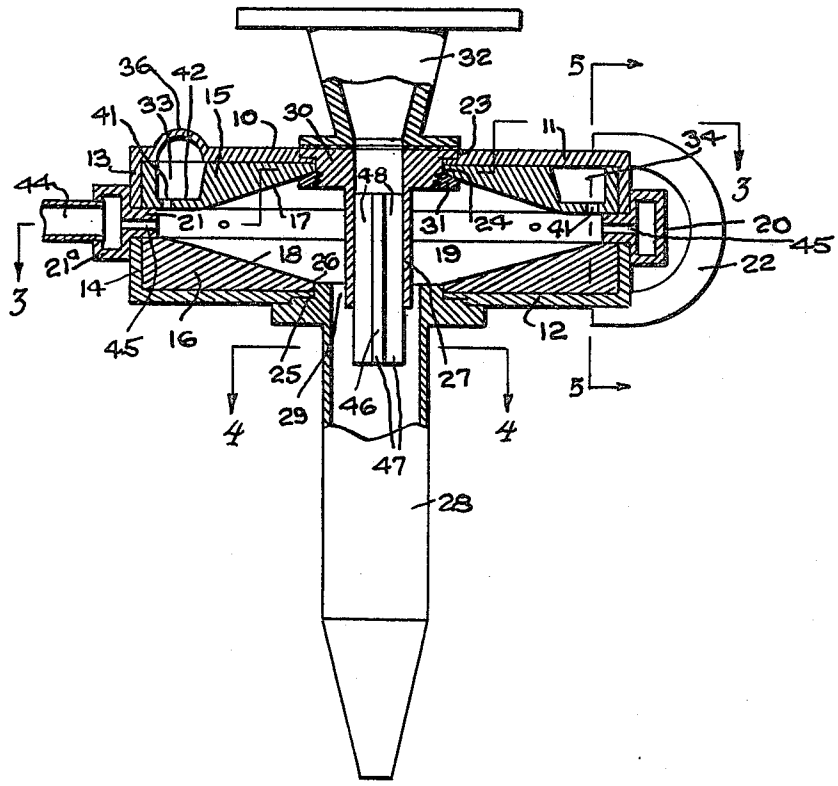
[56] **References Cited**

UNITED STATES PATENTS

2,032,827	3/1936	Andrews	241/5
3,425,638	2/1969	Doyle	241/39

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Attorney—Edelson and Udell

ABSTRACT: A fluid energy mill for pulverizing to finely comminuted state dry solid material the particles of which are injected into a grinding chamber for entrainment in a high velocity vortex of a gaseous grinding fluid established in said chamber. The particles to be pulverized and the primary grinding fluid are conjointly introduced into the grinding chamber in the form of feed jets of the material and grinding jets of the fluid relatively so arranged as to locate each feed jet in such close downstream proximity and so oriented with respect to an associated grinding stream that each pair of the associated jets serves as an individual grinding unit to insure the desired reduction in size of the particles serviced by said unit before they are permitted to be discharged from the mill. The discharge outlet of the mill, which may be provided with one or more of the above-mentioned grinding units or of any conventional form, is internally fitted with a spider having exposed directional vanes for minimizing pressure drop at the intake end of the outlet and correspondingly increasing the vortical velocity of and the available energy in the gaseous energy fluid stream present in the grinding chamber of the mill.



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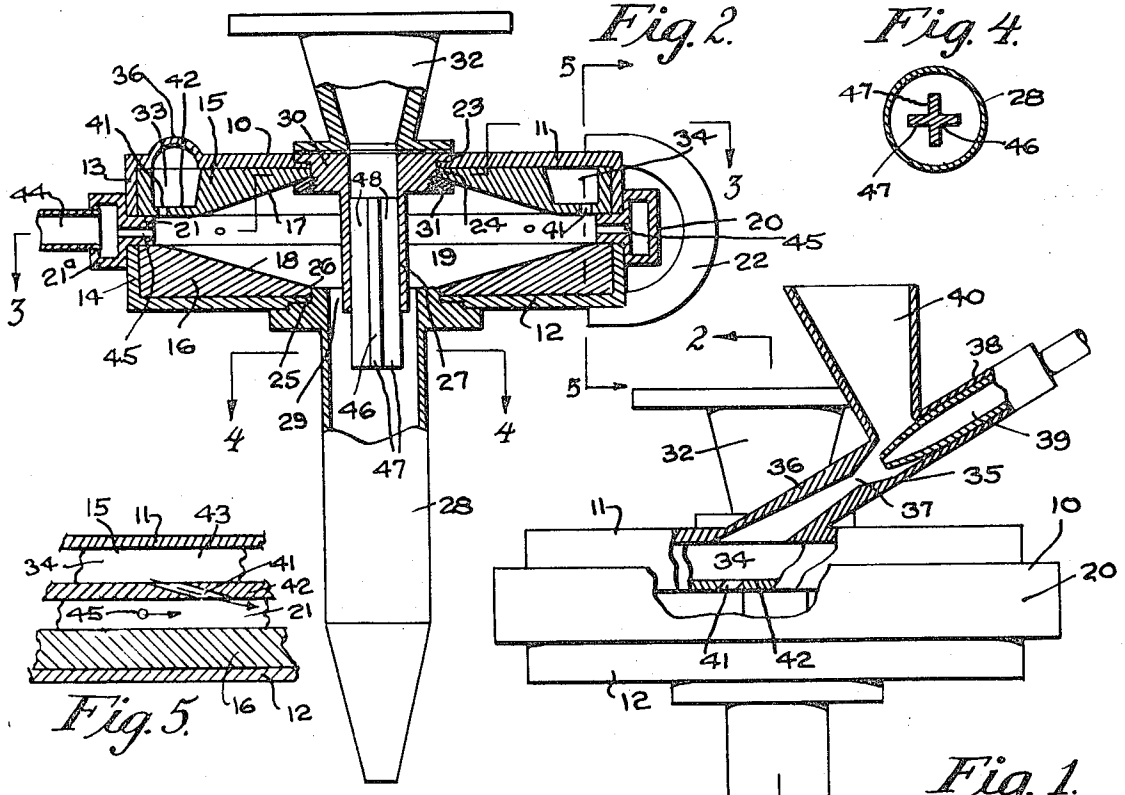


Fig. 2.

Fig. 4.

Fig. 5.

Fig. 1.

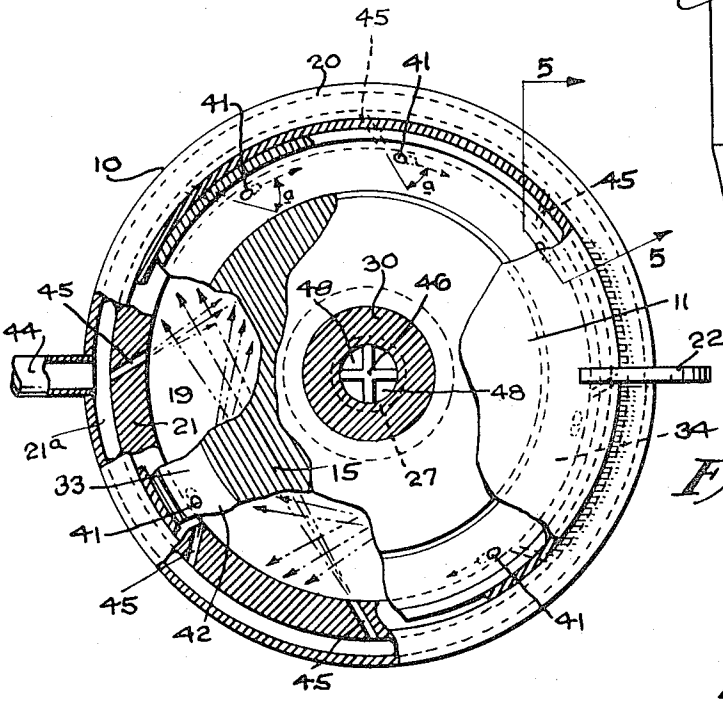


Fig. 3.

