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METHOD OF AND APPARATUS FOR PROVIDING MATERIAL IN FINELY DIVIDED FORM

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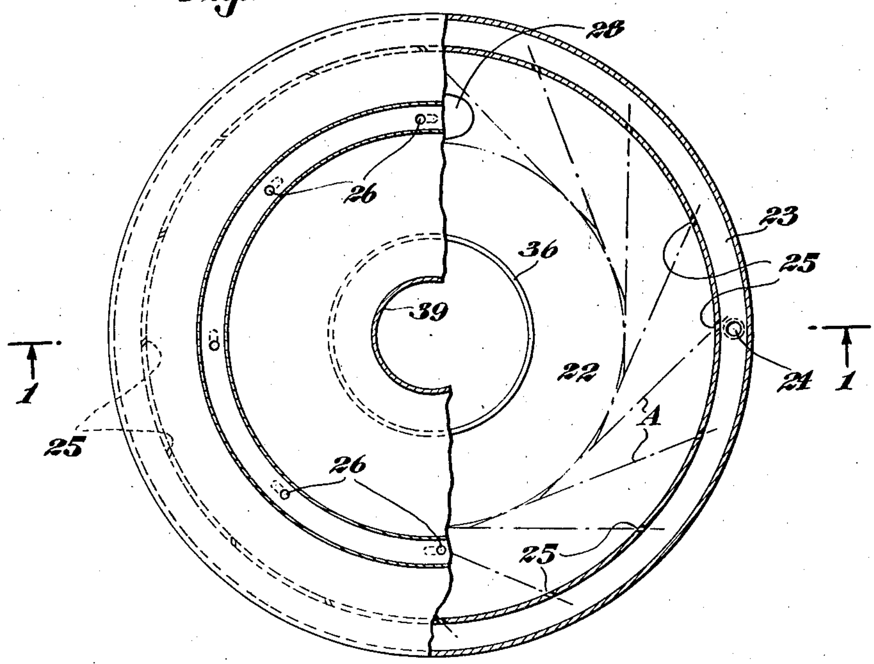
Fig. 2



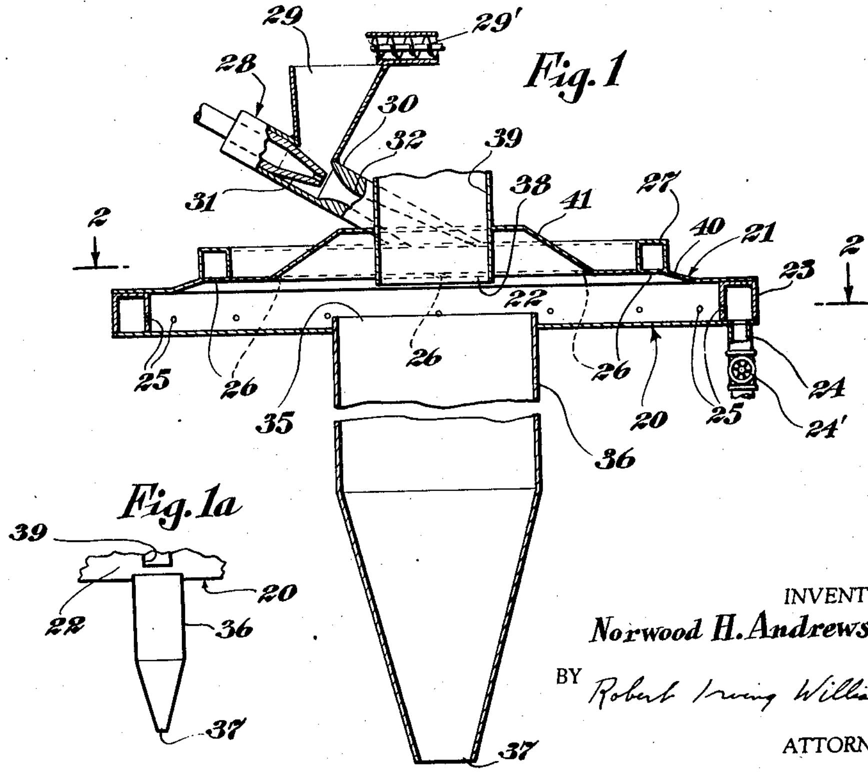


Fig. 1

Fig. 1a

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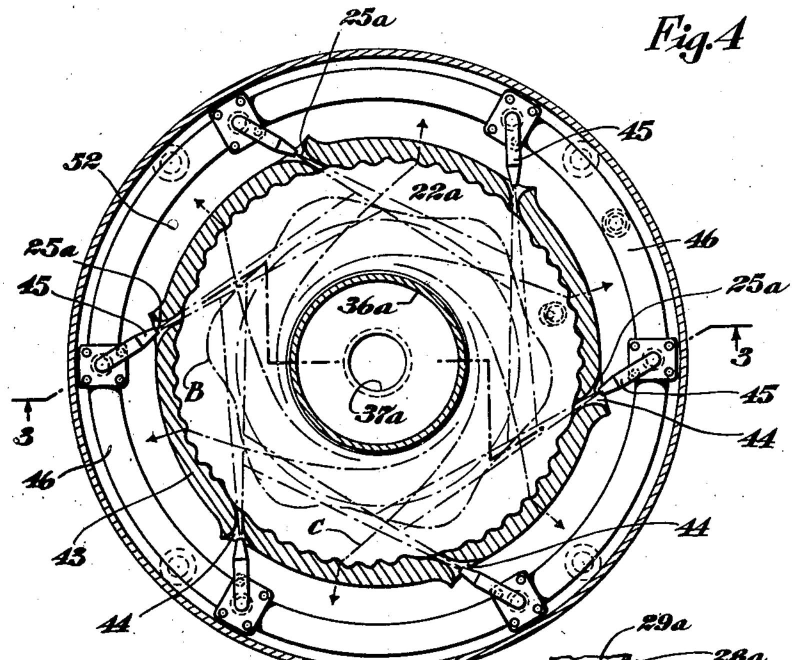

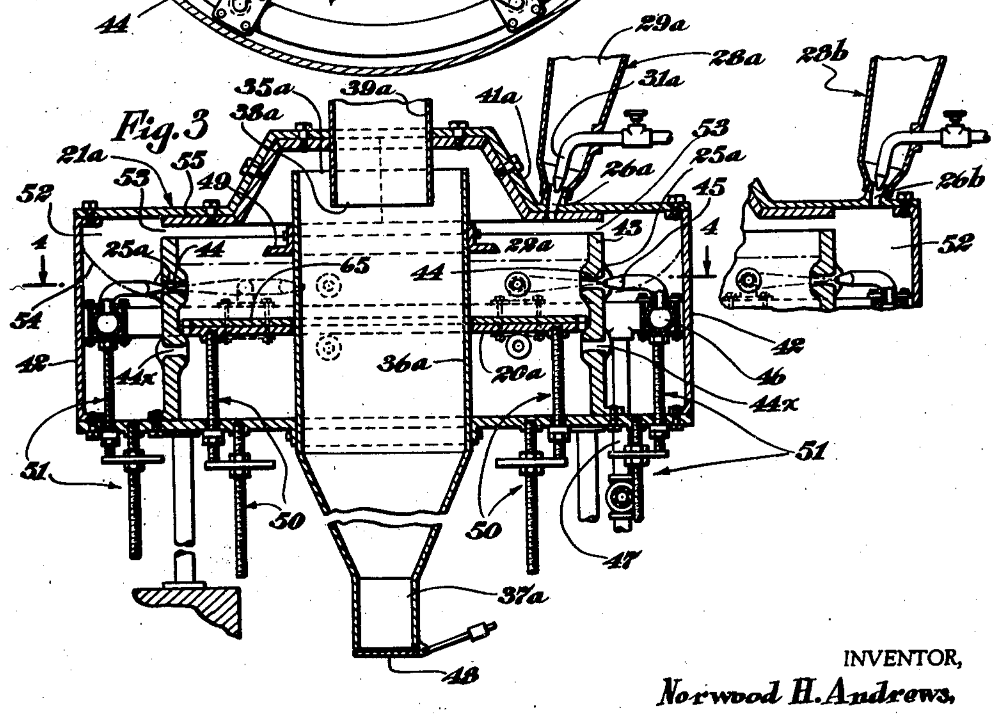

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METHOD OF AND APPARATUS FOR PROVIDING MATERIAL IN FINELY DIVIDED FORM

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Fig. 5

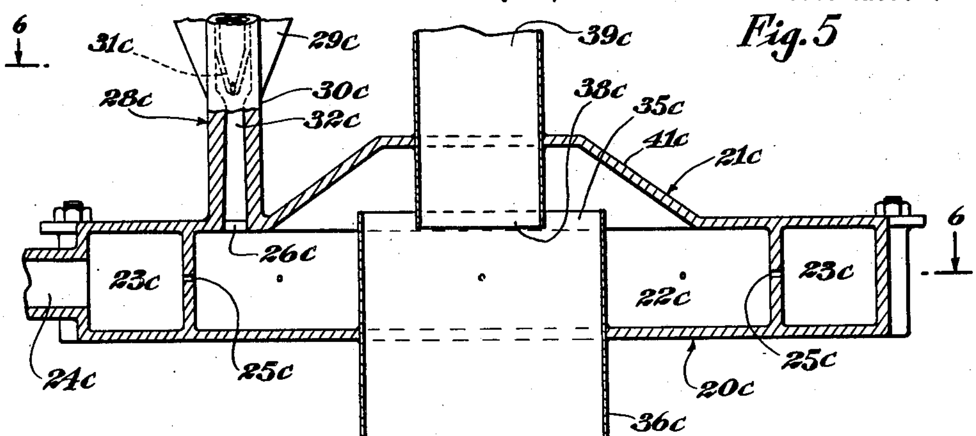
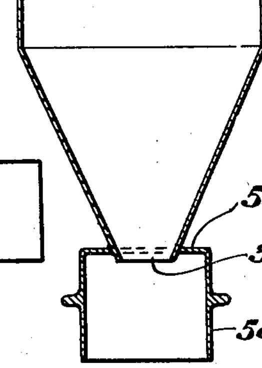

