July 27, 1943. N. N. STEPHANOFF 2,325,080

METHOD AND APPARATUS FOR COMMINUTING OR DRYING MATERIALS

Filed Oct. 15, 1938 3 Sheets-Sheet 1

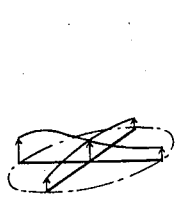


FIG. 1B.

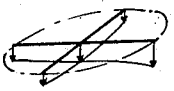


FIG. 1C.

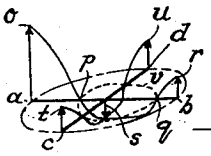


FIG. 1A.

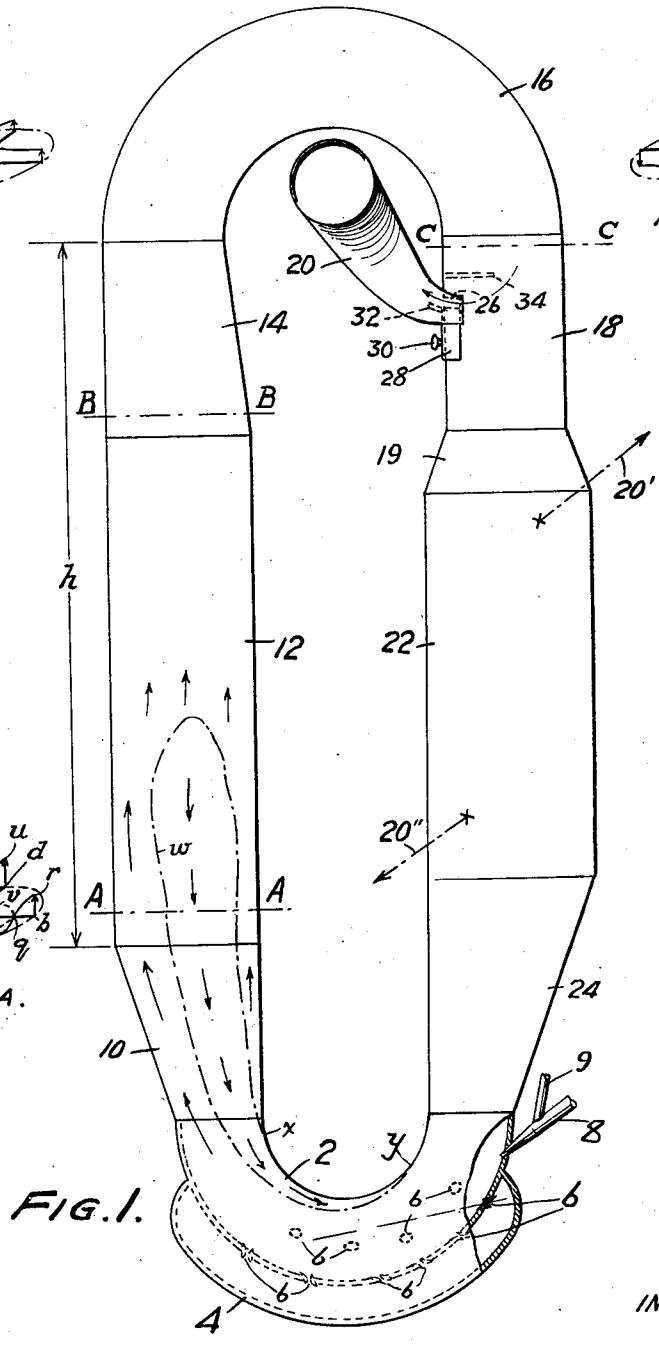


FIG. 1.

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METHOD AND APPARATUS FOR COMMINUTING OR DRYING MATERIALS

Filed Oct. 15, 1938 3 Sheets-Sheet 2

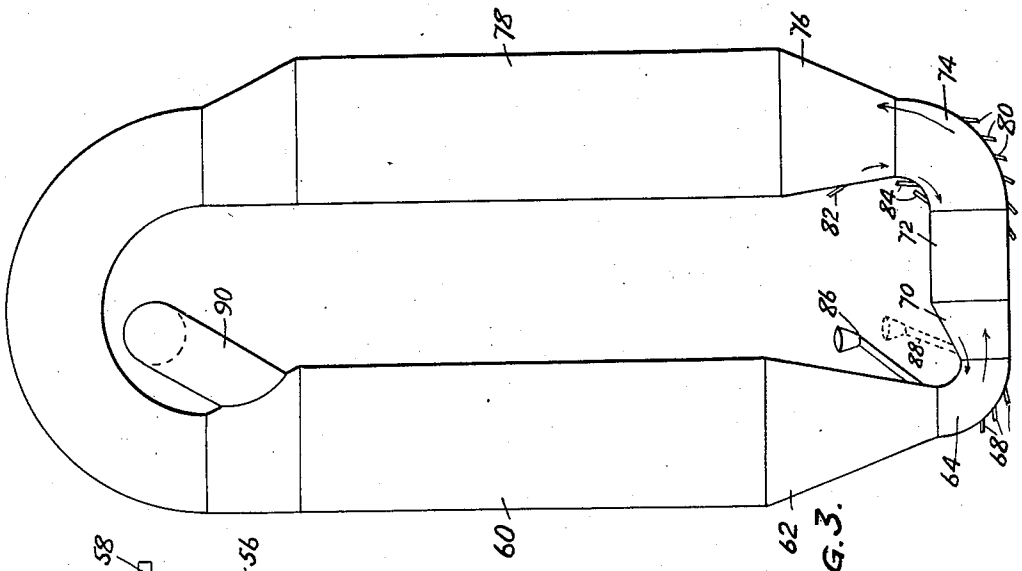


FIG. 3.