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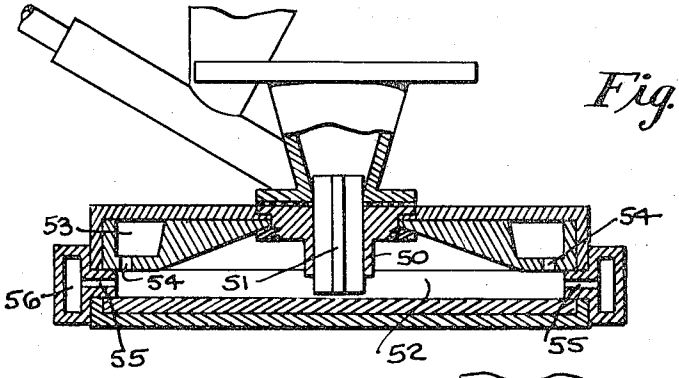


Fig. 8.

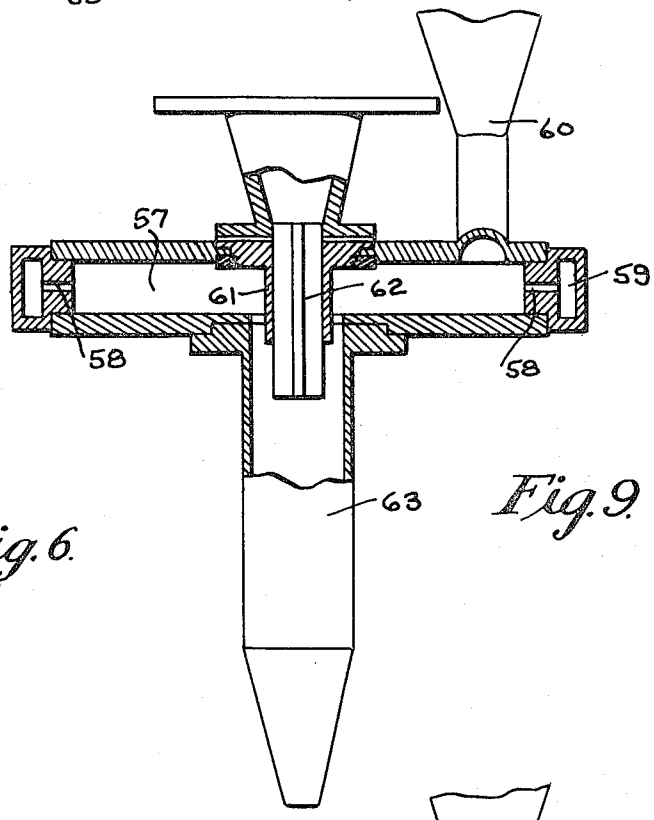


Fig. 9.

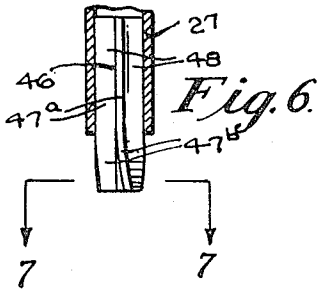


Fig. 6.

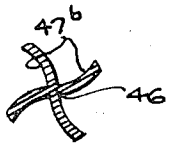


Fig. 7.

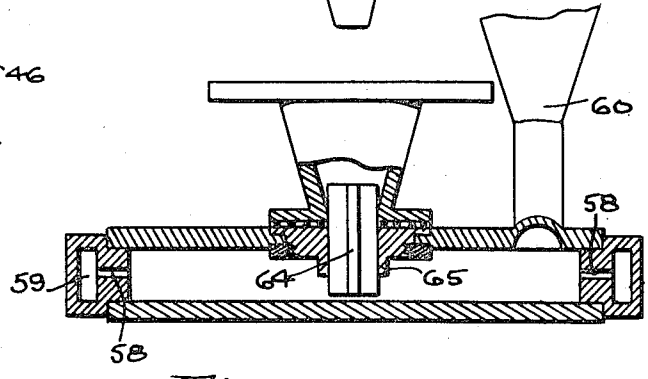
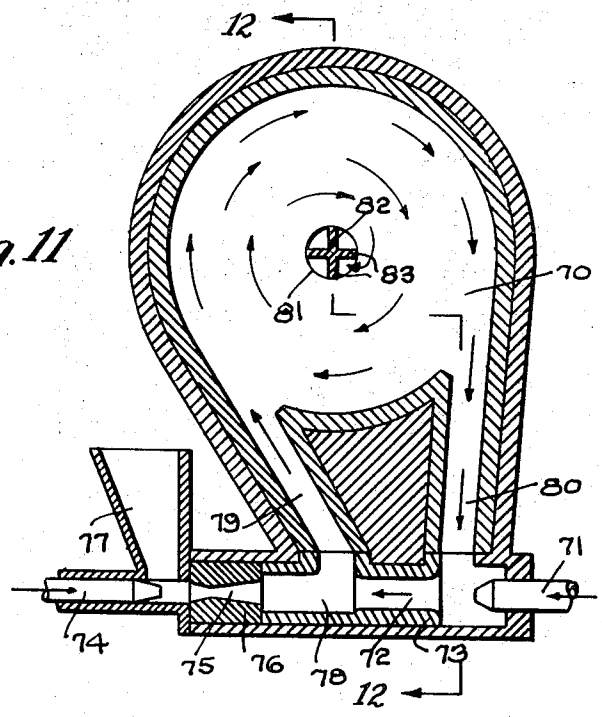


Fig. 10.

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Fig. 11



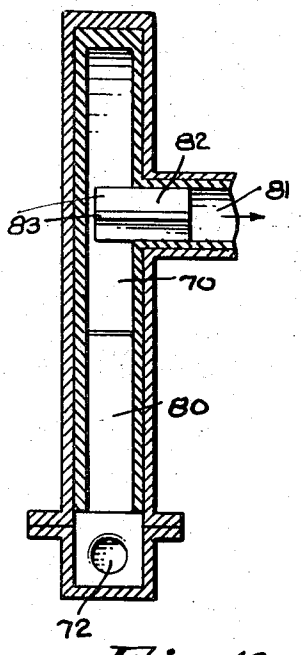


Fig. 12.