Fig. 5a

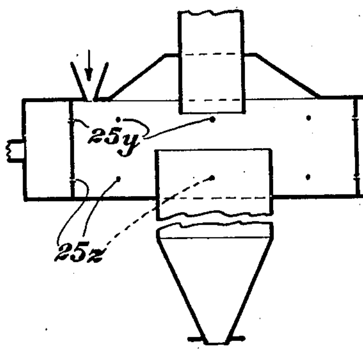

Fig. 6a

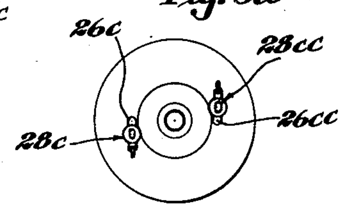

Fig. 6

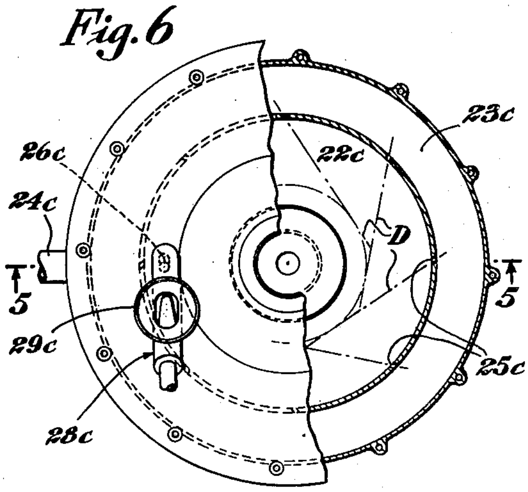

Fig. 6b

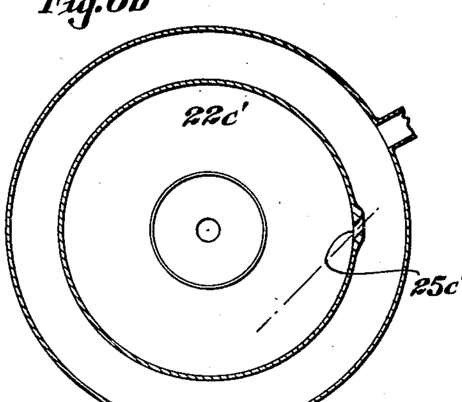

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Fig. 8

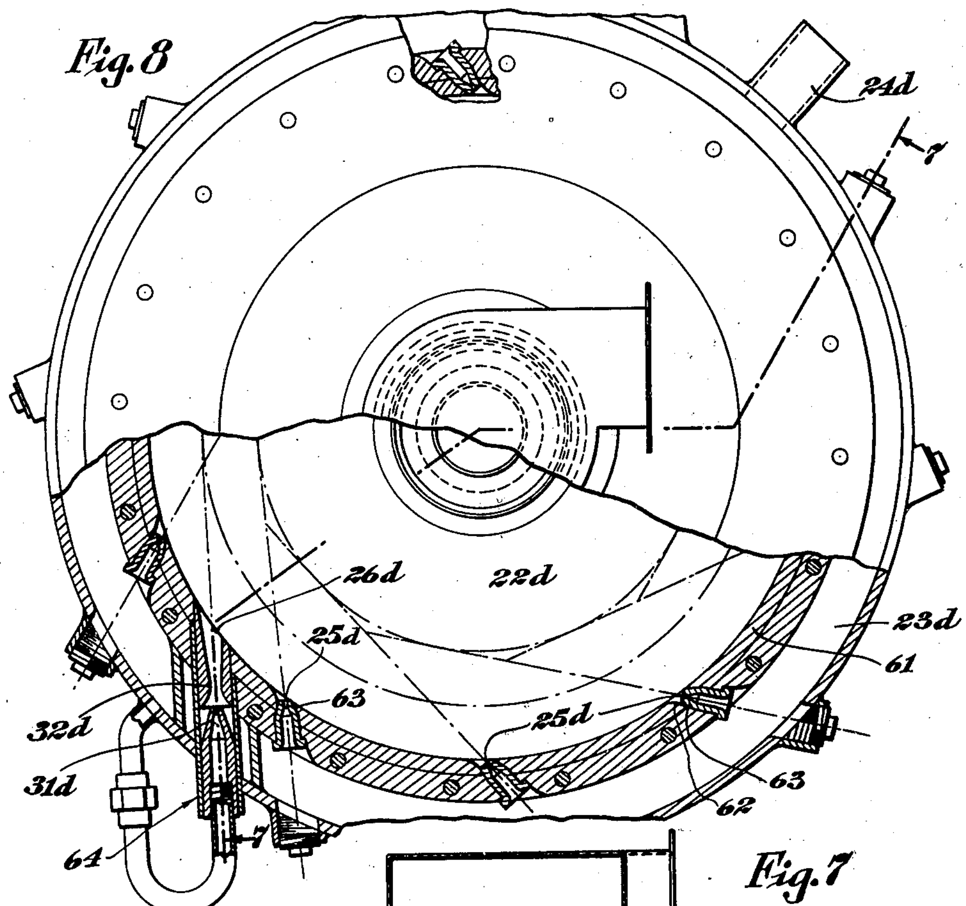

Fig. 7

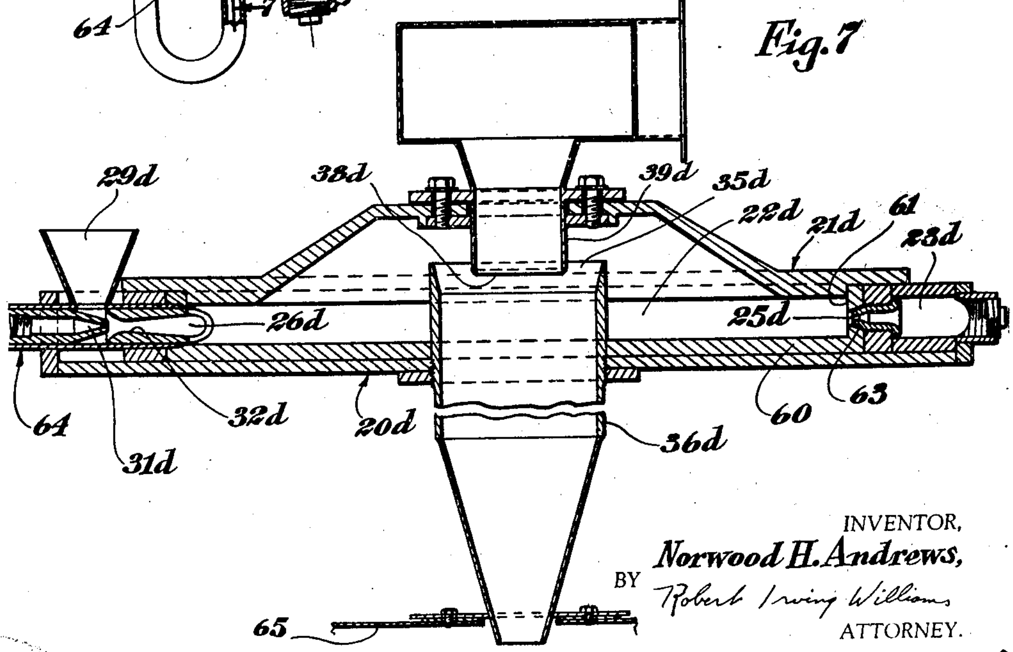

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Fig.9

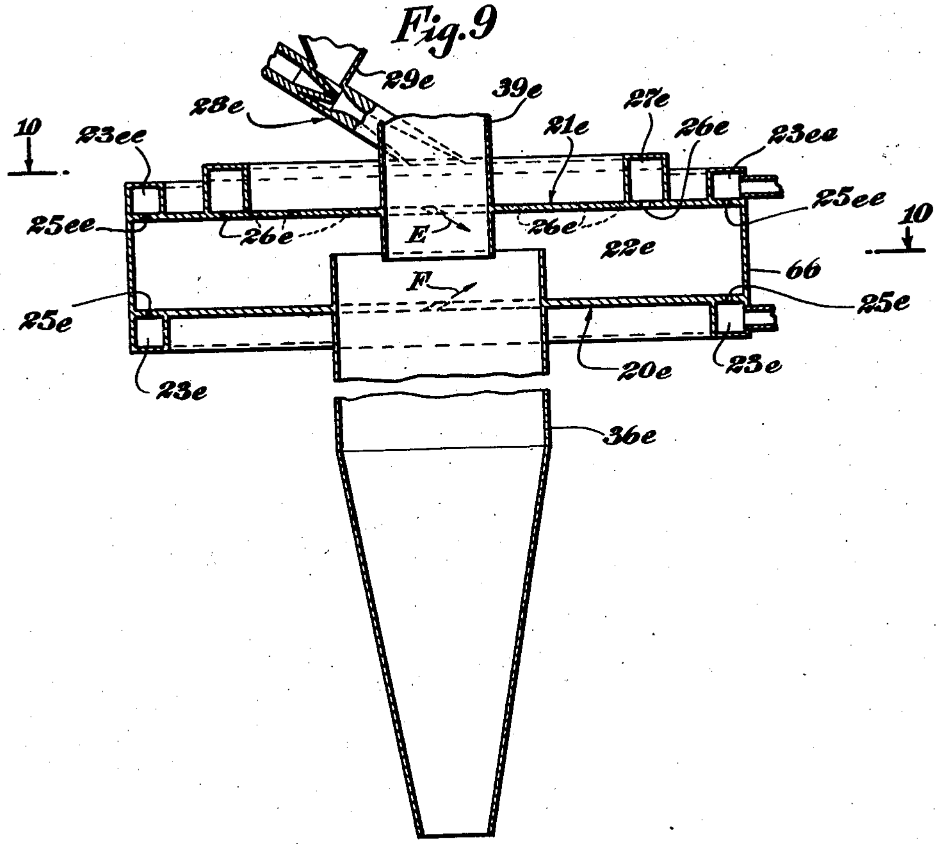

Fig.10

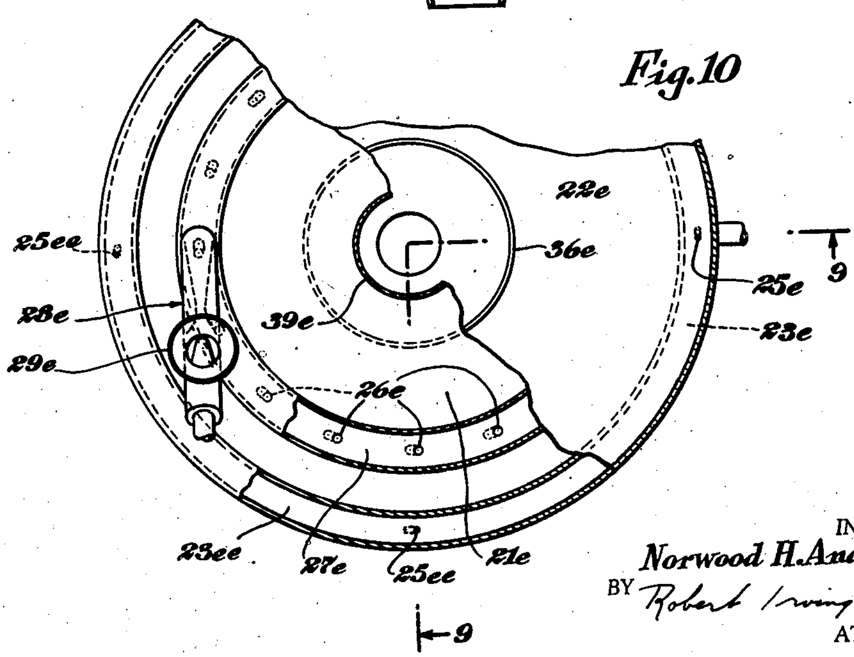

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Fig. 11

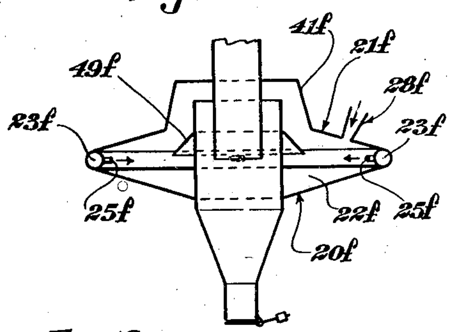


Fig. 14

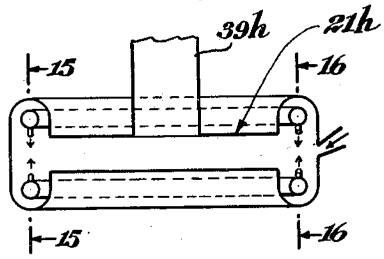


Fig. 12

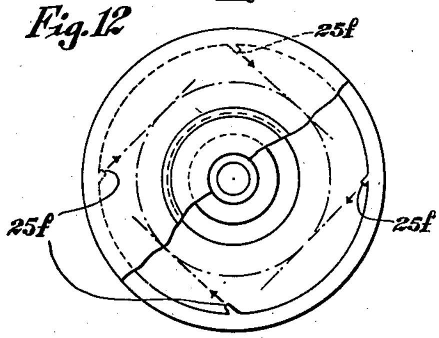


Fig. 15

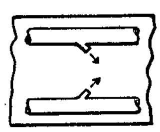


Fig. 16

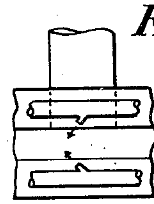


Fig. 17

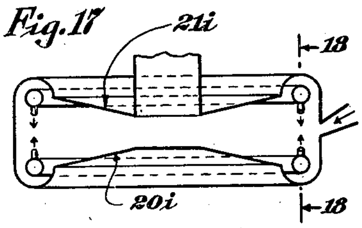


Fig. 13

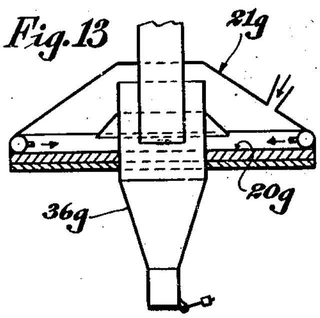


Fig. 18

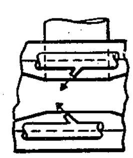


Fig. 19

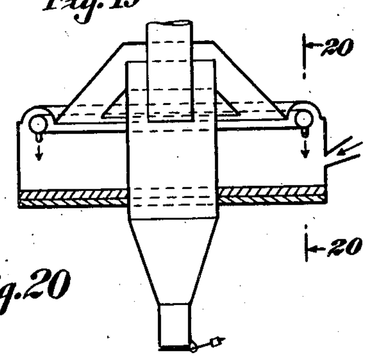


Fig. 20

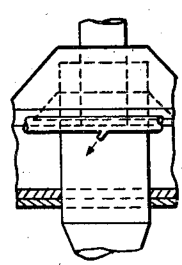
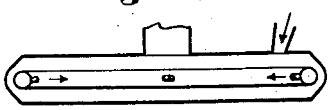


Fig. 21



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METHOD OF AND APPARATUS FOR PROVIDING MATERIAL IN FINELY DIVIDED FORM

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Fig. 22

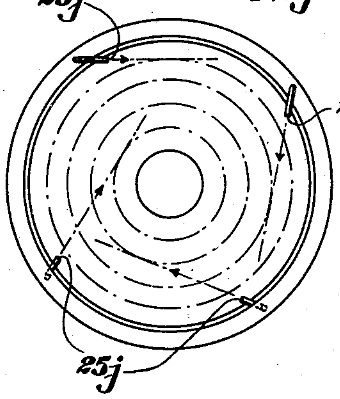

Fig. 24

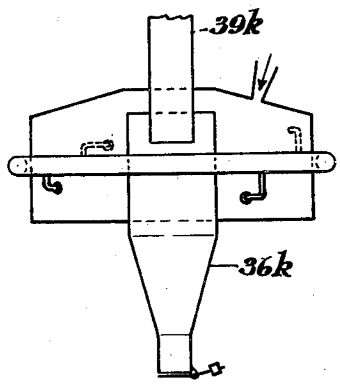

Fig. 23

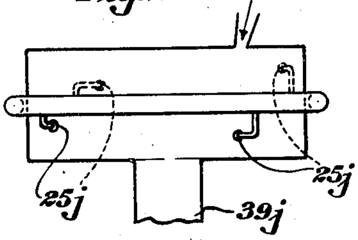

Fig. 25

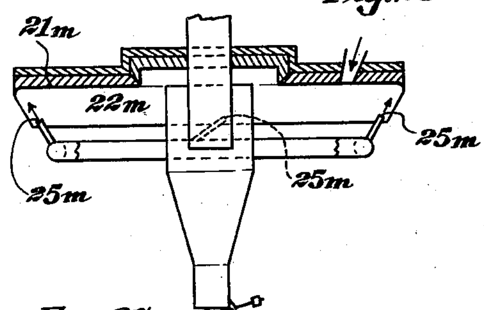

Fig. 27

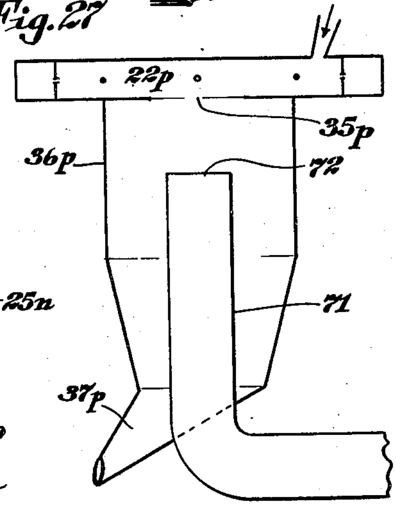

Fig. 26

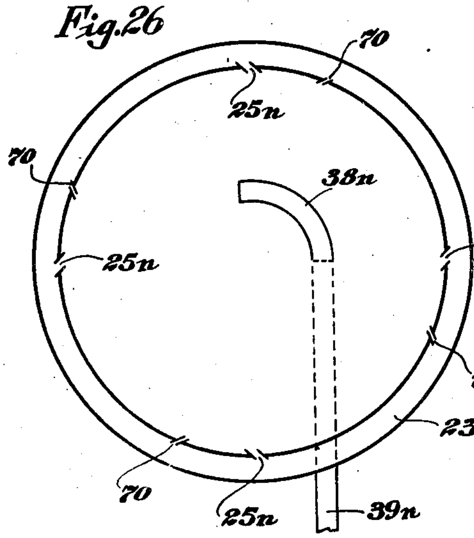

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Fig. 28

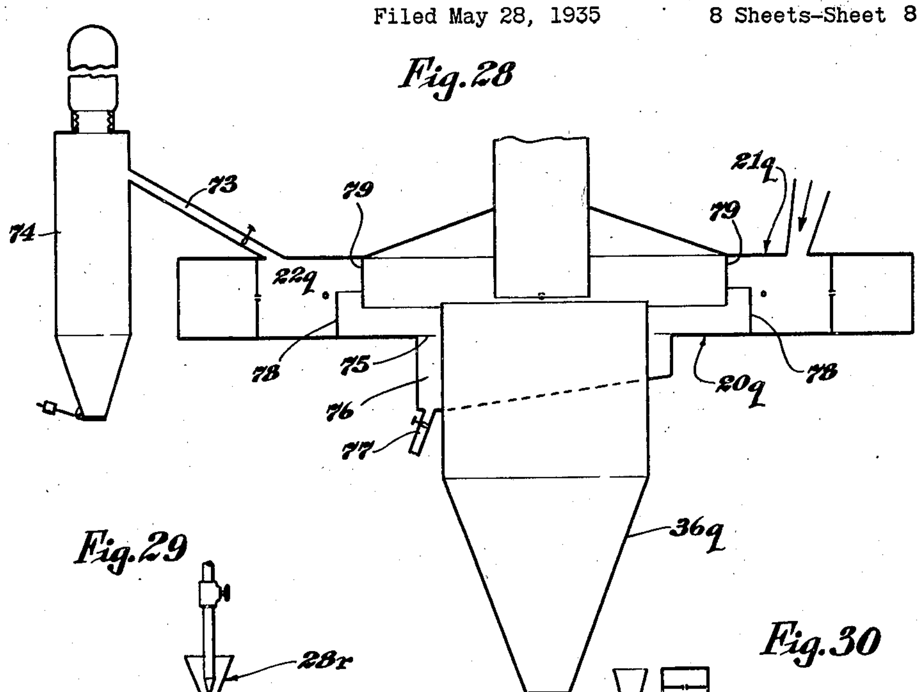


Fig. 29

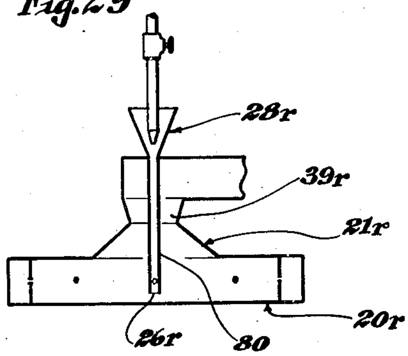


Fig. 30

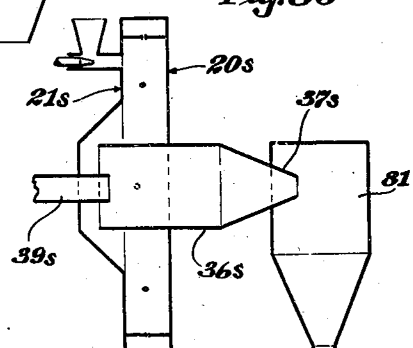


Fig. 31

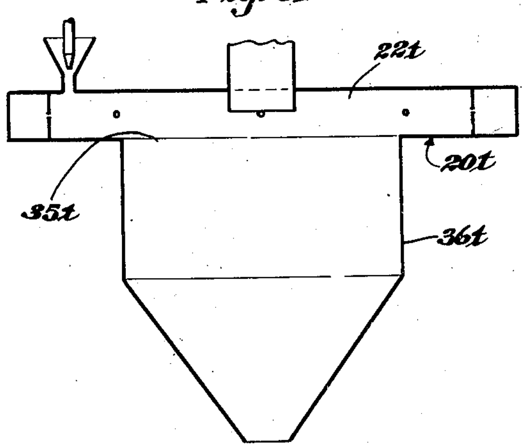
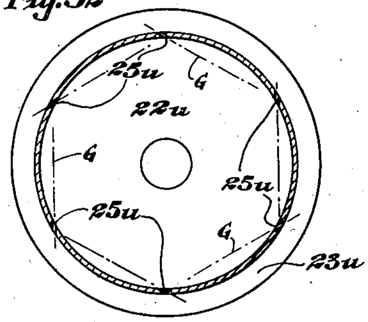