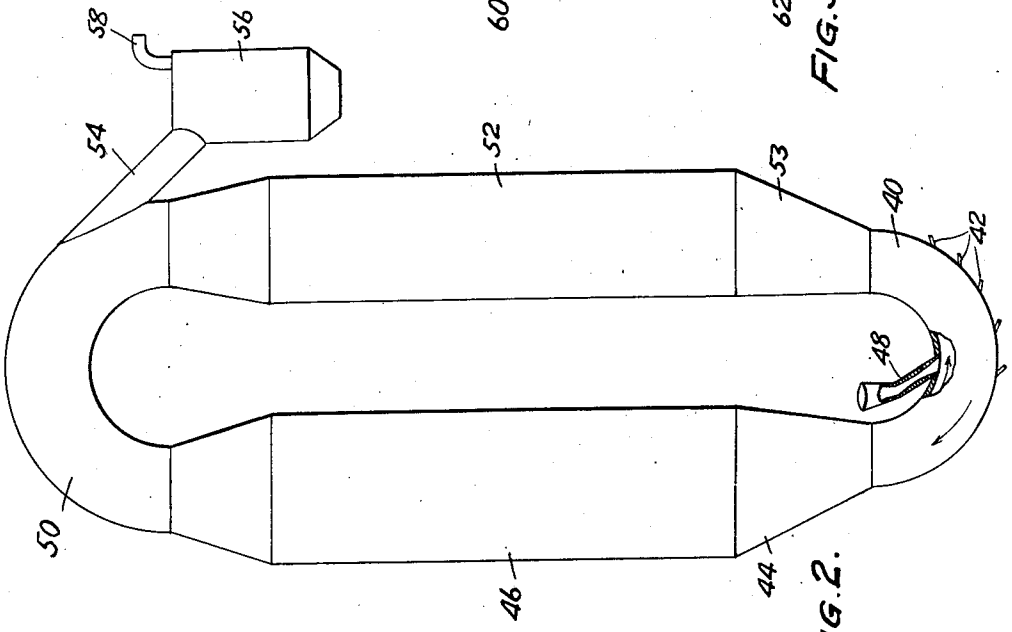


FIG. 2.

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METHOD AND APPARATUS FOR COMMINUTING OR DRYING MATERIALS

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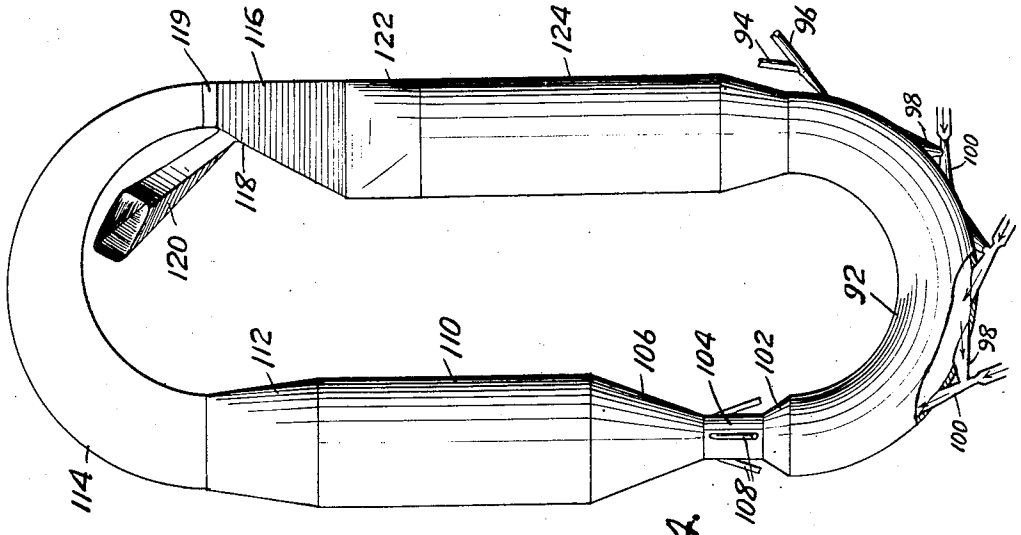


FIG. 4.

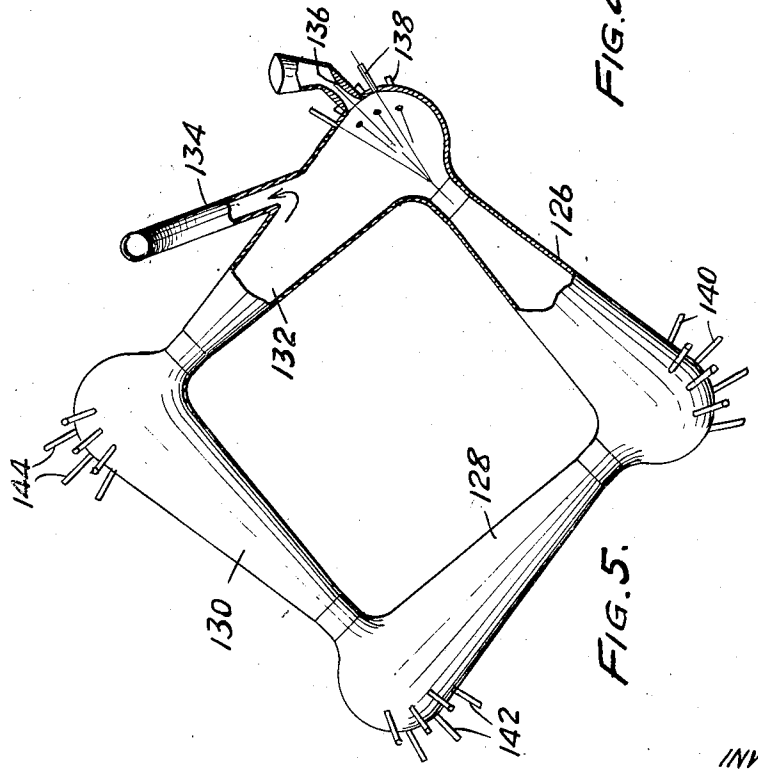


FIG. 5.