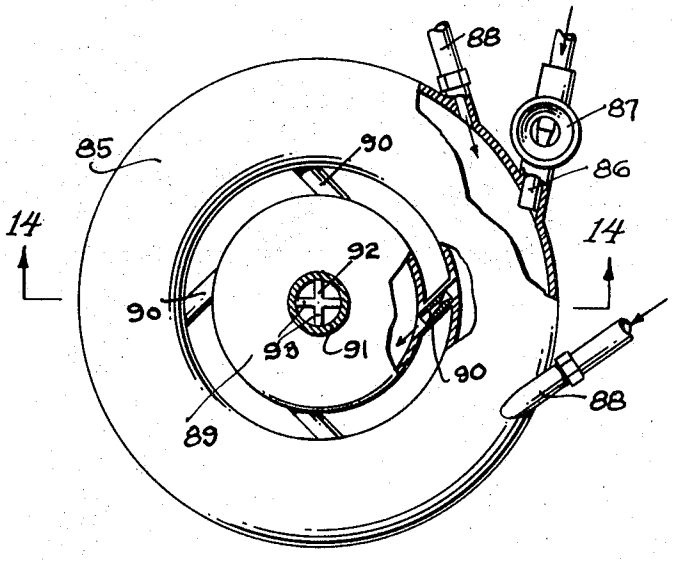
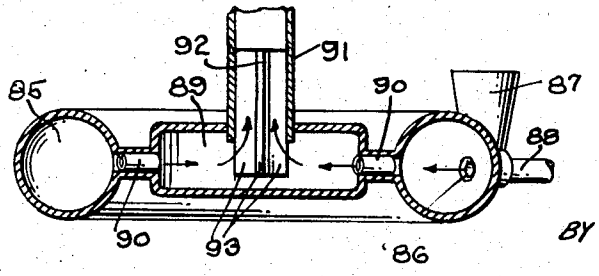


Fig. 13.

Fig. 14.



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APPARATUS FOR AND METHOD OF COMMINUTING SOLID MATERIALS

This invention relates generally to fluid energy mills for the pulverization of dry solid material wherein the particles of said material are reduced to a predeterminedly desired finely comminuted size through attrition caused by bombardment of the particles against one another and against the wall of a grinding chamber in which is established a high velocity vortex of a primary gaseous fluid in which the particles to be pulverized are entrained, the rotational speed of the vortex being high as compared with its component of inward movement toward a discharge outlet located in the central region of the vortex.

Among the principal objects of the present invention is to provide improvements in the apparatus for and method of utilizing to best advantage and with the highest possible efficiency the maximum amount of grinding energy which is available in the fluid introduced into the grinding chamber.

More specifically it is an object of the present invention to so introduce the material to be pulverized into the high velocity vortical stream of the prime gaseous energy fluid so as to prevent premature dispersion of the material particles in said stream such as would result in the discharge of particles from the grinding chamber by the radially inward component of movement of the fluid before they had been reduced to the desired comminuted size.

A further object is to provide an apparatus for and method of entering the material to be pulverized conjointly with the primary gaseous energy fluid for effecting the reduction to desired size of the particles so as to confine and maintain the heavier and coarser particles of the material to a path of travel in the outer region of the gaseous vortex until such time that they are sufficiently reduced in size as to be free to move radially inwardly of the vortex against the restraining influence of centrifugal action of the vortex for eventual discharge from the mill.

Still another object of the invention is to provide a means for and method of decreasing the pressure drop of the energy fluid at the point of its entry into the discharge outlet of the mill and thereby increase the vortical velocity of the fluid with corresponding increase of the fluid energy available for most efficient grinding of the material to its predeterminedly reduced size.

Other objects and advantages of the invention will be apparent from the detailed specification which follows, it being understood that the invention consists in the combination, construction, location and relative arrangement of parts, as well as in the improved method for effecting pulverization of the material, all as described more fully hereinafter, as shown in the accompanying drawings, and as finally pointed out in the appended claims.

In the accompanying drawings:

FIG. 1 is a side elevational view, partly in vertical section, of one form of the pulverizer apparatus constructed in accordance with and embodying the principles of the present invention;

FIG. 2 is a vertical sectional view of the apparatus as taken along the line 2–2 of FIG. 1;

FIG. 3 is a horizontal sectional view as taken along the line 3–3 of FIG. 2;

FIG. 4 is a transverse sectional view as taken along the line 4–4 of FIG. 2;

FIG. 5 is a fragmentary view in vertical section of a portion of the apparatus as viewed along the lines 5–5 of FIGS. 2 and 3;

FIG. 6 is a view of a modified form of the spider element which is fitted in the discharge outlet of the pulverizer;

FIG. 7 is a transverse sectional view of this modified form of spider element as taken along the line 7–7 of FIG. 6;

FIG. 8 is a vertical sectional view of a modified form of the pulverizer apparatus for discharge of both the pulverized material and spent air through a common discharge outlet in the top of the apparatus;

FIG. 9 is a vertical sectional view of a pulverizer apparatus generally similar to that of the modified form shown in FIG. 8 but including provision for independent discharge of the pulverized material and of the spent air respectively through top and bottom discharge outlets provided in the apparatus;

FIG. 10 is a vertical sectional view of another form of pulverizer having a common topmost discharge outlet for the pulverized material and spent air;

FIG. 11 is a vertical sectional view of still another type of pulverizer apparatus in which is incorporated the discharge outlet spider element of the present invention;

FIG. 12 is a sectional view of the pulverizer as taken along the line 12–12 of FIG. 11;

FIG. 13 is a top plan view partly in section, of a still different type of pulverizer apparatus having incorporated therein the discharge outlet spider of the present invention; and

FIG. 14 is a horizontal sectional view as taken along the line 14–14 of FIG. 13.

Pulverizers of the general type to which the present invention relates are conventionally known as fluid energy mills and are ordinarily classified as being either of the horizontal type or of the vertical type. In either case the fluid energy mill essentially includes a chamber wherein the substrate particles of the raw material to be ground to size are whirled at high velocity through a spiralling vortex path terminating in a discharge outlet in the center region of the vortex. In order to effectuate and maintain the high-speed vortical flow of the particles in the vortex chamber a gaseous fluid is introduced into the outer portion of the spiralling vortex at one or more points spaced about its outer circumference under such nozzle pressure to provide the introduced fluid with a high velocity sufficient as to impart a high speed of vortical travel to the particles which, when injected into the vortex chamber, are subjected to the influence of the energizing fluid.

The particles of the material to be pulverized to a predeterminedly desired particle size or classification, when whirled about the spiralling vortex path at high speed, are reduced or ground to the desired smaller particle size through attrition caused by the colliding and rubbing together of the substrate particles and by their abrading contact with the internal wall surfaces of the vortex chamber. Despite the fact that the vortical or rotational speed of travel of the particles is very high as compared with the speed of movement of the particles inwardly of the vortex toward the discharge outlet located proximate the center of the vortex so that the heavier and coarser particles tend to travel about the outer portion of the vortex due to the centrifugal force acting thereon, it has been found that a substantial proportion of these coarser substrate particles are carried to the discharge outlet of the vortex for discharge therefrom together with the more finely reduced particles. Generally, this undesired result occurs in all those fluid energy mills wherein the entire mass of raw material to be treated is injected at one point, thereby causing considerable reduction in velocity of the fluid energy stream at the point of injection thereinto of the material, or where the injection is made in such manner as to allow the escape of unground material before it becomes a part of the mass moving vortically in the vortex chamber.