Fig. 32



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Patented Mar. 3, 1936 2,032,827

UNITED STATES PATENT OFFICE

2,032,827

METHOD OF AND APPARATUS FOR PROVIDING MATERIAL IN FINELY DIVIDED FORM

Norwood H. Andrews, Moorestown, N. J., assignor to International Pulverizing Corporation, Camden, N. J., a corporation of New Jersey

Application May 28, 1935, Serial No. 23,801
In Great Britain November 21, 1933

33 Claims. (Cl. 83—46)

This invention relates to methods and apparatus for pulverization and for the provision of material in finely divided form.

The present application is a continuation-in-part of my co-pending applications, Serial No. 692,755, filed October 9, 1933, and Serial No. 741,556, filed August 27, 1934.

An object of the invention is the provision of a method whereby a wide variety of solid materials may be readily provided in the form of a fine powder.

Another object is the provision of apparatus whereby a wide variety of solid materials may be readily provided in the form of a fine powder.

Another object is the provision of improved methods and means for breaking up particles of material.

Among the more specific objects of the invention are the provision of methods and means whereby powders having an average and/or maximum particle size which is extraordinarily small may be readily obtained in quantity.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the several steps and the relation and order of one or more of such steps with respect to each of the others, and the apparatus embodying features of construction, combinations of elements and arrangement of parts which are adapted to effect such steps, all as exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings in which:

Figure 1 is a vertical sectional view of one form of apparatus embodying the invention;

Fig. 1*a* is a reduced-scale detail view;

Fig. 2 is a plan view partly in horizontal section along the line 2—2 of Fig. 1;

Fig. 3 is a vertical sectional view of another form of apparatus;

Fig. 3*a* is a fragmentary view illustrating a modification;

Fig. 4 is a horizontal section along the line 4—4 of Fig. 3;

Fig. 5 is a vertical sectional view of another form of apparatus;

Fig. 5*a* is a diagrammatic view of a modification;

Fig. 6 is a plan view partly in horizontal section along the line 6—6 of Fig. 5;

Fig. 6*a* is a plan view on a reduced-scale, illustrating a modification;

Fig. 6*b* is a reduced-scale view similar to Fig. 6, illustrating another modification;

Fig. 7 is a vertical sectional view of another form of apparatus;

Fig. 8 is a plan view partly in horizontal section along the line 8—8 of Fig. 7;

Fig. 9 is a vertical sectional view of another form of apparatus;

Fig. 10 is a plan view partly in horizontal section along the line 10—10 of Fig. 9;

Fig. 11 is a diagrammatic vertical sectional view of another form of apparatus;

Fig. 12 is a diagrammatic plan view thereof with certain of the parts broken away;

Fig. 13 is a diagrammatic vertical sectional view of another form;

Fig. 14 is a diagrammatic vertical sectional view of another form;

Figs. 15 and 16 are diagrammatic sectional views on the lines 15—15 and 16—16 of Fig. 14;

Figs. 17 and 18 are views similar to Figs. 14 and 16, showing another form;

Fig. 19 is a view similar to Fig. 13, showing another form;

Fig. 20 is a fragmentary view similar to Fig. 13, showing another form;

Fig. 21 is a view similar to Fig. 11, showing another form;

Figs. 22 and 23 are respectively horizontal and vertical diagrammatic sectional views illustrating another form;

Fig. 24 is a view similar to Fig. 23, showing another form;

Fig. 25 is a view similar to Fig. 13, showing another form;

Fig. 26 is a horizontal sectional diagrammatic view, showing another form;

Figs. 27 through 31 are diagrammatic vertical sectional views, showing various other arrangements embodying the invention; and

Fig. 32 is a diagrammatic sectional view showing another arrangement.

A wide variety of types of pulverizing methods and apparatus have been proposed in the past. Certain of these have utilized fluid energy to effect the pulverization. Of these, the most effective have been pulverizers of the type wherein material in the form of large granules is thrown against a plate or wall and broken up by impact, and pulverizers in which particles are thrown toward each other by two or more converging streams. Impact pulverizers are, however, subject to the difficulties that the plate wears out rapidly, that often the plate material becomes undesirably entrained with the material being pulverized, and that the pulverization for the most part is undesirably coarse for many desired uses. Converging stream pulverizers are subject to distinct limitations because of the difficulty in getting the material into the streams at the points of the greatest energy content, in getting it into the streams in a uniform manner, in the wastage of energy by the slowing down of particles which reach an opposite stream without impinging upon other particles, and also in getting the material which is not reduced to the desired fineness back into the stream.

With a view to overcoming the foregoing and other difficulties, the present invention provides a procedure and means whereby a highly efficient utilization of fluid energy may be obtained, and which permits material to be obtained in powder form such that all the particles are of exceptionally small dimension,—for instance 40, 20, 10, 5, 4, and in some cases 2 microns more or less, depending upon the material treated and the results desired.

While the fineness of the powders which have been obtained in accordance with the invention varies with different materials, the invention has enabled the provision of a large number of materials in the form of powders much finer than could be produced by previous commercial apparatus and procedures, and has made possible an extraordinarily efficient production of fine powders. In accordance with the invention, moreover, many materials heretofore considered difficult or impossible of commercial production in the form of fine powders can be readily produc[illegible] in finely powdered form by means of the in[illegible]tion.

The invention contemplates the effectuation of pulverization by the use of fluid energy in a highly efficient manner which is far out of the range of previous pulverization, and/or the utilization of a pulverizing vortex in such a manner that the material may be classified in an extraordinarily thorough and effective manner. Preferably there is provided a procedure and means whereby both a highly efficient pulverization and a highly effective classification is obtained; but either such highly efficient pulverization as may be obtained in accordance with the invention or such highly effective classification as may be obtained gives results which could not, so far as is known, be obtained without the use of the invention. In accordance with the invention the gaseous fluid may be introduced into the outer portion of an inwardly spiralling vortex in a direction which will maintain the vortex and under such conditions that the energy of the fluid will be very high with respect to the amount of fluid introduced, so that the introduced fluid will have a high velocity to impart high speeds to particles coming under its influence, and so that the speed of rotation of the vortex will be very high compared with its component of inward movement; as by discharging fluid into a vortex chamber under high pressure through an opening or openings of small extent. Because of the high speed given to the particles a great breaking or tearing effect is exerted thereon as they impinge upon other particles (or upon the walls of the chamber), and because of the high rotative movement of the fluid and its relatively low inward movement there will be a large tendency to return to the outer portion of the vortex for further grinding action such undesirably large particles as are thrown or bounced into, or as otherwise reach, the inner portion of the chamber.

It has been found that the introduction of a multiplicity of small streams of gaseous fluid in a direction having a component of movement which will maintain the vortex and a component of movement which is transverse to the vortex effects a pulverization of an order far beyond that which it has hitherto been thought possible to obtain, since a large number of particles moving in a variety of different directions will be continuously impinging upon each other at a high speed with great breaking or tearing effect. The introduction of even one small, but somewhat larger, stream has this effect, but in considerably less degree. It has likewise been found that the provision of a vortex which spirals inwardly at a high rotative speed but at a low inward speed results in maintaining the larger particles in the zone of active pulverization most of the time so that they can be repeatedly acted on by the stream, while at the same time permitting the finer particles to work inwardly so that they will not cushion the pulverizing action and so that they will reach an inward point where they can be readily withdrawn. It has also been found that by continuing the inward movement of the vortex through a radially extended zone inwardly of the zone of active pulverization, a highly effective classification of product may be obtained, so that substantially all the particles entrained by the fluid which is withdrawn at an inward point will be of very small and, if desired, exceedingly small size. It has likewise been found that the axial extent of the vortex must be limited so that the fluid movement in different axial positions in the vortex will be substantially the same so that the streams may perform their work effectively so that particles may not gather at points where they will reenter the vortex in large masses.

Accordingly, the invention permits material to be pulverized in a much more efficient manner than was hitherto possible regardless of whether such a product having an exceedingly small particle size is to be provided by the use of the same vortex, is to be obtained as a separate step, or is not essential for the requirements of a particular case. Likewise the invention permits material to be classified so as to obtain a product of average or maximum particle size much lower than was heretofore possible, regardless of whether the material is efficiently pulverized in accordance with the invention, has been pulverized initially to a greater or lesser extent, or is found naturally in a fairly fine but unclassified condition.

A considerable amount of pulverization and a considerable amount of classification will always be obtained in accordance with the invention, regardless of the particular procedure, or apparatus in which the invention is embodied, but it is not essential for a number of purposes that highly efficient pulverization and highly effective classification be both obtained. Highly improved pulverization, highly improved classification, or both, may be obtained in accordance with the invention.

Further in accordance with the invention, a high order of separation of entrained particles from the withdrawn fluid may be efficiently obtained by the direct utilization of the vortical flow without change in the whirling action of fluid requiring additional expenditure of energy.

Further in accordance with the invention the maximum particle size, the average particle size, the efficiency of separation for particular purposes and other features may be effectively controlled.

In carrying out the invention there are utilized certain combinations or subcombinations of steps under various conditions whereby one or more of the highly advantageous results sought may be readily obtained.

Gaseous fluid may be introduced into the outer portion of an inwardly spiralling vortex at a high velocity in a manner which will maintain the vortex at a high rotative speed and a relatively small inward speed. It is preferable that a plurality of such streams or jets be introduced to give a better balanced vortex, and it is highly desirable for the best results that a multiplicity (3, or ordinarily more) of such streams be introduced, but in certain instances, under proper conditions, the fluid may be introduced in a single stream. Likewise, while fluid may be introduced in certain instances in a direction having no substantial transverse component of movement, it is distinctly preferable for obtaining the most satisfactory results from a pulverization standpoint that the fluid be introduced in a direction having both forward and transverse components of movement. By giving each of said streams a component of movement which is forward in the direction of rotation the vortex will be maintained, and by giving them a component of movement which is transverse to the direction of rotation a large number of particles will be caused to move inwardly at a high speed to impinge upon the particles moving in the direction of the vortex, to be carried into the body of the vortex for impingement upon particles moved inwardly by other streams, to be driven into collision with particles moving in the direction of another stream, if the lines of the streams intersect to a greater or lesser extent, or to be driven toward the centre of a succeeding stream so as to be given a higher velocity than could obtain near the periphery of a stream where they would be more likely picked up for an initial inward movement. It is to be understood that in specifying that each of said multiplicity of streams has both forward and transverse components, the provision of supplemental streams not having both of these components, but having only a minor effect on the action is not excluded.

Air, steam or other suitable gaseous fluid, which may be at any desired temperature, may be utilized.

Ordinarily a vortex is originally formed by the same streams which maintain the vortex, but for facility of expression the procedure may be considered to involve the steps of forming an inwardly spiralling vortex and introducing a stream or streams into the vortex.

In order to obtain the highly effective action which the present invention makes possible, it is of importance that the vortex be axially confined to an extent such that the vortex will have a high rotative speed and a relatively small inward speed so that the centrifugal action will be large in comparison to the entraining force, and at the same time such that there will be no substantial escape of particles from the active influence of the high velocity streams, of the high speed vortex, and of eddies created thereby, to positions from which they will re-enter the vortex in large masses; and the terms "axially confined" and "narrow" as used herein in reference to the zone or zones in which pulverization and classification occur are to be understood as referring to zones having such an axial extent. In this manner, particles carried by the vortex will be almost continuously acted upon in a substantially uniform manner, and the vortex speeds will not vary substantially from time to time. It is, however, to be understood that escape and controlled re-introduction of the particles in a manner which does not result in material variations of the fluid load does not substantially affect the action and is to be considered as a mere equivalent of a substantially complete confining of the vortex at a zone or zones where such confining is desired.

As will be more fully brought out hereinafter, a fluid stream, in order to have a component transverse to the vortex need not have an inward component but may have an axial component either alone or with an inward or outward component and achieve much the same result, provided the stream also has the necessary forward component. Whether the transverse components of the streams referred to hereinafter are radially inward, axial, or outward, or combinations of these, they will be spoken of herein as being introduced into an inwardly spiralling vortex, since regardless of what the relative disposition of the stream and the vortex proper may be if considered technically, the result of cutting into a vortex which carries particles of material and spirals inwardly is secured. As above pointed out, the stream or streams should be introduced into the outer portion of the vortex, since the centrifugal action will tend to keep a large number of particles in this outer portion, which particles will be kept in activity by the streams and by the vortex, so that a very large number of collisions or fracturing or tearing contacts will continually occur.