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UNITED STATES PATENT OFFICE

2,325,080

METHOD AND APPARATUS FOR COMMINUTING OR DRYING MATERIALS

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Application October 15, 1938, Serial No. 235,139

17 Claims. (Cl. 83—46)

This invention relates to a method and apparatus for comminuting and/or drying materials, these terms being used in a broad sense to include the breaking up of large particles, the grinding of particles and the drying of material in the form of droplets or particles, and the production of solid particles from a molten liquid, and more particularly relates to a method and apparatus for effecting such results by the action of a high velocity gas or vapor jet or jets.

It has been found that materials may be ground or dried by rapid recirculation within a continuous tubular passage with subjection to the action of jets of gas or vapor moving at high velocities exceeding the acoustic velocities under the conditions existing in the jets. The endless tubular chambers of such apparatus have flowing in them the gases or vapors carrying the particles in a very turbulent state and without well defined flow except in the general direction of circulation. Comminution and grinding take place to a considerable degree in such apparatus, but the operation may be improved in accordance with the present invention to provide much more effective grinding with the attainment of particles of extremely minute sizes.

While reference is made herein particularly to grinding or comminution of solid and dry materials, it will be understood that the invention is equally applicable to drying in a broad sense, as will be evident from consideration of the disclosure of my application Serial No. 199,687, filed April 2, 1938.

It is one object of the present invention to secure with a minimum of added gas or vapor and accompanying energy the effective treatment of maximum quantities of materials to be ground or dried. The quantity of material which may be thus treated depends not solely, and, in fact, not even to a major degree, upon the gas or vapor added to the apparatus, but rather upon the quantity of gas or vapor which circulates past a given region of the apparatus in a unit time. Such quantity of circulating gas or vapor determines the quantity of material which may be suspended in it so as to be subjected to the grinding or drying actions which occur in the apparatus. Specifically, in accordance with the present invention, the recirculation for a given amount of added gas or vapor is greatly increased by the adoption of one or more converging-diverging nozzles in the circulatory system, these nozzles being of substantial cross-section. As will be pointed out in greater detail hereafter, the presence of such a nozzle in the circulatory system provides a great increase in the effective circulatory velocities so that for a given input of gas or vapor and an equivalent output, the effective length of the apparatus is substantially increased and the materials being treated are subjected on the average to a greater number of repetitions of the actions of the jets which are primarily responsible for the grinding or drying.

The provision of a Venturi portion of the passage also permits the attainment of very high velocities of gases by the use of nozzles entering such passage in which the pressure will be lower than in other parts of the apparatus, giving a large pressure drop for any given supply pressure. If the Venturi throat is curved and the nozzles introducing gas are at the outside of the curvature, centrifugal loading of the nozzle jets with particles takes place greatly promoting the grinding action. Particularly effective action is secured at such regions if the various nozzles are arranged in such fashion as to cause their jets to intersect.

A second object of the invention is the provision of an arrangement in which more effective treatment of heavier particles or larger droplets is secured. It has been found that with the location of a nozzle portion of the apparatus as described above in a position where centrifugal action is occurring, there is produced as a result of the high velocities, particularly in the presence of nozzles which are introducing gas or vapor, and particularly if the nozzle portion is of overexpanded type, a region of reverse flow through the enlarged tubular portions of the apparatus and adjacent the inside of a bend, i. e., through a cross-section of the tubular apparatus it is found that the point to point velocities are not all in the direction of the average flow, but rather that through a substantial length of the tubular portion of the apparatus every cross-section shows some region in which the flows are in a direction opposite the general direction of flow, the velocities of these reverse flows being fairly high. By causing the average velocities in such portions of the apparatus to be upward with the lower reverse velocities downward, it is found that heavy particles passing upwardly under conditions of considerable turbulence have a high probability of entering the regions of reverse flow, whereupon, aided not only by the reverse flow, but by gravity, they will pass downwardly against the average flow back to a region of high velocities where grinding or drying is taking place most actively. Even if they do not return to such region, they will be subjected at

the boundaries of the region of reverse flow to particles flowing in opposite directions and impact and grinding or comminution is thereby accelerated. The reverse flow may be augmented by the use of auxiliary supply gas nozzles.

A third object of the invention is to provide for better grinding of materials by the utilization of a sufficient height of a passage in which upward flow is taking place to give a particle carried into such region by a high velocity imparted to it below the region an opportunity to enter a turbulent zone in which its velocity may be so far reduced that by gravity it may flow back against the upwardly flowing gases or vapors and thus be returned to the active grinding or drying region, perhaps entering, in the preferred embodiment of the invention, the region of reverse flow referred to in the preceding paragraph.

It is a further object of the invention to provide for selective removal of materials of different sizes by the use of suitably arranged outflow passages properly related to regions where centrifugal action is occurring or regions where other peculiarities of flow are taking place. By suitable arrangements of the exit passages, the grading of the particles removed may be readily secured. Experiments have illustrated that in the preferred embodiment of the apparatus the particles are very effectively statistically segregated so that selective removal may be effected.

Additional grading of the particles may be secured by controlling the radius of curvature of the path of the gases at the entrances to variously arranged outlets. By the use of suitable baffles preceding the outlets, the gases may be caused to make either sharp or gradual turns whereby substantial centrifugal separation of particles of different sizes may be secured.

A further object of the invention is the provision of a method and apparatus into which material may be introduced not by aspiration by the use of nozzles, but rather by the creation of relatively high vacuum or reverse flow regions in which the material to be added may be drawn or forced.