While this reduction in velocity of the vortex stream due to injection into that stream of the entire mass of raw material at a single point is not of critical importance in vertical mills where classification occurs by the ability of the high velocity airstream to entrain and lift the particles of finely reduced size out of the vortex stream, leaving the coarser particles to be separated out by gravity or centrifugal force operating in the classifying zone, it is of great importance that there be no such reduction in velocity at the point of entry of the raw material into the fluid energy stream in horizontal mills wherein classification is accomplished solely by velocity of the gaseous stream in which the particles are entrained and the centrifugal force exerted by the stream upon the particles as they move toward the discharge outlet of the vortex. In these horizontal-type fluid energy mills, while the more finely sized particles

are discharged from the grinding chamber together with the spent airstream in which they have been entrained, some of the coarser particles eventually also find their way out of the grinding chamber with the spent airstream, thereby degrading the quality of the classification desired for the finer particles. Obviously, when the velocity of the stream is reduced at the point of injection of the raw material, the fluid energy stream acting in the presence of a reduced centrifugal force is still sufficiently strong to penetrate and disperse the stream of the injected raw material with the result that a substantial increment of the heavier and coarser particles are drawn to and through the discharge outlet before they have had an opportunity of being effectively reduced in size through collision and rubbing contact with other particles of the injected mass of material.

In accordance with the principles of the present invention very considerably improved classification is achieved by providing a construction of fluid energy mill wherein the material to be finely pulverized is injected into the grinding chamber of the mill at a point so related and in a direction so oriented with respect to the high velocity stream of gaseous fluid which forms the inwardly spiralling vortex as to impart a high rotational or vortical speed of travel to the material undergoing pulverization without at the same time creating any tendency for the fluid stream to cut through and so disperse or otherwise change the integrity of the jet or jets of raw material directed into the grinding chamber for entrainment in the high velocity vortical stream of the energy fluid.

The principle of the present invention is applicable to mills provided with any number of uniformly spaced nozzles for introduction of the raw material into the grinding chamber so long as each such nozzle has associated therewith its own individual grinding stream of the gaseous fluid. This gaseous fluid may be air, steam or other suitable gas which is introduced into the grinding chamber at any desired temperature and pressure, usually from 100 to 150 p.s.i. The gaseous fluid is introduced into the grinding chamber through the aforesaid nozzles or jet orifices to provide "grinding jets" as distinguished from the "feed jets" of the material introduced into the grinding chamber for pulverization of the particles to a predetermined classified size. As will appear more fully hereinafter, these feed jets of the particles to be pulverized are supplied with the raw (unpulverized) material from a feeding head or manifold into which the material is fed under relatively slight pressure (usually from 5 to 8 p.s.i.) by an injector-type feeder mechanism which includes a venturi-fitted conduit through which a pressurized gaseous fluid flows as the vehicle for injecting the material to be pulverized into the grinding chamber.

Preferably, a plurality of the feed jet orifices are provided in uniformly spaced relation about the circumference of the grinding chamber, all of which are commonly fed with raw material by a single injector-type feeder mechanism by way of a manifold which embraces the grinding chamber and is in communication therewith through the aforesaid plurality of circumferentially spaced feed jet orifices. Each such feed jet is so oriented in relation to the grinding chamber as to project the raw material feed jets along a circular path which closely adjoins and is concentric with respect to the circular outer wall of the grinding chamber, in consequence of which the feed jets of the raw material particles are each projected more or less tangentially with respect to a circle described within the outer region of the gaseous fluid vortex. In accordance with the principles of the present invention, the gaseous fluid which forms the grinding jets is introduced into the grinding chamber through uniformly spaced orifices equal in number to that of the feed jets and in such positional relationship to the feed jets as to provide each feed jet upstream thereof with its own grinding jet. Further, the grinding jets are each so oriented with respect to the direction of discharge of the feed jets respectively associated therewith as to substantially reduce any tendency of the grinding jets to effect premature dispersion of the feed jets, the relative arrangement of the paired feed and grinding jets being such that each of the feed jets is located downstream from and thus so leads its associated grinding jet as not to be impinged and thereby prematurely disrupted by the grinding jet.

This relative arrangement of the feed and grinding jets not only maintains a high velocity vortical travel of the raw material in the grinding chamber, but even more importantly maintain the heavier and coarser particles in the outer regions of the vortex until such time as they are sufficiently reduced in size to be carried out through the vortex discharge outlet with the spent gaseous energy fluid. Thus, a classification is accomplished solely by the velocity of the energy fluid (grinding jets) and the centrifugal force which maintains the coarser particles in the outer region of the vortex until they have been so reduced in size by attrition as to enable them to be carried out by the flow of the gaseous fluid inwardly of the vortex and out of the discharge outlet with the spent gas.

It will be seen from the foregoing that in accordance with the present invention the raw material to be ground is introduced or injected into the grinding chamber at regions in each of which is also included a coacting grinding jet. Since each feed jet is directed substantially tangential to a circle just within and concentric to the outer wall of the grinding chamber, that is tangential to a circle within the outer region of the vortical path of travel of the particles in the grinding chamber, each jet is in effect embraced at one side thereof by the circular wall of the chamber and at its opposite side by the grinding jet individual to and coacting with the feed jet. Thus, each pair of related feed and grinding jets constitutes in effect an individual grinding unit and when the grinding chamber is provided with a plurality of such units in uniform circumferentially spaced relation, they all operate in unison to form a symmetrical vortex in the grinding chamber, resulting in uniform distribution of the material to be ground within the grinding chamber and greatly increased efficiency in operation of the mill due to the fact that the full work load of mill is equally distributed between the several grinding units.

Another important aspect of the present invention is in the provision of means in the discharge outlet of the mill for reducing the pressure of the gaseous fluid in the grinding chamber to thereby achieve a substantial increase in the vortical velocity of the fluid which forms the grinding jets. The available grinding energy is the difference between that of the pressurized fluid supplied to the grinding chamber and that of the fluid within the grinding chamber which latter fluid energy is determined by the pressure and temperature conditions prevailing in the chamber. It has been found that for each reduction of 1 pound per square inch of pressure within the grinding chamber, an increase of from 2½to 5 percent in velocity can be realized.

Since the vortical velocity in an important factor for efficient grinding in fluid energy mills, the means of the present invention for reducing the internal pressure of the gaseous fluid in the grinding chamber with consequent increase in its vortical velocity is of great value not only in horizontal mills but also in vertical mills and in fact in any type of fluid energy mill for the pulverization of dry particulate material to a predetermined uniformly fine particle size.

To this end the present invention contemplates, in addition to the provision of the individualized grinding units above described, the provision in the discharge outlet of the fluid energy mills of a set of stream straightening vanes which are so arranged and disposed in the discharge outlet tube as to effect a substantially rectilinear passage of the spent gas through the discharge outlet.

The tendency of the gas discharged from the center of vortex in the grinding chamber is to continue to spiral as it moves outwardly through the discharge outlet, in addition to which it is also subject to turbulence tending to restrict its rapid discharge through said outlet. This turbulence is due primarily to portions of the gaseous energy stream impinging against one another as they pass from the grinding chamber radially inward across the outer circle of the intake end of the discharge outlet toward the center thereof. It has been deter-

mined that due to the spiralling action alone of the gas passing through the discharge outlet, the distance of travel of the spiralling stream of gas through the discharge outlet is more than six times that of the gas exiting in the form of a straight line stream. As will be more particularly pointed out in the detailed description which follows, the stream straightening vanes of the present invention not only serve to decrease the distance of travel of the spent gas through the vortex discharge tube and thus reduce the frictional resistance to passage of the gas outwardly of said tube with resulting increase in the vortical velocity of the gaseous fluid in the grinding chamber, but also by virtue of their disposition in the discharge tube, they substantially reduce the turbulence which is normally induced by the abrupt 90° change in direction of the gaseous fluid stream as it leaves the center of the vortex in the grinding chamber and enters the discharge line.