While material pulverized in accordance with the invention may be classified in any desired manner, it is distinctly preferable to classify the material in an axially confined zone of the vortex disposed substantially radially inwardly of the zone of active pulverization. In this manner, the high speed whirling of the vortex is maintained, and substantially all particles above exceedingly small sizes may be carried outwardly by the centrifugal action of the inwardly spiralling vortex. Not only will particles which are fairly fine, but nevertheless larger than desired, be thrown outwardly by the vortex as its angular movement increases as it spirals inwardly, but large particles which are thrown inwardly by the streams to a point beyond the zone of active pulverization will be returned to the latter zone to be further acted upon. The greater the radial extent of the classification zone, the finer will be the product obtained, other conditions being equal or compensated for. It is not essential that the classification of material be effected exactly radially inwardly of the zone of active pulverization and indeed it is preferable in many instances that it have a different axial extent than the pulverization zone, but it is of distinct importance that the classification zone be disposed substantially radially inwardly of the pulverization zone, so that the high speed whirling action will be maintained in this zone, and so that it will include no axially-extended portion in which particles may gather without being returned more or less individually to the pulverization zone, and from which particles would be returned by gravity, vortex action, or otherwise to the active zone in batches or large masses with the result that the material would overload the vortex. Within limits, however, effective control can be exercised by varying the axial extent of the classification zone, preferably in a manner which does not involve sharp changes in extent from an outer to an inner point. By increasing the axial extent of the classification zone the vortex is caused to extend axially, so that its inward component of movement and consequently its entraining effect is diminished while its rotative component of movement remains substantially the same, so that it will have the same centrifugal action. In other words, when the pitch of the spiral is small, a particle will be pulled inwardly to a lesser extent than if the pitch is large, whereas its tendency to move toward the periphery under centrifugal action will be undiminished. The provision of this control feature accordingly permits the provision of a finer product. In instances, however, where a uniformly coarse product is desired, it is desirable that the classification zone be additionally confined axially to a more or less small extent, as for instance to a smaller extent than the axial extent of the pulverization zone. In this case the entraining effect will be greater so that fairly coarse particles may be withdrawn without being returned to the pulverization zone.

As above indicated, while the classification step is preferably practiced in conjunction with a pulverization procedure such as above described, it may be utilized in conjunction with modified pulverization procedures and in other ways in certain instances to give highly satisfactory results.

Fluid and entrained particles may be withdrawn from a radially inward portion of the vortex. This may be either from a portion in proximity to the pulverization zone in instances where classification is not of importance, or preferably, from a portion disposed inwardly of the classification zone. Entrained particles may be separated from the withdrawn fluid in an exceedingly efficient manner by utilizing the vortical energy to centrifugally separate the material from the fluid in a zone disposed substantially axially of the vortex. Freed fluid may be withdrawn from an inner point in the separation zone in any of a wide variety of ways, as by withdrawing it through and beyond an inner portion of the vortex. Furthermore, when desired, the particle size may be controlled by controlling the amount of material fed to the vortex—a decrease in the amount of material fed in acting to decrease the circulating load and resulting in a finer product.

Material may be supplied to the vortex at any of a wide number of variously disposed positions, since the centrifugal action in the vortex will cause the coarser particles of freshly supplied material to work outwardly into the active influence of the high velocity streams even though they are supplied at a relatively inward point. It is of importance in order to produce a fine product, however, that the supplying of material be carried out so that the entraining force of the withdrawn fluid will not act to entrain the coarse particles introduced. Material may be supplied at the periphery, or at any inward position which is sufficiently spaced from the withdrawal opening or openings so that the entraining force at this position will not be sufficient to entrain the coarse particles, so that they will be moved outwardly by centrifugal action. When material is supplied at a point outwardly of the axis, it may in most instances be supplied at a single point, but since such a procedure results in a more or less slight unbalancing of the vortex, it is preferable in many instances to supply the material to a plurality of sectors in a substantially uniform manner. It is to be observed that when material is supplied at or near the axis, as for example, in a manner hereinafter exemplified, material will be supplied to all the sectors of the vortex even though it is introduced at a single point. Material may be supplied substantially continuously during continued operation but a certain amount of pulsation in the feed will ordinarily not be harmful so long as the supply at any time is not sufficiently great, and so long as the intervals between the intermittent supply of material are not sufficiently large, so that substantial variations in the circulating load will occur.

The velocity of the introduced streams may vary considerably but should be of a high order. Such velocities are ordinarily obtained by applying high fluid pressure to a nozzle to release a gaseous fluid such, for instance, as steam or air, through the jet opening of the nozzle.

It is to be noted that the particles in the body of the vortex are ordinarily widely spaced from each other, with the result that each particle will be given a high speed by the fluid in proximity to it. It will be appreciated that a few particles may sometimes move together but that these will act substantially as individual particles under the circumstances being considered. The spacing of the particles will be less toward the periphery of a chamber in which the vortex is formed, and may be so closely spaced at the periphery that their movement will be markedly slowed down. However, these particles appear to be again picked up by the jets and/or by the turbulent condition in the outer portion of the chamber and returned substantially as individual particles to the body of the vortex. In this connection, it is to be noted that it is of importance that the jets be so introduced that their high velocity portions will directly act upon material concentrating in proximity to the periphery of the chamber, so that the vortex will not be slowed down by the weight of material which is not actively affected by the streams.

A further understanding of the operation may be had from the following data concerning a desirable type of operating conditions and of pressure measurements taken in an unloaded vortex. In utilizing a cylindrical pulverizing chamber 12 inches in diameter and 2 inches high and by introducing a jet of steam under pressure of 90 pounds per square inch at a temperature of 450° F. through a single nozzle $\frac{1}{4}$ of an inch in diameter, (giving an initial critical velocity of approximately 1600 feet per second) the static pressure of the steam dropped to slightly above atmospheric pressure so that the pressure in the chamber varied from a pressure of about 4½ pounds at a point 5¾ inches from the axis of said chamber to a pressure of less than two pounds at a point 2¼ inches from said axis; that the linear velocity of the steam at said outer point was 843 feet per second as compared with 720 feet per second at said inner point; that the angular velocity of the steam at said outer point was 280 R. P. S. as compared with 610 R. P. S. at said inner point; and that the centrifugal force developed at said outer point was 46,000 times the static weight as compared with 86,000 at said inner point.

Procedures such as contemplated by the invention are further exemplified in connection with the exemplification of apparatus embodying the invention.

One form of apparatus as contemplated by the invention and one manner of carrying out the procedure as contemplated by the invention, when materials are to be both pulverized and classified, and also separated from the fluid, are illustrated in Figs. 1 and 2. While ordinarily the operation is carried out with the parts positioned as shown, it is to be understood that apparatus embodying the invention, and vortices formed in accordance with the invention, may be arranged to operate at any desired angle to the vertical, and with the collector unit, if used, on any desired side of the chamber. In the exemplified apparatus, there is provided a lower plate 20 and an upper plate 21 providing therebetween a pulverizing and classifying chamber 22, the periphery of which is closed by an annular header 23. Fluid under pressure is introduced into the header through a pipe 24, which may extend to any suitable source of fluid pressure, such, for instance, as a steam boiler or air compressor. The inner wall of the header is formed with a multiplicity of small jet openings 25, (16 in the present instance) which are formed at angularly spaced points, as will be seen from Fig. 2, to release gaseous fluid at a high velocity in a direction as indicated by the lines A in Fig. 2, having a component which is forward in a direction of rotation within the chamber 22 and a component which is transverse to that direction (inward as exemplified) and will cut across the lines of vortical movement in the outer portion of the chamber. As will be apparent, this arrangement serves to provide discharge means comprising orifice means and gaseous-fluid conducting means directly behind said orifice means and having an effective area greater than the cross sectional area of the orifice means. The pipe 24 may be provided with a valve 24' so that the pressure in the header 23 may be regulated. In order to provide material for the streams and the vortex maintained thereby to work upon, there is provided feeding means which, in the present instance, comprise a multiplicity of supply openings 26 (8 in the present instance) in the plate 21. As exemplified eight such openings are provided at evenly spaced points and are formed to admit material in a direction which is forward in the direction of rotation maintained by the jets of gaseous fluid from the jet openings 25, as will be seen from Fig. 2. To simplify the feeding of material through the openings 26, these openings are surrounded by a feeding head 27 into which material to be pulverized is fed under relatively slight fluid pressure by an injector-type feeder construction 28. This comprises a hopper 29, which may be fed by a feed-control means 29', and by which coarse material to be pulverized is introduced into a conduit 30 in which there is disposed a nozzle 31 by which fluid under pressure is released just beyond the opening from the hopper. This fluid carries the particles of material through a Venturi passageway 32 and into the feed head 27. The introduced material spreads around the feed head and enters the various openings 26 in a substantially uniform manner being forced into the header under the pressure established therein by the fluid from the nozzle 31. It is desirable that the amount of fluid entering through the nozzle 31 be restricted to that necessary to carry the desired quantity of material into the feed head 27 and into the chamber 22, and also that the opening 26 be relatively large in comparison with the amount of the fluid supplied through the feeding means 28, so that there will be no undue pressure drop between the feed head 27 and the chamber 22. The openings should, however, be sufficiently small so that the materials will be fed to the various sectors of the chamber 22 through the various openings with substantial uniformity. At an inward position there is provided an opening 35 by which the chamber 22 communicates with a collector member 36, and through which fluid and entrained particles may be withdrawn. The lower end of the separating chamber is constricted to a removal opening 37 for the pulverized material. Opposite the opening 35 and co-axial therewith is a smaller circumference opening 38 at the end of a conduit 39 through which freed fluid may be withdrawn. By the provision of an opening 38 opposite the opening 35 and a conduit 39 leading in a direction opposite to the direction of movement of the fluid into the collector, the freed fluid may be withdrawn exceedingly efficiently and without disturbing the vortical movement in the collector. If desired, replaceable liner members of wear-resistant material may be provided at the walls of the chamber 22. The top plate 21 has a slight upward bend at 40 and a still greater upward bend at 41.

While considerable variations in the dimensions of the device are permissible, and while many of the dimensions may be widely varied, nevertheless too great a variation in certain of the dimensions will result in undesirable and sometimes disastrous results, as will be hereinafter indicated. Accordingly there are indicated below the dimensions of various of the parts of a particular device such as shown in Fig. 1 which has given highly satisfactory results when utilized with various readily available types of pressure-supplying means. In this instance, the diameter of the vortex chamber was 36''; its axial extent at the periphery, 2½''; its axial extent under the feed head, 3''; the difference in height in the top plate at the outer and inner edges of the portion 41, 3''; and the extent of the opening 35, 12''; and of the opening 38, 7''. The jet openings were $\frac{3}{16}$ths of an inch in diameter, the supply openings were ½'' in diameter, the nozzle 31 was $\frac{3}{16}$ths of an inch in diameter, and the Venturi opening at its smallest ¾ of an inch in diameter. It is to be noted that the openings need not be round, but may be of any desired shape.

The operation of the device as deduced from theoretical considerations, from the wear on devices which have been in operation for various lengths of time, from the resulting product, from inspection of the particles deposited on the floor of the device when the operation is stopped, from scratches in a film of material adhering to the surface of the metal in some cases, and from mathematical computations, is indicated below.

The high fluid pressure applied to the header 23 results in the ejection of streams or jets of gaseous fluid at a very high velocity through the openings 25 and in the direction indicated by the lines A. These streams set up and maintain an inwardly spiralling vortex in the chamber 22 and at the same time cut across and through the outer portion of the vortex, so that particles of material engaged by the streams will be hurled inwardly and into pulverizing impingement with other particles moving in other directions including the direction of the vortex. At the same time the centrifugal action, which is many hundreds times gravity, of the vortex tends to drive outwardly the particles entering the vortex through the feed openings, as well as particles which have been carried inwardly by the streams and have not been broken up sufficiently. The result is that there will always be a considerable number of particles moving about the outside of the chamber 22 and along its peripheral wall to be carried inwardly by the jets. Some of these particles will be picked up near the periphery of the streams and moved forwardly and inwardly at varying rates of speed. Others will probably enter the body of the stream and will be hurled violently inwardly. The particles will be repeatedly acted upon until reduced to the desired size. All the speeds in question, as will hereinafter be more fully apparent, will be high and the vortex itself will impart a high speed to the particles moving with it, so that particles moving in the direction of the streams and moving in the direction of the vortex will impinge upon one another at speeds which will fracture or tear the pieces in a highly effective manner. The velocity of a considerable number of particles will be increased by the streams and given a direction partaking somewhat of the direction of the stream (without necessarily exactly following the lines A), and certain of these particles which tend to move toward a succeeding stream will, because of their increased velocity, enter the central portion of the succeeding stream and will have their velocity further increased. It is to be noted that the lines A cross each other, so that particles moving in the direction of one stream will impinge upon particles moving in the direction of a succeeding stream, with the result that a still further increase in pulverizing action is obtained. Certain of the particles will approach an opposite wall and impinge upon particles near the wall. Some will impinge upon the wall itself and be broken up there, but this, as indicated by the wear on the wall, occurs in a relatively small number of instances. Since the vortex is axially confined, there is no tendency for particles to concentrate in positions where they will re-enter the body of the vortex as a batch of such character that it will harmfully unbalance the vortex. This appears to be due to the eddy action in proximity to the streams entering the vortex, and from the high speed action of the axially confined vortex itself which keeps all the particles in substantially continuous movement. It is to be noted that what constitutes "proximity" will be relative, and will encompass a greater extent for larger size vortices into which larger size streams are introduced, and will also depend on other factors, including the positioning of the streams and their effect on the vortex. The main pulverizing effect is in the outer portion of the chamber where particles are being thrown continuously against one another at high speeds with great pulverizing effect. At a portion of the chamber disposed substantially radially inwardly of this outer zone of turbulence, the direct effect of the streams diminishes, and there is provided a zone wherein the vortex spirals inwardly without the turbulence present in the outer pulverization zone. In this inner zone of the vortex, the material is classified by the centrifugal action of the vortex and all particles greater than a desired size (which may be exceedingly small) are returned to the outer zone by the centrifugal action. The classification of material in a zone disposed radially inwardly of the pulverization zone results in only the smallest particles being carried over with the fluid through the opening 35, and the utilization of the same vortex to pulverize and classify, results in highly efficient and effective action. Since the classification zone is axially confined, an exceedingly effective classification is secured, since the high speed rotation of the vortex continues as the vortex spirals inwardly toward the outlet opening, and also there is no possibility for batches of the material to build up and fall or otherwise work back so as to intermittently overload the vortex and interfere with the classifying action. It has been found, however, that it is of advantage, in many instances, to provide a chamber wherein the axial extent is somewhat greater toward the inward part thereof than at the periphery so as to decrease the inward component of the vortex and thus reduce the entrainment effect of the fluid when compared to the centrifugal force, so that when desired a finer product may be secured, other conditions being equal. To this end, in the present instance, the axial extent of the chamber is increased somewhat by the upward bend 40 and still more by the upward bend 41. It is to be noted that there will be considerable eddy action along the walls even in the classification zone, so that material tending to work toward or along the wall 41 will be caught up by these eddies or by the vortical movement sufficiently so that they will be subjected to the strong centrifugal action and carried outwardly again if they are larger than desired. Desirably there is obtained additional insurance against particles working inwardly along the walls by providing the openings, such as 35 and 38, at a point somewhat inward of the walls so that the members 36 and 39 will form ducts, the walls of which act as barriers to the inward movement of particles along the walls. However, as will be hereinafter indicated, the provision of such ducts is not essential and they may be dispensed with in a number of cases.