Another object of the invention is the provision of means for changing velocities of the flowing gases as often as possible through the apparatus. Not only may velocities be changed in a vectorial sense by providing bends, but velocities may be changed in substantially a straight path of flow by the provision of Venturi regions in the apparatus without causing substantial loss of energy. The reason for such changes of velocity of the gases will be apparent when it is considered that the different particles have different masses and are acted on differentially by the gases to such extent that their relative velocities will be changed and additional impacts must result. Since effective grinding is entirely dependent on the frequency of impacts, the increase of the number of impacts thus resulting promotes the grinding action.

These and other objects of the invention will become more apparent from the following description, read in conjunction with the accompanying drawings, in which:

Figure 1 is a diagrammatic elevation, partly in section, illustrating a preferred form of apparatus for practicing the method in accordance with the invention;

Figure 1A is a perspective diagram illustrating velocities of flow in the section of the apparatus of Figure 1 indicated at AA;

Figures 1B and 1C are similar to Figure 1A and illustrate flow conditions in the regions at BB and CC;

Figure 2 is a diagrammatic elevation similar to that of Figure 1, but illustrating a modified form of the apparatus;

Figure 3 is another similar view illustrating a further modification of the apparatus;

Figure 4 is still another view illustrating a modification of the apparatus; and

Figure 5 is an elevation partly in section illustrating a somewhat different form of apparatus but embodying certain features of the invention.

In Figure 1 there is illustrated in more or less diagrammatic fashion one form of apparatus in accordance with the invention designed to be used either for grinding or drying. This apparatus comprises a continuous tubular casing elongated in a vertical direction. It comprises a lower bend 2 into which high velocity jets of gas or vapor may be introduced through nozzles 6 and also into which the material may be introduced from a supply tube 9 by means of a nozzle 8 adapted to produce a high velocity jet and arranged to entrain the material to be treated. As indicated, all of the jets are directed preferably substantially tangentially to the direction of flow through the bend 2 of the apparatus as viewed in the side projection of Figure 1. Nozzles at the sides, however, are preferably arranged to provide jets directed transverse to the apparatus and intersecting each other to increase particle impacts, such jets having preferably, however, forward components of direction.

The bend 2 delivers the fluid carrying the material in suspension into an expanding or diffuser section 10, which may be of divergent form, as illustrated. In order to promote an asymmetrical condition hereafter described, the divergent diffuser portion may be somewhat asymmetrical, as indicated, each horizontal section being circular or elliptical, but the arrangement being such that the divergence occurs primarily outwardly. However, this is not essential as the asymmetrical condition is primarily due to centrifugal action as described later.

The divergent section 10 opens into a vertical stack indicated at 12, which may be cylindrical, though not necessarily so. This, in turn is surmounted by a somewhat convergent section 14, which communicates with the upper bend 16, which is of substantially larger cross-section than the bend 2. The bend 16 may discharge into a cylindrical section 18 from which there extends the discharge passage indicated at 20, communicating with a suitable receiver for the material in its finished state; for example, a separator of conventional type, adapted to separate fine particles from a carrying gas or vapor.

The section 18 communicates in turn through an expanding portion 19 through the down stack 22, which discharges into a converging section indicated at 24 communicating with the bend 2.

Assuming first that grinding is to take place, the action of the apparatus is as follows: The material entrained in the gas or vapor emerging from the nozzle 8 is carried into the bend 2 at a very high velocity, preferably exceeding the acoustic velocity characteristic of the gas or vapor under the conditions existing in the jet. For this purpose, the nozzle 8 may be suitably formed, preferably being of a converging-diverging type for the attainment of maximum velocities. Such arrangements for the feed of material are described more fully in my copending

application referred to above, to which reference may be made.

The material thus carried into the bend meets a series of tangentially and transversely directed jets from the nozzles 6, each of which is preferably so formed as to impart a maximum velocity to its jet preferably substantially exceeding the acoustic velocity for the conditions of the jet. Under these conditions, a state of extreme agitation is produced in the bend 2, and the particles of material to be ground are subjected to intense and numerous collisions to effect very active grinding. Where the jets enter the bend 2 they tend to produce suction and, furthermore, due to the curvature of the bend, a centrifugal action occurs tending to throw the particles to the outside, the forces tending to effect this being greater as the sizes of the particles are larger. As a consequence, the larger particles are subjected to irregular paths productive of grinding. At the same time, a returning stream of gas or vapor enters the bend the action of which contributes to the grinding, as will be hereafter described.

The location of the nozzles at the outside of the bend has another advantage in that the recirculating particles are centrifugally thrown outward thus being concentrated towards the nozzles to produce more effective loading of the jets. The grinding action is thus promoted since the grinding impacts increase with the concentration of particles in the most turbulent portions of the gas.

The location of the nozzles at the outside of the bend also serves the very useful purpose of reducing friction of the recirculating gases through the bend. Since the lower bend has a cross-section less than that of the remaining apparatus, the velocity therethrough is very high and friction with the walls would be serious. The gas here, however, is thrown centrifugally outwardly so that friction with the outside of the bend is the only friction that would tend to substantially retard the flow. By reason of the presence of the jets recirculating gases are kept substantially away from the wall and free flow is thus promoted.

At this point, it may be noted that the sections 24, 2 and 10 constitute a converging-diverging nozzle, using the term nozzle in a broad sense, i. e., not the more restricted sense of thermodynamics as indicating a passage in which acoustic velocities are attained. Preferably the divergence is such that it is over expanded, that is, such that gas flowing through it leaves its walls with production of great turbulence thereat. It is characteristic of such a converging-diverging nozzle, irrespective of whatever it is overexpanded or not, that with sufficiently small differences of pressure before and after it a very slight drop of pressure after the nozzle produces a considerable drop of pressure in the throat (i. e., the bend 2), so that the pressure in the throat never attains the value of the back pressure. The divergent section such as 10 acts as a diffuser and exerts a strong suction effect, so that the gas or vapor flowing through the nozzle increases in quantity quite rapidly with only slight increase in the pressure differential. From the entrance of the nozzle to the throat, i. e., in the section 24, there occurs a substantial adiabatic expansion with the production of kinetic energy. Then in the diffuser there is a reconversion of the kinetic energy into pressure. The losses in such conversion are relatively small and result in a little drop in pressure.