It is known, for example, that the pressure drop of a fluid passing through a 90° elbow in a fluid pressure pipe line is approximately equivalent to that of 5 to 6 feet of straight pipe in the line and under certain circumstances may be as much as 5 to 10 times this approximate equivalent. By providing the outlet tube of the grinding chamber with a set of directional vanes having exposed end portions which freely project beyond the inlet end of the discharge tube a distance equal to from one-half to the full diameter of the outlet tube, the gaseous fluid exiting from the grinding chamber is streamlined as it encounters the exposed directional vanes and thus enters the discharge line with a minimal pressure drop between the gaseous fluid pressure in the grinding chamber and that at the point of its entry into the discharge tube, thereby insuring utilization of the maximum amount of energy for grinding which is available as the difference between the energy of the fluid supplied to the grinding chamber and that of the fluid contained inside the grinding chamber itself.

Referring now to the drawings and more particularly to FIGS. **1** to **5** thereof, which show one form of a horizontal-type fluid energy mill constructed in accordance with and embodying the hereinbefore described principles of the present invention, it will be observed that the mill designated generally by the numeral **10** includes a recessed circular top plate **11** and a recessed circular bottom plate **12** which are respectively provided with oppositely presenting annular flanges **13** and **14** which circumferentially embrace and marginally define the opposed recesses of the plates **11** and **12**. Respectively fitted in the recesses of these plates **11** and **12** are preformed, replaceable liners **15** and **16** formed of any suitable abrasion-resistant material, which may be any plastic material such as Teflon, nylon, polyurethane and the like or a suitable rubber, metal or ceramic material. The exposed faces of these liners **15** and **16** are respectively dished, as at **17** and **18**, to provide therebetween a cavity **19** which increases in vertical depth inwardly from its outer peripheral margin. This cavity **19** is marginally enclosed by an annular member **20** of general T-shape in transverse section to provide it with an annular radially extending inner portion **21** and an annular hollow outer portion **21***a*. The internal radially extending portion **21** of the member **20** is snugly fitted between the oppositely presenting outermost portions of the liner-fitted plate members **11** and **12**, while the annular outer hollow portion **21***a* is disposed in closely embracing relation about the annular flanges **13** and **14** of these plate members.

While the liner-fitted plates **11** and **12** and the intermediate annular member **20** may be secured together in their assembled relation as best shown in FIG. **1** by any suitable means, these parts are preferably held assembled by a plurality of quick-detachable C-type clamps **22**, of which only one is shown in FIGS. **2** and **3**, to facilitate quick and easy disassembly of the mill for cleaning and otherwise servicing the same as may be required. The cavity **19** thus formed by the top and bottom plate members **11** and **12** in assembly with the intermediate annular member **20** constitutes the grinding chamber of the mill.

The top plate **11** is provided with a suitably shouldered central aperture **23** in axial registry with a central aperture **24** formed in the liner **15**. Similarly, the bottom plate **12** is provided with a shouldered central aperture **25** in axial registry with a central aperture **26** formed in its liner **16**. A discharge tube **27** projects axially inwardly through the top plate assembly of the mill to a point just beyond the bottom central opening of the mill cavity **19**, while extending axially downward of the cavity **19** in axial alignment with the discharge tube **27** is a collector member **28**. It will be noted that the internal diameter of the collector in the region thereof which embraces the lower end of the discharge tube **27** is of greater diameter than the external diameter of the terminal portion of said tube to thereby provide an annular space or orifice **29** through which the particles of the material ground to size in the grinding chamber of the mill may pass by gravity flow into the collector **28** and the spent gas from the grinding chamber may pass for discharge through the discharge tube **27**.

The discharge tube **27** is preferably secured to the top plate and liner assembly as a fixed part thereof by providing it with an enlarged head **30** having a flange adapted to be seated in the shouldered aperture **23** of the top plate **11** and held therein by an anchoring ring or nut **31** threaded onto the head **30** for clamping engagement against the bottom of the liner **15**. An air exhaust conduit **32** is suitably bolted or otherwise secured to the outer end of the discharge tube as an extension thereof.

The collector **28** is bolted or otherwise suitably secured to the bottom plate and liner assembly.

The liner **15** for the top plate member is provided with an upwardly presenting annular channel or recess **33** which extends circumferentially about the full circle of the liner closely adjacent the peripheral edge thereof. With the liner **15** secured in position within the recessed top plate **11**, the latter serves as a closure for the open top side of the channel **33** in the liner and so provides in the top plate and liner assembly an annular plenum or manifold **34** into which may be introduced the raw material to be pulverized in the mill. As is best shown in FIGS. **1** and **2**, the top plate **11** is provided with a feeding head, designated generally as **35**, which includes a conduit **36** having a venturi passageway **37** in communication with the interior of the manifold **34**. Connected to the venturi conduit **36** is a pressurized gaseous fluid supply conduit **38** having a nozzle **39** in spaced coaxial relation to the venturi passage **37**.

Operatively associated with the venturi conduit **36** is a material supply hopper **40** having a discharge throat in communication with the inlet to the venturi passage **37** whereby upon the flow of the pressurized fluid through the nozzle **39** and into the venturi passage the raw material from the hopper **40** is drawn into the fluid stream for injection thereby into the manifold **34** of the mill. The material feeder mechanism **35** is so oriented relatively to the annular manifold **34** as to inject the coarse material to be pulverized into said manifold in a direction which causes the material to flow clockwise about the manifold when viewed in plan as shown in FIG. **3** and thus be spread uniformly throughout said manifold. The amount and pressure of the fluid flowing through the venturi passage is desirably restricted to that necessary to carry the material delivered from the hopper **40** into the manifold **34** and thence into the grinding chamber **19** of the mill without any undue pressure drop between the annular manifold **34** and the grinding chamber.

The coarse material thus introduced into the manifold **34** is discharged therefrom into the grinding chamber **19** by way of a plurality of uniformly spaced openings **41** formed in the bottom wall **42** of the manifold. While in the construction shown in FIGS. **1** to **3**, eight such openings are provided, it will be understood that any desired number of such circumferentially equally spaced openings may be provided in the bottom wall of the manifold in order to insure uniform distribution of the coarse material about the circumferential margin of the grinding chamber.

It is of importance to note that the openings **42** are all similarly oriented with their bores each extending at the same angle to the vertical and pointing in the same general direction (clockwise) as does the injection nozzle of the raw material feeding head, as best shown in FIG. **1**. Also it will be noted that the openings **42** are disposed with their axes intersecting at uniformly spaced points the line of a circle which is concentric with respect to and in such closely spaced relation to the outer sidewall **43** of the manifold as to locate the discharge ends of said openings **42** in very close proximity to the interior surface of the annular sidewall of the grinding chamber, as is best shown in FIG. **2**. These openings **42** serve as passages from the material feed distributing manifold **34** to the grinding chamber **19** through which the coarse material to be pulverized is injected into the grinding chamber in the form of spaced jets under uniform pressure, velocity and volume dependent upon the pressure of the injecting fluid passing through the injector-type feeder mechanism **35**. The material thus injected into the grinding chamber is initially constrained to flow circumferentially about the outer region of the gaseous vortex generated in the grinding chamber.