The fluid, as it spirals inwardly, finally reaches the opening 35, by which time all except particles of the desired size will have been eliminated. The fluid, with its entrained fine particles, spirals into the collector chamber 36, retaining its vortical motion so that the energy of the vortex formed and maintained by the streams will be utilized to free the fluid from the fine particles which it has carried into the collector chamber. Because the zone in which the fluid now moves is axially extended, the inward component of the vortex is much less than it was in the vortex proper, so that a very high percentage of the entrained particles is readily separated from the fluid by centrifugal action. This is true even for very fine particles which have been withdrawn after a classifying action in accordance with the invention, since the increased whirling action which will be effective to provide a more intense classification will at the same time provide a greater whirling action in the separating zone, which will separate almost all of the very fine particles withdrawn with the fluid. Furthermore, the fluid moves into the collector without change of its rotative direction, so that there is no substantial dissipation of energy such as would be the case if the whirling fluid were deflected thru a conduit and thence into a collector, where the vortex would have to be re-established.

The fluid, substantially free of the entrained particles, works axially upward past a point interior of the vortex and thence out thru the conduit 39 to a suitable point of discharge. The separated particles work along the walls of the collector chamber to the opening 37, which may be covered with a bag or other suitable receptacle to receive them.

It is to be noted that in the present instance the classification zone is extended a considerable radial distance, so that a highly effective classifying action may be secured even with materials which are difficult to classify either from the standpoint of eliminating particles somewhat coarser than desired, or of eliminating especially coarse particles which may be thrown inwardly by the jets with especial force. It is to be noted also that the chamber does not materially increase in axial extent for a considerable distance inwardly from the periphery.

Particles of material to be acted on are fed to the vortex thru the openings 26 in a forward direction. When the fluid used is steam, it is undesirable to begin supplying material until sufficient time has elapsed so that the entire apparatus is hot and dry.

In Figs. 3 and 4 there is illustrated in a general manner a varied purpose construction exemplifying another method of carrying out the invention and illustrating a number of possible variations. In this exemplification there is provided a lower wall 20*a* and an upper wall 21*a* providing therebetween a chamber 22*a*. As will be observed, the lower wall 20*a* is adjustable, and the entire construction is enclosed in a casing 42 of which the wall 21*a* forms a part. At the periphery of the chamber 22*a* there is provided an annular wall 43 having a series of openings 44 disposed at angularly spaced points therein. These openings, as exemplified, are shaped to admit streams of fluid in a direction similar to the direction of the streams from the openings 25 in Fig. 1, and back of the openings 44 there are provided nozzles 45 having jet openings 25*a* arranged to eject small streams of fluid through the openings 44 in a direction generally similar to the streams from the openings 25 and having a component which is forward in a direction of rotation within the chamber 22*a* and a component which is transverse to this direction (in this case, inward). These nozzles are connected by high pressure connections to a header 46, to which fluid under pressure may be delivered through a valve controlled pipe 47. As will be apparent, the nozzles 45 terminating in the jet openings 25*a* serve to provide discharge means comprising orifice means and gaseous-fluid conducting means directly behind the orifice means and having an effective area greater than the cross sectional area of the orifice means. Material is supplied to the chamber 22*a* through a single opening 26*a* from a feeding means 28*a* comprising a chute or hopper 29*a* by means of a jet of fluid from an injector nozzle 31*a*. At an inward position there is provided an opening 35*a* leading into a collector member 36*a*, the lower end of which is constricted as at 37*a* and is closed by a counterweight flap-valve 48. An opening 38*a* similar to the opening 38 is provided at the end of conduit 39*a* through which fluid may be withdrawn. The opening 38*a* is of smaller circumference than the opening 35*a* and these openings are in effect oppositely disposed, though the collector member 36*a* extends beyond the end of the conduit 39*a* in the present instance. This latter feature is of assistance in certain cases in assuring that the whirling fluid will have a downward component as it enters the collector.

In the present instance, there is provided a flanged ring 49 to afford additional assurance against larger particles at the lower inside portion of the chamber 22 being deflected upwardly toward the top wall 21*a* where under certain conditions they might be carried over into the collector member through the opening 35*a*.

As above indicated, the lower wall 20*a* is vertically adjustable as by screw and nut construction indicated generally at 50 so as to permit the axial height of the chamber 22*a* to be varied to adapt a device for the more satisfactory treatment of various materials under various conditions. For example, when a material of a lower specific gravity is being treated, it is generally desirable that the axial height of the chamber be greater so as to permit a greater volume of this light, readily entrained material to be acted on by the vortex. Similarly, a greater axial extent is generally desirable when the material is soft and easily acted on effectively by the vortex. In this connection, it is to be noted that in the treatment of an especially light, readily frangible material in a vortex having a vertical axis, it is desirable to introduce the fluid nearer the bottom of the chamber than the top in order to maintain all of the material in active circulation and prevent a layer settling on the bottom wall. For this purpose and also to provide a construction which is adapted for operation under a wide variety of conditions, there are provided in the wall 43, if desired, in a plane below the plane of the opening 44 a series of similar angularly spaced openings 44*x* adapted for the reception of nozzles such as the nozzles 45. If desired also, the header 46 and nozzles 45 may be adjustable, as by a screw and nut construction indicated generally at 51 so that the same nozzles 45 may be shifted so as to be disposed opposite the lower openings instead of opposite the upper openings if desired.

It is to be noted that an annular chamber 52 is formed between the wall 43 and the casing 42, and that, in the present instance, the wall 43 does not extend all the way to the upper wall 21, but leaves a communicating space 53 between the chamber 22*a* and the chamber 52. Some of the particles in the top of the chamber 22*a* will accordingly be carried over into the chamber 52 by the centrifugal action of the vortex in the chamber 22*a*. These particles will fill the chamber 52 until they reach the level of the nozzles and will, when the nozzles are disposed opposite the openings 44, tend to fill the chamber up to a line 54. Accordingly, during continued operation, the nozzles will act as refeeders and will carry material from the chamber 52 back through the openings 44 into the chamber 22*a*, thus feeding material to the various sectors of the vortex as well as to the sector in which the opening 26*a* is formed. It is to be noted that this action does not, under proper conditions, interfere with the action of the vortex or with the substantial maintenance of all loose particles continuously in motion by the whirling fluid, as above indicated, since the vortex cannot pick up masses of particles from the chamber 52. As above indicated, it is important in certain instances that the feed to the various portions of the vortex be relatively or substantially uniform, and the exemplified construction assists in obtaining this result. If greater uniformity is desired, it may be obtained without substantial modification of the construction shown. The supply opening may be located to discharge all of the fresh material to be pulverized directly into the chamber **52** instead of directly into the chamber **22*a***, as indicated in Fig. 3*a*, which shows a construction exactly similar to that shown in Fig. 3, except that the feeding means is located as indicated at **28*b*** to empty thru an opening **26*b*** into the chamber **52**.

In order to prolong the life of the apparatus, the wall **43** is formed of hard, wear-resistant material, and the lower and upper walls **20*a*** and **21*a*** may be provided with replaceable liner portions **55** of hard wear-resistant material. As will be observed, the wall member **43** is likewise removable and replaceable.

In carrying out the invention by the use of an apparatus such as shown in Figs. 3 and 4, the action is in general similar to the action in the device shown in Figs. 1 and 2. The streams of gaseous fluid from the openings **25*a*** move in general as indicated by the diverging lines from the jet openings, the amount of spread depending upon the amount of the material in the chamber and other factors, it being appreciated that no exact knowledge of the precise fluid movement in the chamber under operating conditions can be obtained. Under the influence of the streams and of the movement of the vortex set up thereby, an individual particle may move in a circular undulatory path, suggested by the line B, until it is broken up by impingement against another particle, tho probably many of the particles will take a much more varying course and, due to centrifugal action, will tend to work out as suggested by the lines C to positions near the periphery of the chamber whence they may be thrown inwardly again by the jets. The entire mass of particles and fluid in the chamber will whirl rapidly, the particles being for the most part in a continuous rapid movement in and about the chamber with the result that particles moving rapidly in various directions will be continually impinging upon each other and being broken or torn into small pieces. It is to be noted that the directions of adjacent streams intersect in this instance also. The coarser particles are repeatedly acted on by the streams until they are broken up. As was the case in Figs. 1 and 2, the inner portion of the vortex serves to classify the material and to eliminate the coarser particles; the fluid and the entrained fine particles passing into the collector member **36*a*** through the opening **35*a***. The vortical movement is utilized efficiently within the collector or separator member **36*a*** to free the fluid from the entrained particles in the manner previously indicated, and the freed fluid is carried off through the conduit **39*a***. Material is supplied to the chamber either through a feeding means such as indicated in **28*a*** in Fig. 3, or as indicated in **28*b*** of Fig. 3*a*. By the provision of the injector **31*a***, material is fed in against such pressure as may exist in the chamber to which material is supplied.

In Figs. 5 and 6 there is shown a simple form of construction which is satisfactory for use in accordance with and for carrying out the invention in many instances. This construction comprises a lower wall **20*c*** and an upper wall **21*c*** between which there is povided a vortex chamber **22*c***, the periphery of which is provided by a header **23*c*** to which fluid under pressure is introduced by a pipe **24*c***. In the inner wall of the header there are provided at angularly spaced points a multiplicity of small jet openings **25*c*** through which gaseous fluid is discharged into the chamber at a high velocity in directions having a component of movement which is forward in a direction of rotation and a component of movement which is transverse to this direction, as indicated by the lines D in Fig. 6. Material is fed to the chamber **22*c*** through an opening **26*c*** by a feeding means **28*c*** comprising a nozzle **31*c***, which acts to drive material from a chute or hopper **29*c*** thru a Venturi opening **32*c*** and thru the supply opening **26*c***. The upper wall **21*c*** slants upwardly as indicated at **41*c*** to provide an increasing axial extent at the classification zone. The oblique disposition of a wall portion, such as at **41*c***, facilitates the return to the pulverization zone of larger particles working against this wall. The fluid and entrained particles are withdrawn through an opening **35*c*** into a collection member **36*c*** equipped at its reduced lower end **37*c*** with an extension **57**, to which a bag or other suitable receptacle, indicated at **58**, may readily be fastened. Freed fluid is withdrawn through an opening **38*c*** into a conduit **39*c*** and carried off thereby to a suitable point.

It will be apparent that, if desired, a plurality of feeding means may be provided, and in Fig. 6*a* there are shown two such feeding means indicated at **28*c*** and **28*cc***, which act to feed material through supply openings **26*c*** and **26*cc***, respectively, to opposite sectors of the chamber.

One form of mill proportioned as in Figs. 5 and 6 which has given satisfactory results is one where the diameter of the chamber **22*c*** is 12″, the axial height at the periphery being 2″, the diameter of the outlet opening **35*c*** being 5″, and the diameter of the outlet opening **38*c*** being 2½″. In this apparatus 8 nozzles having jet openings ⅛″ in diameter were utilized. The opening of the injector **31*c*** was ⅛″ in diameter and the opening of the venturi **32*c*** was ⅜″.

As above indicated, the proportions of a vortex chamber or the dimensions of a vortex provided in accordance with the invention may be varied considerably so long as the various conditions for effective operation as indicated herein are complied with. For instance, a construction such as shown in Figs. 5 and 6 gave excellent results in obtaining finely powdered limestone at various rates of feed giving quantity production, when the peripheral height was 2″, as indicated; and, also, when the upper part of this construction was raised 2 inches and the peripheral wall extended upwardly so as to be 4″ in height, results satisfactory for a number of purposes were obtained at the same rates of feed, although the product was markedly coarser in each instance. When, however, under the same conditions of operation on the particular material used above, the height was similarly extended another 2 inches, the classification was unsatisfactory, and the product contained a considerable percentage of unpulverized particles at corresponding rates of feed.

In this connection it is to be noted that in embodiments of the invention wherein the axial extent of the pulverization zone is relatively large a better action may be obtained by injecting the streams at a plurality of axially spaced points so that the streams and the vortex will more positively act on the particles throughout a larger axial extent of the vortex. An arrangement of this nature is shown diagrammatically in Fig. 5*a* wherein there is exemplified an arrangement which is similar to that shown in Figs. 5 and 6 with the axial extent at the periphery doubled as indicated above, except that two rows of jet openings **25*y*** and **25*z*** are provided. As exemplified, eight openings are provided in each row to provide conditions nearer to those existing in the arrangement shown in Figs. 5 and 6.

As above indicated, while a plurality of evenly spaced streams are preferably utilized to give a balanced action, it is not essential to the carrying out of the invention in certain instances that more than one stream be utilized to maintain the vortex and to throw particles into impingement with particles carried by the vortex. There is exemplified diagrammatically in Fig. 6b an embodiment of the invention wherein the construction is similar to that shown in Figs. 5 and 6, except that a single jet opening **25c'** is provided to discharge high velocity gaseous fluid into the vortex chamber **22c'** instead of a multiplicity of jet openings **25c**. The particles are hurled into the chamber by the stream passing through the opening **25c'** and impinge upon such particles as are carried in the vortex. While the number of particles carried in the body of the vortex at the time the stream enters the vortex will be less than would be the case in a vortex formed in the chamber **22c**, they will nevertheless be sufficient so that a good pulverizing action is obtained. It is desirable that the jet opening be made of such size that an effective rotative speed will be maintained. The area of the opening **25c'** may be commensurate with the combined area of the openings **25c**. The use, in the grinding of limestone, of a construction such as exemplified wherein the opening **25c'** was $\frac{11}{32}$ inch in diameter and wherein the other dimensions were those indicated in connection with Figs. 5 and 6, gave a product wherein the size of the particles was larger than the size of the particles obtained by the use of a construction such as shown in Figs. 5 and 6, but a satisfactory product for many uses was nevertheless obtained.

Another embodiment of the invention is exemplified in and by Figs. 7 and 8. In these figures there are provided side walls **20d** and **21d**, providing therebetween a vortex chamber **22d** about the periphery of which there extends a header **23d**, to which fluid under pressure is introduced through a supply inlet **24d**. A liner **60** of hard wear-resistant material forms a surface for the wall **20d** and carries an upwardly extending flange **61** providing a wear-resistant peripheral surface. The wall **21d** is composed of a plate of hard wear-resistant material, which can be removed and replaced as desired. A multiplicity of openings **62** are drilled in the header and in the flange **61** at angularly spaced points and in a direction generally similar to the direction of the openings **44** and in these openings there are secured nozzles **63** having jet openings **25d** directed generally similarly to the openings **25**. In the present instance, material is fed to the chamber **22d** through a peripheral feeding means **64**. This feeding means comprises a hopper **29d** from which material is fed by an injector nozzle **31d** through a Venturi construction **32d** and into the chamber through a single opening **26d** This type of feeding means utilizes the energy from the injector nozzle to assist in maintaining the vortex and likewise brings the material into a vortex in a position where it will be acted upon by the jets with particular facility. The fluid and entrained particles pass out of an opening **35d** into a collector member **36d** in which the material is separated from the fluid, and the material collected in a container, the top of which is indicated at **65**, the freed fluid passing out through an opening **38d** and the conduit **39d**.

In a construction such as shown in Figs. 7 and 8, the diameter of the chamber **22d** may, for example, be 21″; the axial extent of the chamber at its periphery being 1¼″, and at its widest portion, 4″; the diameter of the opening **35d** being 5″, and of the opening **38d**, 3″; with the other dimensions substantially in the proportions shown. Ten nozzles having $\frac{5}{32}$″ jet openings may be provided. The injector nozzle may have a similar opening and the Venturi opening may be ⅜″.