The nozzle action just referred to, of course, is accurately true only when there is no fluid added in the nozzle itself. However, in the present case, where such fluid is added, the nozzle action is superimposed upon the action which results from the high velocity jets emerging from the nozzles 6 and 8. The result is a very high velocity through the throat 2 of the large nozzle and a through-put many times greater than the volume of gases entering the nozzles 6 and 8.

The through-put of this type of nozzle which produces high velocities at the throat is very high, and with a large size nozzle such as utilized in this apparatus in which the cross-section of the bend may be, for example, from three to eighteen inches or more in diameter, the consumption of gas or vapor would be extremely high consistent with the maximum possible flows. However, the nozzle in this case is turned back on itself so as to deliver through the sections 12, 14, 16, 18 and 22 to the inlet section 24. In a sense, it may be said that the nozzle cannot recognize that it is feeding itself, and consequently the velocities existing in its throat will be those established by the relative pressure conditions and approach velocity conditions existing in the system. As a result of this action, given certain flows through the introducing nozzles 6 and 8, the circulatory velocities attained in the apparatus are much higher than those secured if a tubular return apparatus is provided having uniform cross-section throughout its extent. That is, the existence of the converging-diverging nozzle portion at the point where the gases or vapors are introduced produces a maximum velocity of flow which means that on the average any unit of the gas introduced will circulate more times through the apparatus than in an apparatus of uniform cross-section.

For a given pressure in the gas or vapor chest 4, much higher jet velocities may be attained with introduction of the jets into the Venturi throat than with introduction elsewhere since at the throat a minimum back pressure exists. This adds to the velocities of circulation to a very considerable extent.

An unusual and highly desirable result of the extraordinarily high velocities and greater recirculation may now be described. The high velocities in the bend 2 which carry over into the diffuser section 10 create an intense centrifugal action. This action is so intense as to create a very unusual condition in the bend 2, through the diffuser 10, and to a substantial height in the upright stack 12. This may be best illustrated by reference to Figure 1A, which indicates in perspective velocity conditions existing at the cross-section indicated at AA in Figure 1. In Figure 1A the circular section at AA is indicated by the ellipse shown in chain lines. *ab* may be taken to represent a line lying in the plane of the cross-section and extending across the stack 12 from left to right, as indicated in Figure 1, i. e., from the outside to the inside of the passage through the stack. *cd* is a line perpendicular to this and also in the plane of the section. Associated with the line *ab* there is a curve *opqr* which represents the boundary of vectors indicating velocities in the stack along this line *ab*. Where the curve is above the line *ab*, upward velocities corresponding to its ordinates are indicated. On the other hand,

where the curve lies below the line *ab*, downward velocities indicated by its ordinates are indicated. It will be noted that at the outside of the passage, namely at point *a*, a high upward velocity exists as indicated by the vector *ao*. Again at *b* there is an upward velocity indicated by the vector *br*, but this velocity is considerably lower than the velocity at *a*. At *p* and *q* the velocities are zero. Intermediate *p* and *q* the velocities are downward, as indicated, for example, at the central portion by the vector *s*. Across the tube along the line *cd* a similar condition exists. At *c* an upward velocity *ct* exists. At *d* an upward velocity *du* exists. In the central region between these points, downward velocities exist with the result that there is a certain area asymmetrically located toward the inner side of the passage as indicated at *v* within which flow is not upward, but downward.

The boundaries of this region are indicated by the trace *w* in Figure 1. From a point *x* adjacent the discharge end of the bend **2** up to the upper end of the trace *w* upward velocities of flow occur adjacent the walls. On the other hand, within central regions downward velocities occur. From a point *y* to the point *x* on the other hand, backward velocities exist in the bend **2** adjacent the inner or upper side thereof, as indicated by the arrows which are used to mark the regions of upward and forward velocities. These conditions are readily found by means of a Pitot tube, and while the extents of the various regions are largely dependent on dimensions and velocities, it will be found, in general, that with high velocities in a relatively sharp bend and with a substantial expansion in a section such as **10**, there exists a well-defined region of reverse flow. While asymmetry of the diffuser section **10** by having it diverge outwardly towards the left as viewed in Figure 1 aids to some extent in enlarging the reverse flow region, the reverse flow is primarily due to the centrifugal action in the bend **2** which causes the gas and particles to follow the outer wall portions of the stacks.

It will, of course, be understood that the region of reverse flow is not sharply defined in the sense that there can be located at its boundaries zero velocities. As a matter of fact, there is intense turbulence, particularly at the boundaries of the regions, and the region itself represents merely an average condition of flow. The existence of the region, however, means several things. First, considering a certain quantity of recirculatory flow through the apparatus, it is obvious that the cross-sectional area of the flow path in the lower portion of the stack **12** is not the cross-sectional area of the stack, but is rather the cross-sectional area of the annular portion surrounding the reverse flow region. Furthermore, since the reverse flow region is receiving some gas or vapor from the gas or vapor flowing upwardly outside it, it will be obvious that the velocities surrounding this region are extremely high. The result is the maintenance for a considerable distance up the stack of high velocities of flow of a very turbulent nature contributing to the grinding action.

A second effect of the reverse flow region is the carrying back of heavier particles to the bend **2** and the vicinity of the jets. A heavy particle which will have acquired a high velocity in the bend **2** may be slowed down or caused to drop under the action of gravity in the upper portions of the stack **12**, where the velocities are lower. Under such conditions, if it drops into the reverse flow region, of which there is a considerable probability, it will not only drop to the region of the diffuser, but may be carried into the region between *x* and *y*, from which it would be returned to the jets. This action is readily observed in the case of large particles, which can be seen to pass upwardly into the stack and then drop downwardly and disappear, to reappear in a broken or disintegrated form subsequently in the stack.