This inwardly spiralling vortex is set up and maintained at high velocity by the gaseous energy fluid which is introduced under a relatively high pressure (100 to 150 p.s.i.) to the interior of the hollow outer ring portion **21***a* of the member **20** forming the circular side enclosing wall of the grinding chamber. This high-pressure fluid is applied to this hollow outer portion of the annular member **30** by a conduit **44** connected to a suitable supply of the pressurized fluid and is injected into the interior of the grinding chamber in the form of a plurality of high velocity jets by way of uniformly spaced openings **45** extending through the radially projecting inner portion **21** of the member **20**. These jet openings **45**, which produce the high velocity fluid grinding jets hereinbefore mentioned, are equal in number to the number of the material feed jets which discharge into the grinding chamber by way of the openings **41** provided in the bottom of the material feeding manifold or plenum **34**. The several grinding jets each enter the grinding chamber in such intersecting angular relation to the outer boundary of the grinding chamber as to set up in the latter a high velocity inwardly spiralling vortical flow of the pressurized fluid coursing in the same general direction as do the material feed jets, namely, in a clockwise direction when the mill is viewed as in FIG. **3**.

It will be noted, however, that each of the grinding jet openings **45** is located upstream of and in close proximity to a feed jet opening **41** and that the angle of injection of each grinding jet into the grinding chamber is such that its bore extends at an acute angle to the direction of initial discharge of the material to be pulverized from its closely related feed jet opening **41**, this angle being that designated *a* in FIG. **3**. Since the feed jets are each located downstream with respect to its associated grinding jet, there is no impingement of these paired jets one against the other in the immediate region of their entry into the grinding chamber and thus the integrity of the feed jets is not prematurely destroyed as would occur through immediate impinging engagement of the grinding jets with the feed jets. Instead, the feed jets containing the coarse material to be pulverized are directed along paths substantially tangential to a circle closely adjacent the circumferential outer wall of the grinding chamber and thus are each embraced on its outer side by said wall and on its inner side by a coacting grinding jet, in consequence of which each feed jet at its point of injection into the grinding chamber is constrained to move in a circle immediately adjoining the grinding chamber wall. This effectively reduces to a minimum any tendency for the heavier and coarser particles of the material to be pulverized from being prematurely carried by the inwardly directed force component of the vortex toward the discharge outlet of the mill and thus these heavier and coarser particles of the material continue to be reduced in size by collision against one another and against the wall of the grinding chamber until they have been sufficiently reduced in size to relieve them from the influence of centrifugal force and permit their movement inwardly toward the center of the vortex across the divergent end regions of the grinding jets.

As is most clearly shown in FIGS. **2** and **3**, the discharge tube **27** is interiorly fitted with a spider member **46** having a plurality of angularly related vanes **47** extending lengthwise of the tube to provide therein a plurality of circumferentially spaced channels or passages **48** (see FIG. **3**) through which the gaseous energy fluid may pass for discharge from the grinding chamber. The vanes **47** of the spider member **46** project freely beyond the inlet end of the discharge tube a distance equal to from one-half to the full diameter of the discharge tube and in the form of mill shown in FIGS. **1** to **5**, these freely extending exposed end portions of the spider project downwardly into the inner, i.e., top, end of the collector **28** with the longitudinally extending outer edges of the spider vanes **47** spaced inwardly of the cylindrical wall of the collector.

These exposed end portions of the spider vanes **47** are thus disposed in the path of travel of the gas discharging from the grinding chamber and entering the inlet end of the discharge tube and effectively operate to prevent disrupting impingement between circumferentially spaced segments of the gas stream which seek to enter the discharge tube by travel radially across the circular end of the discharge tube toward and thence upwardly through the center of the tube. The exposed ends of the vanes **47** serve to divide and separate the gaseous stream as it leaves the vortex into spaced segments which are then smoothly deflected by the vanes to move upwardly about the inlet end of the discharge tube with minimal turbulence at the center of said inlet. Upon such streamlined entry of the spent gas into the discharge tube, the upper sections of the vanes enclosed within the tube insure continued streamlined flow of the gas upwardly and out through the discharge end of the tube. As has been pointed out hereinbefore, by so reducing turbulence of the exhausting gas stream at the point of its entry into the discharge outlet to thereby preclude excessive or undue pressure drop at this point, the grinding energy of the pressure fluid within the grinding chamber is rendered available to the maximum degree possible.

The spider **46** may if desired be provided with vanes **47***a* which have their exposed extremities **47***b* each similarly curved, as shown in FIGS. **6** and **7**, to provide concave surfaces to smoothly deflect and direct the above described segmental portions of the gaseous stream exiting from the vortex in the grinding chamber about the solid center of the exposed portion of the spider and thence upwardly through the passages **48** formed by the spider vanes in the discharge tube **27** for straight line flow therethrough toward and through the terminal outlet for the spent gas.

In operation of the mill as described and shown in FIGS. **1** to **7**, the high-pressure gaseous fluid introduced into the hollow annulus **21***a* is injected into the grinding chamber by way of its orifices **45** in the form of a plurality of high velocity jets or streams each in the direction as indicated by the arrows in FIG. **3**. As shown the direction of discharge of these grinding jets is chordally across the interior of the grinding chamber at an acute angle with respect to the peripheral wall of the chamber. These grinding jets set up and maintain in the grinding chamber an inwardly spiralling vortex into the outer circular region of which is introduced the raw material to be pulverized by way of the orifices **41** of the material distributing manifold **34**.

As the particles of the material are ground to size by attrition thereof in the grinding chamber, those of finely reduced size are carried by the inwardly directed force moment of the vortical stream to the center thereof for discharge thereof by gravity into the collector **28** by way of the annular discharge orifice **29** formed between the concentric wall portions of the discharge tube **27** and the collector **28**. The heavier and coarser particles of the material are restrained from undesired premature movement across the vortical path of the energy fluid by the confining action of the grinding jets each acting in

conjunction with an associated feed jet as above described and so are held bound in the vortex against discharge therefrom until they have been so sufficiently reduced in size that they may move inwardly to the discharging center of the vortex against the restraining centrifugal action thereof.

As the gas-entrained particles of the desired reduced size enter the zone of the material discharge orifice **29**, the comminuted particles separate out from the gas stream and flow by gravity into the collector **28** at the same time that the spent gas escapes by way of the discharge tube **27**. Classification of the material is achieved in the inner or central zone of the vortex, since only the particles which have been reduced to the desired size are carried out of the vortex for discharge into the collector, while the particles of greater size remain bound in the vortex until they too are reduced to the desired size. Since the spent gas is discharged to atmosphere with minimal pressure drop at the point of its entry into the discharge tube, the vortical velocity of the fluid energy stream in the grinding chamber is maintained at a high level for most efficient pulverization of the material injected into the mill.