Still another embodiment of the invention is illustrated in and by Figs. 9 and 10. In this construction a vortex chamber **22e** is formed between a lower plate **20e** and an upper plate **21e**, which in the present instance extends directly inwardly from its periphery. The periphery of the chamber is provided by a plate **66**, and fluid pressure headers **23e** and **23ee** are provided respectively below the outer portion of the plate **20e** and above the outer portion of the plate **21e**, which plates are bored at angularly spaced points to provide openings **25e** and **25ee** respectively. The openings **25e** and **25ee** are so directed that they point generally forward in a direction of rotation within the chamber. They also point transversely to the direction of rotation, but in the present instance, instead of pointing inwardly, point upwardly and downwardly respectively, as well as forwardly, the direction of the streams passing through these openings being indicated by the arrows E and F. As will be noted, the openings are so disposed and the streams so directed that the streams will cross each other, so that particles moving in the direction of oppositely disposed streams will impinge upon each other with a great increase in pulverizing effect. The chamber **22e** is fed through a plurality of uniformly spaced openings **26e** from a feed head **27e** similar to the feed head **27**. A feeding means **28e** similar to the feed head **28** in Fig. 1 is provided to feed material to the header **27e**. A collector member **36e** and a conduit **39e** are likewise provided.

In an apparatus constructed and proportioned as shown in Figs. 9 and 10, the diameter of the chamber **22e** may, for example, be 14″ and the height 1¾″. The jet openings may be positioned ¼″ from the periphery and may be ⅛″ in diameter, if four jet openings are provided at both top and bottom. The injector opening may be ⅛″, the Venturi opening ⅜″ and the supply opening $\frac{3}{16}$″. Sixteen of these feed openings may be provided.

As above indicated, the invention is capable of embodiment in a wide variety of types of methods and apparatus a number of which are illustrated diagrammatically by and in Figs. 11–32.

In Figs. 11 and 12 fluid is injected into the chamber **22f** from a header through jet openings illustrated diagrammatically at **23f** and **25f** respectively, and the walls **20f** and **21f** diverge from the periphery of the chamber inwardly, the wall **21f** diverging rapidly at an inward point as indicated by **41f**. A guard flange **49f** is provided. Material is fed downwardly into the chamber by a feeding means **28f**.

In Fig. 13, the construction is generally similar, but the wall **20g** is flat and the wall **21g** slopes upwardly from the periphery to a point just above the collector **36g**.

In Figs. 14, 15, and 16, there is provided an arrangement of the type shown in Figs. 9 and 10, except that the coaxial collector is omitted, since the invention in its broader aspects contemplates the carrying off of the fluid and entrained particles together as through a conduit 39h for collection in any suitable manner.

In instances where a radial wall does not diverge from the other wall to any great extent near the outlet opening, the advantage of extending an outlet duct interiorly of the chamber becomes less, and in instances of this nature, the termination of an outlet conduit may be flush with the plate without substantially affecting the operation, except possibly in instances where the radial distance of the plate outwardly of the outlet opening is particularly small. It is to be noted that in the present exemplification, the plate 21h extends directly radially inwardly and the conduit 39h does not extend interiorly of this plate.

In Figs. 17 and 18, there is shown a similar arrangement, except that the walls 20i and 21i converge inwardly so as to increase the entrainment component of the vortex in certain instances, as where a relatively uniform product which is coarser than would otherwise be obtained, is desired.

In Figs. 19 and 20, there is shown an arrangement of the type shown in Figs. 9 and 10, except that no upwardly directed jets are provided, and that the upper wall slants upwardly.

In Fig. 21, there is shown an exceedingly simple arrangement similar to the construction of Fig. 14, except that the jets are directed forwardly and inwardly.

As will be apparent, it is not of importance that the jets all be in the same plane or all have the same direction, and in Figs. 22 and 23 show an arrangement wherein the four jet openings 25j are disposed in a different plane and having different forward and inward components. In this exemplification also no collector is provided, the outlet conduit 39j in this instance acting to carry off both fluid and entrained particles.

Fig. 24 shows a similar arrangement embodying a collector member 36k and a conduit 39k.

As above indicated the jets may be directed forwardly and outwardly to give the very effective action which the invention makes possible, as well as forwardly and inwardly or forwardly and axially so long as the jets have a forward component of movement, a component of movement transverse to the lines of a vortical movement so that they will cut across it. In extreme instances, the efficiency of such an arrangement might be reduced, but there is shown in Fig. 25 an embodiment of the invention which gives satisfactory results. In this instance, the jet openings 25m give a direction to the jets which is forward in a direction of rotary movement and transverse thereto in an obliquely outward direction. The peripheral wall of the chamber 22m slants upwardly and outwardly in this instance so that the particles which work centrifugally to the walls will be picked up by the streams and be given an active movement across the lines of vortical movement. The eddies set up by the streams will likewise tend to keep all the particles in active circulation. It is to be noted also that the upper wall 21m is extended axially for a short distance at an inward point, and then inwardly, but that the vortical movement and eddies formed thereby are sufficient to prevent undesirable concentration of material against the short axial portion of this wall.

As above indicated, it is not necessary that all of the fluid be injected in streams having both forward and transverse components of movement, nor is it necessary that the withdrawal opening or openings include the axis of the vortex. In Fig. 26, there is shown an arrangement wherein a multiplicity of jet openings 25n discharge streams of high velocity fluid from a header 23n at angularly spaced points, each of said streams having a component of movement which is forward in the direction of rotation (clockwise looking down on the figure), and a component of movement which is transverse to the direction of rotation (inward). There are also provided a multiplicity of relatively small openings 70 leading from the header 23n in a direction having an inward component and a component which is counterclockwise (looking down on the figure). If, for instance, the diameter of the jet openings 25n is three times the diameter of the openings 70, the fluid entering through the openings 70 will not be sufficient to diminish the whirling action of the vortex undesirably, in many instances, and will create an additional turbulence which is desirable in certain instances, as, for example, when material which compacts readily is being treated. Likewise, in this exemplification there is provided a withdrawal opening 38n, which is in the form of a curved slot disposed outwardly of and providing an entrance to a conduit 39n which extends outwardly and downwardly from the device.

While the provision of oppositely disposed outlet openings, such as 35 and 38, 35a and 38a, etc., is desirable, this is not essential for collection in accordance with the invention. For instance, an arrangement such as exemplified in Fig. 27 may be utilized. In this embodiment of the invention, an opening 35p leads from the vortex chamber 22p to a collector member 36p, which has disposed therein a duct 71 adapted to receive fluid through an opening 72 at an inward point in the separating zone within the collector member, and to carry it outwardly. The collector member in this instance is formed with a laterally extended removal portion 37p.

While it is important that the vortex be axially confined, it is not essential, as indicated in connection with Figs. 3 and 4, that it be completely enclosed; and, as also indicated in connection with Figs. 3 and 4, it is not essential that all the material be kept in circulation in the vortex, so long as it does not gather at points where it would re-enter the vortex in undesired concentrations. Moreover, while it is desirable in most instances that the vortex be relatively unobstructed, baffle means may be supplied in many instances without unduly disturbing the operation, and in some instances with beneficial effects. The embodiment of the invention illustrated in and by Fig. 28 involves an arrangement wherein material is permitted to work out from the vortex as through a conduit 73 leading from the vortex chamber 22q to a receptacle 74 wherein material is entrapped. The entrapped material may be tested from time to time to determine the condition of the operation, or may be otherwise utilized. Likewise, there is provided an annular opening 75 in the bottom wall 20q leading to a chamber 76 having an outlet conduit 77. Material, which is fairly fine but not so fine as to be entrained by the fluid entering the collector member 36q, will work into the chamber 76 and can be carried out through the conduit 77 without material interference with the vortical action. Such a procedure or a construction may be desirable where the provision of material of two grades of average fineness is desired. In the present instance also there are provided baffle means **78** and **79** extremely interior from the plates **20***q* and **21***q* respectively, at the points indicated.

While the feeding means is ordinarily disposed outwardly of the withdrawal openings so as to insure against entrainment of the supplied material with the withdrawn fluid, it is only essential that the material be supplied at a position where the withdrawn fluid has no substantial entraining effect. A construction adapted for this purpose, but wherein the feeding means is nevertheless substantially axial, is exemplified in Fig. 29. Material is supplied to a central point, as through a tube **78** coaxial with the vortex and an opening **26***r* which is just above the center of the bottom plate **20***r* from feeding means **28***r*. The fluid is withdrawn through an outlet opening **39***r* which is in the upper plate **21***r* and which is spaced a considerable distance from the opening **26***r*. The coarse material supplied will all be thrown outwardly by the centrifugal action of the vortex before it has an opportunity to work upwardly to the outlet opening. Also under certain operating conditions (as for example a low feed rate) the material may be fed into the chamber through tube **80** by gravity due to the suction at the opening **26***r* which is disposed much further in than the periphery of the outlet opening **39***r*.

As above indicated, the axis of a vortex formed in accordance with the invention may in certain instances be other than vertical since gravity is an exceedingly small factor in the operation, where the circulating load is small. Even when the entrained particles are separated from the fluid in accordance with the invention, this remains true. In Fig. 30 there is exemplified an arrangement wherein the axis of the vortex formed by the use of the apparatus and in carrying out the invention is horizontal. The walls **20***s* and **21***s*, in this instance, extend generally vertically, and the collector **36***s* and the conduit **39***s* extend generally horizontally. The constricted portion **37***s* of the collector opens into a bin **81**. The separated particles work outwardly through the portion **37***s* due to the pressure differential resulting from the slowing down of the vortex towards the right hand end of the collector, and the freed fluid escapes through the conduit **39***s*. It is further to be noted in this connection, that while many of the plates **20**, **21**, **20***a*, **21***s*, etc., are spoken of as "lower" and "upper" plates, that such positioning is merely the normal one in the exemplification shown, and that it is not essential that the collector be on the bottom or even on the side, or that the axis of the vortex be in any particular position whether or not a collector is used.

There are a number of cases where thorough classification of the material is unessential, where the fresh material introduced is already very fine, or where for any other reason the classification step is not to be especially provided for. In such cases, results which are very satisfactory from many standpoints may be obtained, without thoroughly classifying the material. If desired also, particles which are not thoroughly classified may be separated from the fluid in accordance with the invention. An embodiment of the invention adapted for such situation is illustrated in and by Fig. 31 wherein the lower wall **20***t* extends inwardly from the periphery of the chamber **22***t* only a short distance, where it terminates in a withdrawal opening **35***t*. From the withdrawal opening a collector member **36***t* extends downwardly in the present instance.

There are many instances in which it is permissible or desirable to utilize streams having a relatively small transverse component of movement, and it is to be appreciated that the transverse component of the stream does not need to be as large as in the previous exemplifications in order to obtain an efficiency of pulverization which is satisfactory in most instances. In Fig. 32 there is shown an arrangement wherein the jet openings **25***u* are arranged to discharge fluid from a header **23***u* into a vortex chamber **22***u* in a direction having a relatively small, but ample, transverse component of movement.

It is also to be appreciated that in instances where classification of the material is of outstanding importance and where efficiency of pulverization is of relatively less importance, (as where a powder in which substantially all the particles are of exceedingly small size is desired regardless of the quantitative production obtained or of the wear characteristics, where the greater proportion of the material to be treated is already sufficiently fine, or where the material to be treated is very readily frangible) the small, high velocity stream or streams may be introduced, and the jet opening or openings arranged to discharge, in a direction which has no substantial transverse component, and a qualitatively excellent product obtained. In such instances the smaller pulverizing action to be had will be exerted (with a relatively light circulating load when relatively difficultly frangible materials are being treated) without obtaining the full benefit of the invention from a pulverization standpoint, but the very high degree of classification made possible by the invention is obtained. Moreover the combination of classification and collection in accordance with the invention will be unimpaired. It is accordingly to be understood that the invention in its broader aspects as applied to the provision of a highly classified product is not limited to the introduction of fluid in a direction having a transverse component of movement as above exemplified, or to the provision of jet openings so formed that a stream will have such component, but contemplates the provision of a procedure and of means for classifying material by the introduction of a small quantity of high velocity fluid into the outer portion of an inwardly spiralling vortex which passes through a classification zone disposed substantially radially inwardly of said outer portion, whether or not the stream or streams have a substantial component of movement which is transverse to the direction of rotation. For example, in instances such as above indicated the jets of various of the showings, including those of Figs. 1 and 2, 5 and 6, 5*a*, 6*b*, and 7 and 8, may be tangentially directed, and certain new and useful results obtained in accordance with the invention. It is to be observed that in all the procedures and all the means exemplified, with the exception of certain cases as discussed in connection with Fig. 31, classification is effected in an axially-confined (narrow) zone which is continuous with the axially-confined outer portion of the chamber in substantially the same plane; and the fluid and entrained fine particles are withdrawn at the inner end of the classification zone, so that the withdrawn particles may be directly centrifugally collected as in Fig. 1, etc., carried off for collection as in Fig. 14, etc., or otherwise employed outside of the chamber.

In order to give a general idea of operating conditions under which satisfactory results have been obtained in accordance with the invention, several typical procedures which have been successfully carried out are exemplified below.

Example 1

Steam at a pressure of 115 pounds per square inch and at a temperature of 450° F. was introduced into the header of a construction such as shown in Figs. 7 and 8. When a certain graphite substantially uniformly 5 mesh in size was supplied to the vortex at a given rate, a product having an average particle size of about 1 micron and a maximum particle size of about 3 microns was obtained at an expenditure of approximately 11 pounds of fluid per pound of product.

Example 2

Under the conditions of Example 1 when the same material was supplied to the vortex at an increased rate under conditions requiring an expediture of approximately 3.7 pounds of fluid per pound of product, a product having an average particle size of about 6 microns and a maximum particle size of about 10 microns was obtained.

Example 3

Under the conditions of Examples 1 and 2 when steam at a pressure of 180 pounds per square inch and at a temperature of 710° F. was introduced into the header, a product having an average particle size of about 1 micron and a maximum particle size of about 2½ microns was obtained at an expenditure of approximately 10 pounds of fluid per pound of product.

Example 4

Steam at a pressure of 180 pounds per square inch and at a temperature of 710° F. was introduced into the header of an apparatus of the general form illustrated in Figs. 5 and 6, having a vortex chamber 14'' in peripheral diameter, 1¾'' high at the periphery and for about 2'' inwardly thereof and 4½'' high, 2½'' further inwardly and having a 5'' collector opening and a 2'' freed-fluid outlet and provided with a single row of 6 nozzles directed forwardly and inwardly delivering 710 pounds of steam per hour. When coarse graphite was fed to the vortex, a product having an average particle size of about 5 microns and a maximum particle size of about 10 microns was obtained at an expenditure of approximately 10 pounds of fluid per pound of product.

Example 5

Air at atmospheric temperature and at a pressure of 55 pounds per square inch was introduced into the header of an arrangement as described in Example 4. When coarse graphite was introduced into the machine, a product having an average particle size of about 22 microns and a maximum particle size of about 70 microns was obtained at an expenditure of approximately 15 pounds of fluid per pound of product.

Example 6

When the pressure of Example 5 was increased to 110 pounds per square inch, a product having an average particle size of about 6 microns and a maximum particle size of about 12 microns was obtained at an expenditure of approximately 15 pounds of fluid per pound of product.