Figures 1B and 1C are similar to Figure 1A in indicating the existing velocity conditions, and their representations will be obvious without further description. It will be noted that in the regions where these diagrams are taken only forward velocities exist, though the velocities differ rather considerably throughout the cross-sectional areas.

The particular nature of the reverse flow region is dependent on various conditions, including, for example, the degree of expansion of the diffuser section **10**, the curvature of the bend **2** and whether or not there is between the bend and the diffuser section a straight passage. It has been found, for example, that the reverse flow region may have its shape considerably altered by having a straight portion of substantial length located between the bend and the diffuser. In such a portion of the passage the centrifugal action seems to result in a reflection of the stream, which would be toward the right in Figure 1 and the reverse flow region in such case may occur toward the left hand side of the stack and diffuser, passing inwardly in the region of the bend to produce reverse flow at the inner portion of the bend in a fashion similar to that indicated between *x* and *y*. This may be further modified by asymmetrical arrangement of the diffuser section. With a high degree of overexpansion, some reverse flow may occur even without the presence of a bend preceding the diffuser by a moderate distance, though generally the reverse flow will not be so well defined nor of such considerable extent as is indicated in Figure 1. It may be said that what is desirable in any modifications of this nature is the provision of a reverse flow region of substantial cross-section in which the flow is in a downward direction so that there is offered, first by reason of its size, a substantial probability that heavy particles will enter it, and second because of its downward flow that flow therein will be aided by gravity. Thus a maximum return of large particles will be secured.

The height *h* of the stack is important in securing the most effective grinding of large particles in connection with the reverse flow region. If the height *h* in advance of the upper bend is not sufficiently great, large particles may be carried about the bend. In such case, they would normally return to the lower bend for further grinding. It is to be remembered, however, that a statistical distribution of particles, velocities, etc., occurs in an apparatus of this type, and consequently if any particle of large size passes through the upper bend there is some probability that it may get into the exit and thus contaminate the fine product. This is particularly true if an ultra-fine product is not desired, but rather a moderately coarse one, in which case the outlets would be located so as to remove coarser grains, from which there should be excluded, however, any very coarse ones. The above makes it desirable that large particles should not reach the upper bend. While the average velocity of

such particles may generally be low in portions of the stack above the reverse flow region, at which points the upward velocities of the gas are comparatively low, nevertheless some large particles may have initially high velocities, and it is desirable to have the stack sufficiently high so that these particles will be subjected to a retarding frictional force by the gases through which they are moving, and by reason of this and their own weight, will be slowed down first to the relatively low velocity of the gases and then, under their own weight, will drop backward until they enter the reverse flow region wherein they will be returned to the turbulent lower portions of the apparatus. The height of the stack to insure highly improbable carrying over of particles greater than a predetermined size may be readily calculated from the measurements of the highest velocities in, for example, the expanding portion 10 of the nozzle passage and a consideration of Stoke's law, the latter giving the sizes of particles which will or will not settle down by gravity in a gas of given upward velocity, and the former, with consideration of the frictional forces, acting on the particles, giving the distance through which a particle will travel starting with a given velocity before its velocity is reduced substantially to that of the gas through which it is passing.

The stack 12 terminates in the slightly converging section 14, which is made so to provide an increase in velocity in the upper bend 16. The purpose of this is to promote separation and return of the larger particles by centrifugal action in the bend 16, while the lighter particles are taken off by reverse flow through the discharge passage 20, which communicates with the section 18. The recirculating gas or vapors carrying the heavier particles then return through the passage 22 to the converging-portion of the lower nozzle section of the casing.

By provision of an expanding region at 19 there may be provided the relatively elongated nozzle section consisting of 14, 16 and 19. In this nozzle section there will be set up changes in velocities and possible reverse flow in the vicinity of the diffuser 19, though with the presence of a relatively long straight section 18 and the use of a baffle as indicated at 34, as described below, reverse flow in this region may be destroyed. At this point it is not important, and hence the apparatus has been indicated as involving substantially no reverse flow thereat.

As many changes in velocity as possible in the apparatus are desirable if grinding is to be effected. Any particles, no matter how small are, of course, substantially denser than equal volumes of the gas. If the gas is accelerated, the particles lag behind it, while if they are moving with substantially the velocity of the gas and the gas is decelerated, they tend to move at a higher velocity than the gas. This lag or advance of the particles is dependent upon their size, and consequently particles of different sizes will move relatively to each other in any such region where change of velocity is occurring if the change is either of the magnitude or direction of the velocity. Centrifugal action in the bends is an example of change of velocity in the sense of change of direction, while actions at converging or diverging portions of the passages are examples of changes of magnitude of velocity which may or may not be attended with changes in direction. In any case, whether the change is in magnitude or direction, relative movements of the particles will occur attendant with grinding actions.

An important feature of the operation of this type of grinder is that the grinding is not due to abrasion of the particles on the walls. In fact, it has been observed that in many portions of an apparatus such as this, unless they are impinged by directed jets there may exist a cushion of concentrated particles moving relatively slowly and apparently protecting the walls of the apparatus from impact by the more rapidly moving particles. Even when materials are ground which are quite abrasive in nature, very little wear on the walls of the apparatus occurs.

While the above is important from the standpoint of wear on the apparatus, the major significance of the fact that the grinding takes place between the particles themselves is that the temperature in the apparatus does not rise to any such extent as would accompany corresponding intensive grinding by mechanical means. It has been found that even where most intensive grinding is occurring, there seems to be no appreciable temperature rise. While it cannot be said that the reason for this is definitely known, it appears likely that when particles are carried in a gas and get quite small their impacts become more and more of such nature that there is conservation of kinetic energy except to the extent of the relatively small amount of energy necessary to overcome cohesion in the particles. Stated otherwise, if two particles collide it appears likely that the energy they have prior to the collision is transformed merely into the energy necessary for breaking the cohesion and a final kinetic energy of the particles without the production of any substantial transformation of energy into heat. The final kinetic energy is permitted to exist because of the fact that the particles are freely floating in gas. In most grinding operations, as contrasted with this, the materials are restricted from free movement and consequently the energy which would become kinetic is dissipated in the form of heat.