FIGS. **8**, **9** and **10** show modified forms of fluid energy mills embodying one or more of the features of the present invention. The fluid energy mill of FIG. **8** is similar in all material respects to that of FIGS. **1** to **5** except that the discharge tube **50** thereof with its streamlining spider **51** is entirely disposed within the grinding chamber **52** of the mill. As in the previously described mill shown in FIGS. **1** to **5**, the mill of FIG. **8** is provided with a material distributing manifold **53** having circumferentially spaced orifices **54** through which the material to be pulverized is injected into the grinding chamber in the form of spaced feed jets. The gaseous energy fluid is introduced into the grinding chamber in the form of high velocity grinding jets through the jet orifices **55** communicating with the hollow fluid distributing ring **56**, each feed jet having associated with it one of the grinding jets to provide a series of spaced grinding units operating as hereinbefore described. However, in the mill of FIG. **8**, the pulverized material together with the spent gas exhausting from the grinding vortex is discharged upwardly through the discharge tube to a suitable collector (not shown) connected in line with the discharge outlet. Classification is achieved as in the previously described form of mill in the vortex discharge zone immediately surrounding the exposed streamlining portions of the spider **51**.

FIG. **9** shows another form of horizontal mill wherein the vortex in the grinding chamber **56** is established by pressurized gaseous fluid injected thereinto through a plurality of jet orifices **58** uniformly spaced about the periphery of the mill, these orifices being all in communication with a common hollow annulus **59** to which the gas is supplied under suitable pressure. The material to be pulverized is introduced into the grinding chamber at only a single point by way of an injector-type feeder mechanism **60** in accordance with conventional mills. However, this mill is also provided in its discharge tube **61** with a streamlining spider **62** having its end exposed beyond the corresponding end of the discharge tube to provide for maximum high velocity flow of the vortex stream of gas in the grinding chamber to thereby render available maximum energy for efficient grinding of the material in the grinding chamber. As in the first described form of the mill, in the mill of FIG. **9** the pulverized particles pass by gravity into a collector **63**, while the spent gas exhausting from the vortex escapes by way of the discharge tube **59** which is fitted with a streamlining spider **60** constructed and operating in accordance with the principles of the present invention.

FIG. **10** shows the application of the streamlining spider **64** of the present invention to another more or less conventional design of horizontal mill wherein the particles of material reduced to their desired minute size is carried out of the mill together with the spent gas exhausting from the vortex in the grinding chamber by way of the discharge tube **65**.

FIGS. **11** and **12** illustrate a vertical type of fluid energy mill in the discharge outlet of which is incorporated the spider feature of the present invention for streamlining the flow of the spent gas out of the grinding chamber and thereby maintain in said chamber the highest possible vortical velocity of the energy fluid supplied thereto. In this vertical type of fluid energy mill the pulverized material is introduced into a classifying chamber **70** in which the gaseous fluid stream whirls at high velocity about a horizontally extending central axis for discharge of the finely sized particles through a discharge outlet disposed with its axis coincident with that of the rotational axis of the vortex. The gaseous fluid energy stream which serves as the primary grinding fluid is injected from a suitable pressurized supply thereof into the vortex chamber **70** through a nozzle **71** in axially spaced registry with a passage **72** extending through a venturi tube **73**, while the material to be pulverized is injected into said chamber by a material conveying stream of gas which issues through a nozzle **74** and passes through the bore **75** of an axially spaced venturi tube **76** to pick up and convey the feed material from a supply hopper **77** into the grinding chamber. It will be noted that the material injecting jet and the primary fluid injecting jet are directed toward one another from opposite ends of a bottom chamber **78** which communicates with the vortex chamber **70** by the communicating passages **79** and **80**.

The material to be pulverized is initially shattered in the chamber **78** by impact of the primary grinding fluid with the entering stream of the feed material, following which the grinding fluid and its entrained material then passes upwardly through the passage **79** for vortical travel at high velocity within the vortex chamber **70** and subsequent discharge through the outlet tube **81** leading to a collector not shown of any conventional construction. Because of the centrifugal force acting on the particles within the vortex chamber, the more heavy and coarser particles migrate to the outer periphery of said chamber and are carried by the fluid energy stream tangentially thereof through the passage **80** back into the primary impact zone **78** for further reduction of these larger particles of the material to the desired smaller size.

The particles of material which are reduced by attrition and impact to the smaller size desired are carried by the spent gas leaving the center of the vortex through the discharge outlet **81**, which latter is provided with a streamlining spider **82** having the circumferentially spaced directional vanes **83** as incorporated in the previously described fluid energy mills. Thus, in the last-described vertical type of mill, as in the previously described horizontal mills, the vanes **83** have their inner portions extending freely beyond the corresponding inner end of the outlet tube **81** to smoothly direct the discharging stream of the primary grinding fluid into and through the discharge outlet with minimum turbulence in the immediate region of its entry into the discharge outlet, thereby minimizing the pressure drop in this region with consequent decrease of pressure and corresponding increase in vortical velocity and energy of the primary fluid energy stream circling through the mill.

FIGS. **13** and **14** illustrate still another construction of the horizontal-type fluid energy mill in which the spider feature of the present invention may be employed with great advantage to increase the quantity of energy which is available from the primary grinding fluid introduced into the mill at a given pressure and so provide for increased efficiency toward producing a more uniform and finer grinding of the material being pulverized. In this construction of mill, a multistage action is obtained by means of an outer toroidal chamber **85** having a feed material injection inlet **86** through which the material to be pulverized, supplied from a hopper **87**, is entrained in a gaseous stream under suitable pressure, and injected into the chamber **85** for distribution circumferentially therewithin.

This outer chamber **85** is also provided with a plurality of circumferentially spaced nozzles **88** through which the primary grinding fluid from a suitable source under requisite pressure is also injected into the chamber **85**, which primary grinding fluid acts to circulate the feed material about the interior of said toroidal chamber to effect a first-stage reduction in size of the material particles. This latter chamber is in communica-

tion with a central chamber **89** through a plurality of nozzles **90** uniformly spaced about the circumference of the central chamber and arranged with their axes similarly oriented to create a high velocity vortex of the primary fluid in said central chamber having in its central region a discharge outlet **91**. Further reduction in particle size of the material being pulverized is effected in this central vortex chamber **89** and upon reduction to desired size of the particles they move radially inward of the vortex for eventual discharge through the outlet **91** with the spent gas in which said finely comminuted particles are entrained.

As in all of the previously described forms of energy mill, the outlet **91** is fitted with the spider **92** of the present invention having its angularly related directional vanes **93** with their end portions projecting freely beyond the corresponding intake end of the outlet to achieve the objectives of the present invention as hereinabove described.

While the spider vanes have been described as having their end portions exposed preferably a distance equal to from one-half to the full diameter of the discharge tube in which the spider is fitted, it is to be understood that while this length of the exposed portions of the vanes is preferred, the length thereof is not necessarily limited to the range specified but may be greater than the diameter of the discharge or less than one-half its diameter depending upon other design factors of the mill so long as the exposed portions of the spider vanes are of a length sufficient to effect smooth, streamlined entry of the spent grinding fluid into the intake end of the discharge outlet. Also, it will be understood that while the spider feature of the present invention may be employed to good advantage in all of the mills hereinbefore described, the construction of mill as shown in FIGS. **1** to **8** inclusive, insofar as concerns the described relationship of the feed and grinding jets for conjoint action of each paired set thereof, provides increased efficiency in operation of the mill even in the absence of the spider feature for the reasons hereinbefore set forth. Further, various changes and modifications may be made from time to time without departing from the general principles or real spirit of the several different aspects of the present invention and it is accordingly intended to claim the same broadly, as well as specifically, as indicated by the appended claims.