Example 7

Steam at a pressure of 140 pounds per square inch and at a temperature of 675° F. was introduced into the header of an apparatus such as shown in Figs. 1 and 2. When a fairly heavy, easily frangible, coarse material of uniform 50 mesh size was supplied through the feeding means, a product 97% less than 5 microns was obtained at an expenditure of approximately 3.7 pounds of fluid per pound of product.

Example 8

Under the same conditions of Example 7, except that the axial height of the vortex chamber was 1'' less throughout, utilizing the same material, a product having an average particle size of about 8 to 10 microns was obtained at an expenditure of approximately 4½ pounds of fluid per pound of product.

Example 9

Steam at a pressure of 140 pounds per square inch and at a temperature of 700° F. was introduced into the header of an apparatus such as shown in Figs. 1 and 2. When coarse barytes screened through ⅜'' mesh was supplied to the vortex through the feeding means, a product having an average particle size of about 10 microns was obtained at an expenditure of approximately 2.5 pounds of fluid per pound of product.

Example 10

Air at atmospheric temperature and at a pressure of 40 pounds per square inch was introduced into the header of an apparatus such as shown in Figs. 5 and 6. When coarse limestone screened through ¼'' mesh was supplied to the vortex through the feeding means, a product having an average particle size of about 25 microns was obtained at an expenditure of approximately 6½ pounds of fluid per pound of product.

Example 11

Air at atmospheric temperature and at a pressure of 110 pounds per square inch was introduced into the header of an apparatus of the general form exemplified in Figs. 7 and 8 having a vortex chamber, the periphery of which had a diameter of 18'', a height of 2'' at the periphery, a height of 5'' near the collector opening, a collector opening 6'' in diameter, a freed-fluid outlet 2½'' in diameter and having two rows of 5 angularly spaced nozzles each ⅛'' in diameter directed forwardly and inwardly and disposed ½'' from the top and bottom walls respectively; the nozzles in one row being located midway between adjacent nozzles in the other row. When coarse synthetic resin screened through ¼'' mesh was supplied to the vortex, a product having an average size of about 25 to 30 microns was obtained at an expenditure of approximately ¼ pound of fluid per pound of product.

Example 12

Air at atmospheric temperature and a pressure of 100 pounds per square inch was introduced into the header of an apparatus such as shown in Figs. 9 and 10. When talc of the order of 200 mesh was fed into the vortex, a product having an average particle size of about 15 microns was obtained at an expenditure of approximately 4½ pounds of fluid per pound of product.

Example 13

Steam at a pressure of 200 pounds per square inch and a temperature of 600° F. was introduced at a rate of approximately 1200 pounds per hour, into the header of an apparatus of the general form illustrated in Figs. 7 and 8, having a vortex chamber 18 inches in diameter, 1¼ inches high at the periphery and for about 1½ inches inwardly thereof, and having an extreme height in the classification zone of 3½ inches, a 5 inch collector opening and a 2½ inch freed-fluid outlet. When a type of hard carbon lumps was fed into this chamber at the rate of one pound of material for every 18.5 pounds of steam, a product having an average particle size of about 3 microns was obtained.

Example 14

When the area of the nozzles in Example 13 was decreased to deliver approximately 790 pounds of steam per hour at the same pressure and temperature, other conditions remaining the same and the same material used, a product having the same average particle size as in Example 13 was obtained at a feed rate of one pound of product for every 12 pounds of steam.

In the examples where figures are referred to without dimensions being given (as in Examples 1, 7, 9, 10 and 12) the apparatus utilized had the dimensions described in connection with the figures referred to respectively in the examples.

As will be apparent from the foregoing, the relationship of the velocity of the entering fluid to the quantity of fluid introduced, the relationship of this to the cubical contents of the vortex and to the radial extent of the vortex outwardly of the withdrawal zone, and the interrelation of various of the foregoing and other features, all are factors in obtaining various of the highly improved results made possible for the first time by the invention.

It is to be appreciated that for a given apparatus operating under given pressure conditions when an exceptionally small particle size of a given material is desired in the product, the conditions of energy input and friction at the confining walls of the vortex may be such that the desired product cannot be obtained in commercial quantities. Under these conditions the product may be obtained in commercial quantities by increasing the pressure upon the jet orifices. By reducing the effective area of the jet openings, the quantity of fluid supplied can be kept substantially constant, and the increased energy input due to the higher pressure utilized to overcome friction and maintain a higher whirling rate in the vortex.

It is to be understood that the expressions "inwardly spiralling" and the like are used herein to designate a general type of fluid movement wherein the fluid rotates about an axis and more or less gradually approaches it during such rotation, and are not to be restricted to an exact mathematical meaning.

It will thus be seen that there may be provided in accordance with the invention procedures and constructions which vary considerably, but which embody certain fundamental and novel inventive concepts whereby highly desirable results may be obtained in an extraordinarily efficient manner, and whereby results which could not be obtained without the use of the invention may be secured.

Since certain changes in carrying out the above method and in the constructions set forth, which embody the invention, may be made without departing from its scope, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

The invention claimed is:

1. The method of providing material in finely divided form, which comprises the formation of a gaseous vortex in which the fluid spirals inwardly, the supplying of material to said vortex, the pulverization of material by causing a multiplicity of angularly spaced small streams of high velocity gaseous fluid to penetrate an outer zone of the vortex, each of the aforesaid streams having a component of movement which is forward in the direction of rotation so as to maintain the vortex and a component of movement which is transverse to the direction of rotation so as to cause impingement of particles moving in different directions at a high speed, the classification of material in a zone disposed substantially radially inwardly of said outer zone, and the withdrawal of fluid and entrained fine particles from a zone disposed radially of said classification zone, at least one of said streams having a direction such that particles projected thereby will impinge upon particles being projected by at least one other of said streams.

2. Apparatus for providing material in finely divided form, which comprises a generally circular vortex chamber, means to supply material to a vortex in said chamber, means to discharge a multiplicity of angularly spaced small streams of high velocity gaseous fluid into an outer portion of said chamber, each of the aforesaid streams having a component of movement which is forward in a direction of rotation within the chamber so as to maintain the vortex and a component of movement which is transverse to the direction of rotation so as to cause impingement of the particles moving in different directions at a high speed, said chamber being formed to provide a classification zone disposed substantially radially inward of said outer portion, and means to withdraw fluid and entrained fine particles from a radially inward point in said classification zone, said discharging means being so formed that at least one of said streams will have a direction such that particles projected thereby will impinge upon particles being projected by at least one other of said streams.

3. The method of providing material in finely divided form, which comprises forming and maintaining an inwardly spiralling vortex by discharging gaseous fluid into an axially confined annular zone from which fluid will spiral inwardly, said fluid being discharged at a high velocity and in a direction such that the vortex will have a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, supplying material to said vortex, centrifugally classifying material in said inwardly spiralling vortex in an axially confined zone which is continuous with said annular zone in an inward direction in substantially the same plane while substantially maintaining all loose particles continuously in motion by the whirling fluid, said vortex acting to develop in the coarser pieces in the classification zone by the rotative action of the fluid centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly and to drive the coarser pieces outwardly, the coarser

pieces being continuously returned by said centrifugal forces for pulverizing action in said annular zone until sufficiently reduced to be entrained and carried off by the fluid, and withdrawing fluid and entrained fine particles at the inner end of said classification zone.

4. Apparatus for the provision of material in finely divided form, comprising a generally-circular axially-confined vortex chamber, means to discharge gaseous fluid into the outer portion of said chamber at a high velocity and in a direction such that there will be set up in said chamber an inwardly spiralling vortex having a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, means to supply material to said chamber, the walls of said chamber being formed to substantially maintain all loose particles of material continuously in motion by the whirling fluid and to provide a classification zone which is continuous with said outer portion in an inward direction in substantially the same plane and wherein centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly are developed in the coarser pieces by the rotative action of the fluid to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing action in said outer portion until sufficiently reduced to be entrained and carried off by the fluid, and means to withdraw fluid and entrained fine particles at the inner end of said classification zone.

5. The method of providing material in finely divided form, which comprises forming and maintaining an inwardly spiralling vortex by discharging into an axially confined annular zone from which the fluid will spiral inwardly a multiplicity of small streams of gaseous fluid, supplying material to said vortex, each of the said streams having a high velocity and a component which is forward in the direction of rotation so as to impart a high rotative speed to the vortex and also having a component of movement which is transverse to the direction of rotation so as to cause impingement of particles moving in different directions at a high speed, the quantity of discharged fluid being sufficiently small so that the vortex as it spirals inwardly will have a relatively low inward speed, centrifugally classifying material in said inwardly spiralling vortex in an axially confined zone which is continuous with said annular zone in an inward direction in substantially the same plane while substantially maintaining all loose particles continuously in motion by the whirling fluid, said vortex acting to develop in the coarser pieces in the classification zone by the rotative action of the fluid centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly and to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing action in said annular zone until sufficiently reduced to be entrained and carried off by the fluid, and withdrawing fluid and entrained fine particles at the inner end of said classification zone.

6. Apparatus for the provision of material in finely divided form, comprising a generally-circular axially-confined vortex chamber, means to discharge into an outer portion of said chamber a multiplicity of small streams of high velocity gaseous fluid, means to supply material to said chamber, each of the aforesaid streams having a component of movement which is forward in a direction of rotation within the chamber so as to set up an inwardly spiralling vortex having a high rotative speed and having a component of movement which is transverse to the direction of rotation so as to cause impingement of particles moving in different directions at a high speed, said discharge means being arranged to discharge a sufficiently small quantity of fluid so that the fluid as it spirals inwardly will have a relatively low inward speed, the walls of said chamber being formed to substantially maintain all loose particles of material continuously in motion by the whirling fluid and to provide a classification zone which is continuous with said outer portion in an inward direction in substantially the same plane and wherein centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly are developed in the coarser pieces by the rotative action of the fluid to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing action in said outer portion until sufficiently reduced to be entrained and carried off by the fluid, and means to withdraw fluid and entrained fine particles at the inner end of said classification zone.

7. The method of providing material in finely divided form, which comprises forming and maintaining an inwardly spiralling vortex by discharging into an annular zone at least one small stream of high velocity gaseous fluid having a component of movement which is forward in the direction of rotation and a component of movement which is transverse to said direction, causing the fluid to spiral inwardly thru a classification zone and causing coarser particles in the classification zone to be centrifugally returned to said annular zone while substantially preventing the particles from dropping out of the vortex, supplying material to said vortex, and withdrawing fluid and entrained fine particles at the inner end of said classification zone.

8. The method of providing material in finely divided form, which comprises the formation of a gaseous vortex in which the fluid spirals inwardly, the supplying of material to said vortex, the discharge of gaseous fluid into an outer portion of said vortex at a high velocity and in a direction having a component which is forward in a direction of rotation so that the gas will be caused to whirl at a high rotative speed and having a component which is transverse to the direction of rotation so as to penetrate the vortex and cause the impingement of particles moving in different directions at a high speed, the conduction of the whirling fluid inwardly to develop in the particles centrifugal forces tending to return the same outwardly for further pulverization by the action of the vortex and of the discharge fluid, the amount of gaseous fluid supplied to such vortex being sufficiently small so that the fluid as it spirals inwardly will have only sufficient inward speed with respect to its rotative speed at an inward point to overcome only the relatively small centrifugal forces developed in the finer particles and to entrain the same, the withdrawal of fluid and entrained particles at said inward point, and the maintenance of a uniform action by preventing material from gathering outside the active influence of the vortex and from reentering the active vortex in batches.

9. Apparatus for the provision of material in finely divided form, comprising a generally circular vortex chamber, means to discharge into an outer portion of said chamber at least one

small stream of high velocity gaseous fluid having a component of movement which is forward in a direction of rotation within the chamber and a component of movement which is transverse to said direction, means to supply material to said chamber, the walls of said chamber including lateral portions which extend generally radially inwardly to define the sides of a classification zone from which particles are centrifugally returned to said outer portion, said lateral wall portions being in sufficient proximity to each other to prevent material from gathering in batches at positions outside the active influence of a vortex set up by said discharging means and from which positions the material could re-enter the vortex in irregular amounts, and means to withdraw fluid and entrained fine particles at the inner end of the classification zone.

10. Apparatus for the provision of material in finely divided form, comprising a generally circular vortex chamber, means to discharge a small quantity of gaseous fluid into an outer portion of said chamber at a high velocity and in a direction having a component which is forward in a direction of rotation within the chamber and a component which is transverse to the direction of rotation so as to set up within said chamber an inwardly spiralling vortex having a high rotative speed but a relatively low inward speed and to drive particles transversely to the direction of vortical movement so as to cause impingement of particles moving in different directions at a high speed, means to supply material to said chamber, said chamber being provided with generally radial walls at least one of which is in sufficient proximity to said discharge means to prevent material carried by said vortex from dropping out of the vortex, said walls being formed to provide a classification zone inwardly of said outer portion and wherein there will be developed in the coarser particles centrifugal forces sufficient to drive them outwardly, and withdrawing fluid and entrained fine particles from the inner end of the classification zone.

11. The method of providing material in finely divided form, which comprises forming and maintaining an inwardly spiralling vortex by discharging gaseous fluid into an axially confined annular zone from which fluid will spiral inwardly, said fluid being discharged at a high velocity and in a direction such that the vortex will have a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, supplying material to said vortex, centrifugally classifying material in said inwardly spiralling vortex in an axially confined zone which is continuous with said annular zone in an inward direction in substantially the same plane while substantially maintaining all loose particles continuously in motion by the whirling fluid, said vortex acting to develop in the coarser pieces in the classification zone by the rotative action of the fluid centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly and to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing action in said annular zone until sufficiently reduced to be entrained and carried off by the fluid, withdrawing fluid and entrained fine particles from the inner end of the classification zone into an axially-extending separating zone without dissipating the whirling action, utilizing the whirling action to centrifugally separate entrained material from the fluid in the separating zone, withdrawing fluid from which particles have been separated near the axis of the separating zone, and collecting the separated particles.

12. Apparatus for the provision of material in finely divided form, comprising a generally-circular axially-confined vortex chamber, means to discharge gaseous fluid into the outer portion of said chamber at a high velocity and in a direction such that there will be set up in said chamber an inwardly spiralling vortex having a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, means to supply material to said chamber, the walls of said chamber being formed to substantially maintain all loose particles of material continuously in motion by the whirling fluid and to provide a classification zone which is continuous with said outer portion in an inward direction in substantially the same plane and wherein centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly are developed in the coarser pieces by the rotative action of the fluid to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing action in said outer portion until sufficiently reduced to be entrained and carried off by the fluid, an axially extended collection chamber co-axial with the said vortex chamber and opening thereinto at the inner end of said classification zone to permit the fluid to continue to whirl about its axis of rotation as it enters the collection chamber so that the whirling action of the fluid set up by said discharge means will act in said collection chamber to centrifugally separate entrained material from the fluid, means for the withdrawal of fluid from which entrained material has been separated near the axis of the collection chamber, and means for the withdrawal of the separated particles.