The practical advantage of this is particularly illustrated in the comminution of materials which might be easily softened or detrimentally affected by heat. For example, various materials of a waxy nature which may be introduced into the apparatus in molten condition and comminuted by the high velocity jets, and cooled by them so that solid particles are produced, will apparently be ground without coalescence and remelting in portions of the apparatus prior to their removal from a recirculating stream of gas. Whereas if the energy of the impacts was converted substantially entirely into heat, it would be expected that remelting and coalescence of the particles would occur in those portions of the apparatus where lower velocities would exist. Grinding of readily oxidizable particles may be accomplished even in air without danger that the temperatures will rise to a point where active oxidation will occur. Thus the apparatus is made effective for the handling of organic materials.

Another factor contributing to changes of gas velocity resulting in relative velocities of particles of different sizes, and consequently their grinding, is the presence of surges within the apparatus resulting from sound waves which may be frequently observed in the nature of travelling waves through dust clouds in the apparatus. An elongated tubular apparatus of this type

tends to act to a substantial extent as an organ pipe and the operation is accompanied with considerable noise. The turbulent regions probably maintain the vibrations and as the sound waves travel within the apparatus concentrations and rarifications are superimposed upon the movements of the gases and the particles which they carry in such fashion as to produce relative movements and grinding. Under some substantially uniform conditions of operation, standing waves may be observed in the recirculating gas stream. Such waves represent, of course, the super-position of wave motions on the motions of average flow.

In the operation of the apparatus a limit is somewhat automatically imposed on the amount of material which can be loaded into the gases. As the loading of the gases with material approaches an effective limit, the velocity of flow is materially reduced and thus serves as a warning of overload and relatively ineffective grinding. In general, the condition of overload may be readily recognized from the sound of the apparatus even without measurements of the change of flow velocity and the apparatus is preferably operated with a controlled flow providing supply to the apparatus of a maximum amount of material to produce effective grinding at high efficiency. The optimum amount of material depends largely upon the size of the particles introduced and the extent of recirculation necessary to give the desired end product. While overloading is to be avoided, nevertheless fairly heavy loading is desirable, since this appears to result in finer materials, probably by reason of the greater probability of impact.

The outlet **20** has been referred to broadly, but is desirably of special design, as indicated in Figure 1, in which figure it is located so as to take off only the smallest particles. The inside of the portion **18** of the apparatus (i. e., inside with respect to the curvature of **16**) is provided with a transverse slot indicated at **26**, the vertical dimension of which may be changed by means of a sliding damper **28**, which can be manipulated by means of a knob **30** and which is provided with a lip **32** extending into the outlet passage **20** with which the slot communicates so as to guide the entering gases and particles at their entrance into the outlet. Above this slot **26** there is provided a baffle indicated at **34**, which may be made adjustable inwardly of the passage if it is desired to control to a fine extent the size of particles entering the outlet passage.

By the above construction, an extremely effective centrifugal separation of particles of different sizes and the outlet may be effected. Assuming that the barrier **34** is not present, and that the slot **26** is made very narrow by reason of an upper positioning of the damper **28**, it is obvious that any gas entering the outlet must undergo an extremely sharp curvature in its path. Let it be assumed, for example, that the average velocity of the gas through the portion **18** of the apparatus is 200 feet per second, and that the maximum radius of curvature of the path of gas entering the slot **26** is one-half inch. In such cases, there is a centrifugal separating force exerted which is about 60,000 times the force of gravity. Since through the curved portion **16** of the apparatus there is already produced some centrifugal separation of heavy and light particles, it will be obvious that the separating force at this small radius would result in the presence of only extremely minute particles in the outlet passage.

By increasing the vertical extent of the slot **26** by opening the damper, the maximum radius of curvature will be substantially increased; in fact, to a rough approximation, the radius of curvature is of the order of the vertical dimension of the slot. Thus if larger particles are to be passed, it is only necessary to open the slot.

If still larger particles are to be passed, a baffle such as indicated at **34** may be provided. In such case, the flow of the gas is considerably changed in advance of the outlet, with the result that larger radii of curvature into the outlet occur, in any such case the radius of curvature being no longer so dependent upon the vertical height of the slot. By a combination of means for moving the slot height and the use of a baffle **34** it will be obvious considerable variations in centrifugal separation may occur at the outlet.

The location of the slot **26** on the inside of the apparatus and closely adjacent the end of the curved portion **16** will effect selective removal of only the smallest of the particles. It is frequently not desirable to have extremely small particles because of the difficulty in handling them, since they tend to form large amounts of dust in processing. When larger particles are, desired, it is, of course, necessary to prevent extremely fine grinding by reduction of the intensity of the grinding actions in the lower portions of the apparatus; i. e., the nozzle velocities may be lowered, the number of nozzles used may be reduced, etc. Even in such cases, however, selective separation is frequently desirable, and at times it is desirable to provide a number of grades of particles, some very fine and others of larger size. To effect such selection, the outlet of the type of **20** may be differently located in the apparatus. For example, the outlet might be at the side and directed upward, as indicated at **20'**, or perhaps on the inside and directed downward, but at the lower portion of the down flow passage **22**. Each of these outlets may be combined with a baffle arrangement and a damper chosen in accordance with what it is desired to separate. As examples of the various actions which take place, there may be considered what will occur with passages at **20'** and **20''**, respectively.