I claim:

1. Apparatus for the pulverization of material into finely divided form comprising a generally circular grinding chamber for the particles of material to be pulverized, means for injecting a pressurized gaseous grinding fluid into said chamber through plurality of circumferentially spaced jet orifices in communication between a source of supply of said pressurized fluid and the interior of said chamber to establish therein a high velocity inwardly spiralling vortex of the gaseous fluid, and means for injecting the material to be pulverized into said grinding chamber through a plurality of circumferentially spaced jet orifices in communication between a source of supply of said material and the interior of said chamber for entrainment of said particles of material in said vortex and movement therewith at a vortical speed of travel which is high as compared with the speed of movement of said particles radially inward toward a discharge outlet at the center of said vortex, said fluid jet orifices being equal in number to that of said material jet orifices with each said material jet orifice located downstream of a single one of said fluid jet orifices in such close proximity thereto and with its axis so oriented relatively to that of its proximate fluid jet orifice that the axis of each jet of the material at its point of entry into the grinding chamber extends in nonintersecting relation to the axis of its proximate gaseous fluid jet at the point of entry of the latter into the grinding chamber.

2. In the apparatus as defined in claim **1** wherein each jet of the gaseous fluid entering the grinding chamber is disposed inwardly of and extends at an acute angle to its closely related jet of material entering the grinding chamber whereby to initially confine said material jet between said gaseous fluid jet and the surrounding wall of the grinding chamber.

3. In the apparatus as defined in claim **1** wherein each jet orifice for entry of the material into the grinding chamber is disposed immediately adjacent the confining sidewall of the grinding chamber with its axis so oriented with respect to the axis of its proximate fluid jet as to direct the feed jet of said material tangentially with respect to a circle in closely spaced concentric relation to said sidewall of the grinding chamber and outside of a circle substantially tangent to the axes of said fluid jets whereby to introduce said material into the outermost circular region of the vortex.

4. In the apparatus as defined in claim **1** which includes a pair of opposed plate members and an annular member secured in intervening position between the peripheral portions of said plate members to form said grinding chamber, at least one of said plate members being provided with a replaceable liner having an annular recess extending about its circumferential margin spaced inwardly of said annular member, the open end of said annular recess being sealed off by its associated plate member to provide an annular manifold into which the material to be pulverized is injected, the wall of said manifold opposite its said associated plate member being provided with said plurality of jet orifices through which said material issues in jet form for entrainment in the vortex of the gaseous energy fluid operating within said grinding chamber.

5. In apparatus as defined in claim **4** wherein each of said material injecting orifices in the aforesaid wall of said manifold is similarly oriented with its axis extending at an angle to the plane of wall and along a line coincident with a circle closely adjacent and concentric with respect to the outer circumferential wall of said manifold whereby said material is injected into the grinding chamber in a direction corresponding to the direction of rotation of the vortex in said chamber and within an area external of a circle tangent to the axes of said jets of the grinding fluid.

6. Apparatus for finely comminuting solid material in pulverulent state comprising in combination a circular chamber in closed communication with a source of pressurized gaseous fluid through a jet forming nozzle for establishing in said chamber an inwardly spiralling vortex of said fluid of high vortical velocity adapted to discharge from said chamber through a discharge outlet extending outwardly from the center region of the vortex, means for injecting the pulverulent material into the outer marginal portion of the vortex for movement inwardly thereof to and through said discharge outlet, and means in said outlet for reducing turbulence of the gaseous fluid and attendant pressure drop thereof in the region of its entry into said outlet to thereby maintain a high rotational speed of travel of the gaseous vortex in said chamber and utilization of the maximum amount of grinding energy available as the difference between the energy of the fluid supplied to the grinding chamber and that of the fluid contained within the chamber itself, said last-mentioned means comprising a spiderlike member fitted in said discharge outlet and having a plurality of angularly related vanes which provide a plurality of circumferentially spaced separated passages extending rectilinearly through said outlet in parallel relation to its central axis, said vanes extending freely beyond the intake end of said discharge outlet in intercepting relation to the gaseous fluid discharging from the center of the stream and moving radially inward across the peripheral edge of the intake end of said discharge outlet.

7. Apparatus according to claim **6** wherein the freely projecting ends of said vanes extend beyond the intake end of said discharge outlet a distance equal to from one-half to the full diametrical dimension of the outlet.

8. Apparatus according to claim **6** wherein the freely projecting ends of said vanes are respectively longitudinally and laterally curved to provide the same with corresponding concave surfaces for intercepting the gaseous fluid exiting from the central region of the vortex and effecting streamlined flow thereof into the discharge outlet.

9. The method of pulverizing solid pulverulent material into finely divided form which consists in injecting the material to

be pulverized in the form of a feed jet into the outer region of an inwardly spiralling vortex of a gaseous energy fluid having a rotational speed substantially higher than that at which the fluid moves inwardly toward the center of the vortex the said vortex of the fluid being established and maintained at said high rotational speed within an enclosed grinding chamber into which the energy fluid is injected in the form of a grinding jet for effecting high velocity vortical flow of the fluid toward a discharge outlet at the center of the vortex, said feed jet of the material to be pulverized being introduced into the vortex at a selected number of circumferentially uniformly spaced points each in close proximity to and downstream of the point of entry of one of an equal number of similarly spaced grinding jets into the grinding chamber, the axes of each grinding jet and its associated proximately located feed jet being relatively so oriented that said feed jets are each embraced on one side thereof by said grinding jet and on its opposite side by the encircling wall of the grinding chamber.

10. Apparatus for the pulverization of material into finely divided form comprising a generally circular grinding chamber for the particles of material to be pulverized, means for injecting a pressurized gaseous grinding fluid into said chamber through a jet orifice in communication between a source of supply of said pressurized fluid and the interior of said chamber to establish therein a high velocity inwardly spiralling vortex of the gaseous fluid, means for injecting the material to be pulverized into said grinding chamber through a jet orifice in communication between a source of supply of said material and the interior of said chamber for entrainment of said particles of material in said vortex and movement therewith at a vortical speed of travel which is high as compared with the speed of movement of said particles radially inward toward a discharge outlet at the center of said vortex, said material jet orifice being located downstream of the fluid jet orifice in close proximity thereto and with its axis so oriented relatively to that of the fluid jet orifice that the axis of the jet of the material at its point of entry into the grinding chamber extends in nonintersecting relation to the axis of the gaseous fluid jet at the point of entry of the latter into the grinding chamber, and means in said discharge outlet for reducing the pressure of the gaseous energy fluid in the grinding chamber to thereby achieve a substantial increase in the vortical velocity and the grinding energy of said fluid, said pressure reducing means comprising a spiderlike member having a plurality of angularly related vanes to form a plurality of circumferentially spaced passages extending rectilinearly through said outlet parallel to its central axis, said vanes having end portions extending freely beyond the intake end of the discharge outlet to intercept and effect streamlined entry into the discharge outlet of the spent gaseous fluid exiting from the center of the vortex.