13. The method of providing material in finely divided form, which comprises forming and maintaining an inwardly spiraling vortex by discharging gaseous fluid at a high velocity into an outer zone in a manner which will cause the fluid to spiral inwardly, supplying material to the vortex, withdrawing the whirling fluid and entrained particles from an inner zone into an axially extended separating zone, utilizing the whirling action to centrifugally separate entrained material from the fluid in the separating zone, withdrawing fluid from which particles have been separated near the axis of the separating zone, and collecting the separated particles.

14. Apparatus for the provision of material in finely divided form, comprising a generally circular vortex chamber, means to discharge gaseous fluid at a high velocity into the outer portion in a manner which will cause the fluid to spiral inwardly, means to supply material to said chamber, an axially extended collection chamber coaxial with said vortex chamber and communicating therewith at an inward point in a manner which will permit the fluid to continue to whirl about its axis of rotation as it enters the collection chamber so that the whirling action of the fluid in the collection chamber will centrifugally separate entrained material from the fluid, means for the withdrawal of fluid from which entrained material has been separated near the axis of the collection chamber, and

means for the withdrawal of the separated particles.

15. Apparatus for the provision of material in finely divided form, comprising a generally-circular axially-confined vortex chamber, means to discharge gaseous fluid into the outer portion of said chamber at a high velocity and in a direction such that there will be set up in said chamber an inwardly spiralling vortex having a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, means to supply material to said chamber, the walls of said chamber being formed to substantially maintain all loose particles of material continuously in motion by the whirling fluid and to provide a classification zone which is continuous with said outer portion in an inward direction in substantially the same plane and wherein centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly are developed in the coarser pieces by the rotative action of the fluid to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing action in said outer portion until sufficiently reduced to be entrained and carried off by the fluid, and means to withdraw fluid and entrained fine particles at the inner end of said classification zone, said chamber walls including generally radial wall portions which diverge inwardly along at least a portion of said classification zone to increase the axial extent thereof toward said withdrawal means so as to decrease the entraining force of the fluid near the inner end of the classification zone.

16. Apparatus for the provision of material in finely divided form, comprising a generally circular vortex chamber, means to discharge gaseous fluid into an outer portion of said chamber at a high velocity and in a direction such that the fluid will be caused to whirl about said chamber at a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, means to supply material to said chamber, the walls of said chamber being formed to axially confine the vortex in said chamber so that substantially all the loose particles of material will be continuously maintained in motion by the fluid and to cause the fluid to spiral continuously inwardly from an outer pulverization zone thru an inwardly disposed classification zone, said rotative speed being sufficient to develop in the coarser pieces in said classification zone centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly at said low inward speed and to continuously return the insufficiently reduced pieces by said centrifugal forces for pulverizing action in said outer pulverization zone until sufficiently reduced to be entrained and carried off by the fluid, means to withdraw fluid and entrained particles at the inner end of said classification zone, and interiorly-extending barrier means to prevent inward movement of unclassified particles until the whirling action has developed sufficient centrifugal forces in the coarser pieces to return them to said pulverization zone for further reduction.

17. Apparatus for the provision of material in finely divided form, comprising a generally circular vortex chamber, means to discharge gaseous fluid into an outer portion of said chamber at a high velocity and in a direction such that the fluid will be caused to whirl about said chamber at a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, means to supply material to said chamber, said chamber being provided with lateral walls extending generally radially from the periphery of the chamber to an inward point for a distance greater than the maximum distance between said walls to define an outer zone wherein pulverization of the material is effected by the action of the fluid on the particles and an inner zone wherein classification is effected by developing sufficient centrifugal forces in the coarser particles to return same for further reducing action in said pulverization zone until sufficiently reduced to be entrained and carried off by the fluid at said inward point, and means to withdraw fluid and entrained particles at said inward point.

18. Apparatus for the provision of material in finely divided form, comprising a generally circular axially-confined vortex chamber, means to discharge into an outer portion of said chamber a multiplicity of small streams of high velocity gaseous fluid, means to supply material to said chamber, each of the aforesaid streams having a component of movement which is forward in a direction of rotation within the chamber so as to set up an inwardly spiralling vortex having a high rotative speed and having also an inward component, said discharging means being so disposed that particles moving at a high velocity under the influence of one stream will impinge upon particles moving at a high velocity under the influence of another stream, and means to receive fluid which has spiralled inwardly to an inner point and to withdraw the same.

19. Apparatus for the provision of material in finely divided form, comprising a generally circular axially-confined vortex chamber, means to discharge into the outer portion of said chamber a plurality of small streams of high velocity gaseous fluid, each of the aforesaid streams having a component of movement which is forward in a direction of rotation so as to maintain an inwardly spiralling vortex and having also an axial component transverse to the vortex, said discharging means being so disposed that particles moving at a high velocity under the influence of one stream will impinge upon particles moving at a high velocity under the influence of another stream, and means to receive fluid which has spiralled inwardly to an inner point and to withdraw the same.

20. Apparatus for the provision of material in finely divided form, comprising a generally-circular axially-confined vortex chamber, means to discharge gaseous fluid into the outer portion of said chamber at a high velocity and in a direction such that there will be set up in said chamber an inwardly spiralling vortex having a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, means to supply material to a plurality of sectors of said chamber, the walls of said chamber being formed to substantially maintain all loose particles of material continuously in motion by the whirling fluid and to provide a classification zone which is continuous with said outer portion in an inward direction in substantially the same plane and wherein centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly are developed in the coarser pieces by the rotative action of the fluid to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing

action in said outer portion until sufficiently reduced to be entrained and carried off by the fluid, and means to withdraw fluid and entrained fine particles at the inner end of said classification zone.

21. Apparatus for providing material in finely divided form, which comprises a generally circular axially-confined vortex chamber, means to discharge a multiplicity of small streams of high velocity gaseous fluid into an outer portion of said chamber in a direction which will maintain an inwardly spiralling vortex in said chamber, said chamber being formed to provide a classification zone disposed substantially radially inwardly of said outer portion and wherein there will be developed in the coarser particles centrifugal forces sufficient to drive them outwardly, means to supply material to said chamber at a multiplicity of angularly spaced points, and means to withdraw fluid and entrained fine particles from a radially inward point in said classification zone.

22. Apparatus for the provision of material in finely divided form, comprising a generally-circular narrow vortex chamber having at least one inwardly disposed outlet opening, means to discharge into an outer portion of the chamber a small quantity of gaseous fluid at a high velocity in a manner which will cause the fluid to have a high rotative speed but a relatively low inward speed, means to supply material to said chamber, the walls of said chamber being formed to provide a narrow classification zone disposed inwardly of said outer portion, said discharge means comprising orifice means and gaseous-fluid conducting means directly behind said orifice means and having an effective area greater than the cross sectional area of the orifice means, whereby the material will be comminuted in said outer portion and the particles will be centrifugally classified in said classification zone with the centrifugal return of coarser particles to said outer portion and the escape of fluid and entrained fine particles thru said outlet opening.

23. The method of providing material in finely divided form, which comprises the formation in a generally circular narrow space of a gaseous vortex in which the fluid spirals inwardly, the supplying of material to said vortex, the pulverization of material by causing a multiplicity of angularly spaced small streams of high velocity gaseous fluid to penetrate a narrow outer zone of the vortex, each of the aforesaid streams having a component of movement which is forward in the direction of rotation so as to maintain the vortex and a component of movement which is transverse to the direction of rotation so as to cause impingement of particles moving in different directions at a high speed, and the withdrawal of fluid and entrained particles from a zone disposed inwardly of said outer zone, at least one of said streams having a direction such that particles projected thereby will impinge upon particles being projected by at least one other of said streams.

24. The method of providing material in finely divided form, which comprises forming and maintaining an inwardly spiralling vortex by discharging gaseous fluid into an axially-confined annular zone from which fluid will spiral inwardly, said fluid being discharged at a high velocity and in a direction such that the vortex will have a high rotative speed and in such small quantity that the fluid as it spirals inwardly will have a relatively low inward speed, supplying material to said vortex, centrifugally classifying material in said inwardly spiralling vortex in an axially-confined zone which is continuous with said annular zone in an inward direction in substantially the same plane while substantially maintaining all loose particles continuously in motion by the whirling fluid, said vortex acting to develop in the coarser pieces in the classification zone by the rotative action of the fluid centrifugal forces sufficient to overcome the inward drag of the fluid as it spirals inwardly and to drive the coarser pieces outwardly, the coarser pieces being continuously returned by said centrifugal forces for pulverizing action in said annular zone until sufficiently reduced to be entrained and carried off by the fluid, withdrawing fluid and entrained fine particles at the inner end of said classification zone, and controlling the size of the entrained particles by regulating the rate at which material is supplied to the vortex, a lower rate of feed resulting in a reduction of the maximum size of the particles in the product.

25. The method of providing material in finely divided form, which comprises discharging gaseous fluid into a zone in proximity to the periphery of a generally-circular axially-confined vortex chamber at a velocity which is in the order of many hundreds of feet per second and in a manner which will cause the fluid to rotate rapidly in said chamber and in an amount which is sufficiently small so that the rotating fluid will travel a distance which is many times the radial extent of the chamber from its periphery to an inward point in said chamber, supplying material to said chamber, causing a centrifugal classifying action of the particles of said material together with comminution of the larger particles, and causing the fluid and entrained fine particles to pass off from said inward point.

26. A method for pulverizing material which comprises causing particles of said material to rapidly move in the circular path of a substantially peripherally confined narrow zone so as to cause the larger particles of the said material to be thrown outwardly into the peripheral portion of said zone, injecting at a high velocity a relatively small proportion of a gaseous fluid into the said circular path from a portion of the said zone in proximity to its periphery to cause a rapid rotation but a relatively slow inward movement of the said gaseous fluid, causing a centrifugal classifying action of the said particles together with comminution of said larger particles, and causing the finely comminuted particles of said material to move inwardly in substantially the plane of the said zone and to pass off from the central portion of said zone.

27. Apparatus for the provision of material in finely divided form, comprising a generally-circular axially-confined vortex chamber, means to discharge into an outer portion of said chamber a small quantity of gaseous fluid at a high velocity in a manner which will cause a rapid rotation but a relatively slow inward movement of the gaseous fluid, means to supply material to said chamber, the walls of said chamber being formed to provide an axially-confined classification zone disposed inwardly of said outer portion, and means to withdraw fluid and entrained fine particles at the inner end of said classification zone, whereby material will be comminuted in said outer portion and the particles will be centrifugally classified in said classification zone with the centrifugal return of coarser particles to said outer portion

and the escape of fluid and entrained fine particles thru said withdrawal means.

28. In a pulverizing apparatus, the combination of a casing providing a substantially circular pulverizing chamber, substantially closed on all sides, a circular series of jets, preferably symmetrically disposed and spaced to discharge into said chamber and directed to the periphery of a circle within said pulverizing chamber, means to supply a fluid to said jets, under pressure, to cause said fluid to be discharged into said chamber as a relatively small stream having a high velocity; means to continuously feed material to be pulverized into said chamber; said casing being provided with a discharge opening through the top substantially coaxially with the axis of said chamber for the escape of said medium therefrom, and of an area much less than that of the pulverizing chamber, and a substantially cylindrical collector chamber disposed coaxially with respect to said pulverizing chamber and having its upper end open and within said pulverizing chamber and spaced from said discharge opening; whereby said fluid medium is constrained to travel in said collector chamber spirally downwardly from the upper end thereof and with a rotary motion immediately prior to the escape of said medium from said opening in the said casing.

29. Means for simultaneously pulverizing and classifying materials, comprising a casing providing an annular pulverizing chamber within which pulverizing is effected, and the top of the inner wall of which terminates within said casing and provides a central circular outlet for the continuous discharge downwardly thereinto of the dust laden fluid delivered from the annular pulverizing chamber, of a circular series of jets to discharge a fluid into said pulverizing chamber in a direction which is generally forward in a direction of rotation within the chamber, and to impart to the material under treatment therein a high speed of rotation in said chamber around the axis of said chamber, said speed being sufficient to effect a continuous separation by centrifugal force of the sufficiently pulverized particles from the larger heavier insufficiently pulverized pieces under treatment in said pulverizing chamber.

30. In a machine for reducing solid materials and for separating the sufficiently from the insufficiently reduced particles, the combination of a casing providing a closed, upright, substantially cylindrical pulverizing chamber, means to discharge a jet of a gaseous fluid into said chamber at high velocity and in a direction which is generally forward in a direction of rotation within the chamber to set up in said chamber a multiplicity of substantially rotating rings of said fluid moving at constantly increasing angular velocity as the diameters of the rings diminish and the fluid expands, a cylindrical collection chamber, the cross-sectional area of which is much smaller than the cross-sectional area of said pulverizing chamber and with its axis substantially coincident with the axis of said pulverizing chamber and having an open upper end within said casing into which the fluid leaving the pulverizing chamber flows with a rapid rotary movement around the axis of said chamber, and a discharge tube for the spent fluid extending through the upper wall of said casing coaxial with the axis of said casing and having its lower end adjacent the upper end of said collection chamber.

31. In a machine for reducing solid materials and for separating the sufficiently from the insufficiently reduced particles, the combination of a casing providing a closed, upright, substantially cylindrical pulverizing chamber, means to discharge a jet of a gaseous fluid into said chamber at high velocity and in a direction which is generally forward in a direction of rotation within the chamber to set up in said chamber a multiplicity of substantially rotating rings of said fluid moving at constantly increasing angular velocity as the diameters of the rings diminish and the fluid expands, a cylindrical collection chamber, the cross-sectional area of which is much smaller than the cross-sectional area of said pulverizing chamber and with its axis substantially coincident with the axis of said pulverizing chamber and having an open upper end within said casing into which the fluid leaving the pulverizing chamber flows with a rapid rotary movement around the axis of said chamber, a discharge tube for the spent fluid extending through the upper wall of said casing coaxial with the axis of said casing and having its lower end within said casing and adjacent the upper end of said collection chamber, and means to continually introduce fresh material to be pulverized into said pulverizing chamber to maintain the quantity of material under treatment substantially constant.

32. Means for concommitantly pulverizing and classifying materials or the like, comprising the combination of a casing providing a circular chamber, and means to impel material to be pulverized in said chamber in substantial orbits around the casing of said chamber by streams of fluid under high pressure discharged at high velocity into said chamber in a direction which is generally forward in a direction of rotation within said chamber, said pulverizing chamber communicating with a second chamber of smaller diameter within said pulverizing chamber and substantially concentric therewith, thereby constituting an annular space within which is effected the pulverizing of said material and a centrifugal classification of said material being pulverized, the top of the inner wall of which annular space providing an outlet from said annular chamber into said inner chamber for the continuous passage thereinto of said fluid laden with the finest of the pulverized material floating therein.

33. Apparatus for providing material in finely divided form, comprising the combination of a circular chamber having within it a second chamber of smaller diameter, the outer wall of which second chamber constitutes the inner wall of an annular space forming the pulverizing chamber, means to discharge a fluid at high linear velocity into said annular space in a direction which is generally forward in a direction of rotation within said space to effect a revolution of the pieces of said material around the axis of said chamber and a classification of the pieces of material under treatment by the centrifugal force developed in said pieces of material so revolving in the pulverizing chamber, the upper end of the inner chamber being open and into which the dust laden fluid from said annular space is discharged with a high rotary velocity sufficient to centrifugally separate in said second chamber the dust particles from said fluid, and means to conduct the dust free fluid from said second chamber.

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