In the former case, it is obvious that the slot is going to receive particles of larger size than in the case of the slot located in conjunction with the outlet **20**. The reversal of flow, however, if the discharge is directed upwardly will again produce some centrifugal separation preventing the largest particles from passing outwardly. If the outlet is directed downwardly, on the other hand, large particles will be passed.

In the case of an outlet at **20''**, if it is directed downwardly fairly large particles may be passed because, by the time they reach the lower portion of the passage **22** they will have diffused inwardly. If on the other hand, the passage **20''** is directed upwardly to produce a reversal of flow, then it will reject very large particles, though there will pass into it larger particles than those entering the outlet **20**. Outlets of this type may obviously be used either as the sole outlet of the apparatus or together for the purpose of providing various grades of the product.

It is to be noted that the amount of gas flowing through any such outlet in the type of ap-

paratus disclosed is generally only a small fraction of that circulating when violent grinding is being done, since the outlet gas corresponds to that added (plus that evaporated if drying is taking place) and since, as pointed out above, the amount of circulation past a given point is greatly in excess of the amount added. Hence the separation is made still more effective because large velocities of entrance into the outlets do not exist to carry along larger particles.

The majority of the features of the invention have been illustrated in the modification of Figure 1. Various alternative modifications will now be described with reference to Figures 2 to 5.

Referring first to Figure 2, there is illustrated therein an apparatus bearing considerable resemblance to that of Figure 1 and comprising a lower bend **40**, a diffuser passage **44** with which the bend communicates, a stack **46**, an upper bend **50**, a downtake passage **52** and a converging passage **53**, communicating with the entrance end of the lower bend **40**. Nozzles **42**, which may be arranged in the same fashion as the nozzles **6** of Figure 1, are arranged to introduce the carrying fluid into the bend **40** and cause it to move through the apparatus and recirculate as previously described. The arrangement of the bend **40** in conjunction with the diffuser passage **44** and the stack **46** will produce the type of reverse flow previously referred to with the result that at the upper portion of the passage **40** there will be a reverse flow occurring and the production of a partial vacuum. Into this there may be drawn through a nozzle, as indicated at **48**, the material to be treated. The nozzle **48** is preferably so formed that if the material is carried thereinto in suspension in a gas it will be accelerated and a relatively high velocity jet of the material will issue from the nozzle **48**. If the vacuum at the mouth of **48** is sufficiently high the material may be introduced at atmospheric pressure. Alternatively, if higher velocities are desired the material may be introduced under pressure. By the introduction into the region where reverse flow is taking place it will be carried automatically into the region of the nozzles **42** and there will be comminuted to the necessary extent to cause it to pass through the remaining portions of the apparatus for effective grinding or drying.

The introduction of material into the reverse flow region may occur well up into the stack **46**. This is particularly desirable in the case of easily flangible material or wet materials, since grinding and drying may then be completed without having the material centrifugally thrown against the walls of a curved passage such as **40**. In the case of wet materials, the centrifugal action may occasion sticking of the material to the walls. Such introduction into the upflow stack is equally adapted to the other modifications disclosed herein.

The apparatus of Figure 2 also differs from that of Figure 1 in having an outlet provided in such fashion as to carry off comparatively coarse particles of the material being handled. For this purpose the outside of the bend **50** communicates with a tangential tube **54**, which leads the centrifugally separated material into a separator diagrammatically illustrated at **56**, from the bottom of which the material may be discharged and from the top of which, at **58**, the gas may be removed. It frequently happens that a fairly coarse material rather than a very fine material is desired as a result of grinding or drying. In such case, the apparatus of Figure 2 may be used to remove the coarser product without having it recirculated.

Instead of having the outlet for the gas at the top of a separator such as **56**, the separator may be replaced by an ordinary container and the outlet located elsewhere, for example, extending from the downflow stack **52**. Thus the device acts not only as a grinder or dryer, but additionally as a centrifugal separator.

Figure 3 illustrates still another modification of the apparatus. In this apparatus the downflow tube is indicated at **60** and communicates with a converging passage indicated at **62**, which directs the flow into a curved passage **64** in which the material is accelerated by means of nozzles **68**. The curved passage **64** discharges into a diverging diffuser passage **70**, which in turn discharges into a cylindrical passage **72**. This communicates with a second curved passage **74** followed by a diffuser passage **76** and the vertical stack **78**. Nozzles **80** may be directed into the curved portion **74** to accelerate flow therethrough.

By the arrangement just described it will be noted there are provided two Venturi or nozzle passages for the recirculating fluid and the materials which it carries. Since there are two bends followed by diffuser passages, reverse flow may occur at two regions, as illustrated by the arrows. Through the last of these the reverse flow may be aided by means of a nozzle **82**, entering the diffuser passage **76**, and by nozzles **84** entering the curved passage **74**. If desired, additional nozzles may be used to aid the reverse flow at the bend **64**. The material to be treated may be introduced at **86**, where it will enter in the direction of forward flow, or alternatively, or additionally, at **88**, where it will enter in the direction of reverse flow. In any case, the material is entrained in the high velocity jets from the nozzles **68** and carried on to be accelerated and further comminuted or dried by the action of the nozzles **80**.

The apparatus of Figure 3 carries out even more effectively than that of Figures 1 and 2 the feature of multiplying the impacts of particles by repeatedly changing the velocities of the flowing gaseous fluid so as to secure the differential accelerations and retardations referred to above. In this apparatus of Figure 3, it will be noted that there are actually three venturis. Each of these is provided with a curved throat in which centrifugal acceleration will take place and a maximum of turbulence is insured in the two lower venturis by the position of the accelerating nozzles. Reverse flow additionally creates a great amount of turbulence and further vectorial acceleration of the gases. The result is that the apparatus of Figure 3 is an extremely effective grinder even in the limited region at the bottom of the apparatus containing the two venturis. The Venturi passage at the top of the apparatus is also effective in promoting further grinding as well as serving for the return of the material for additional treatment.

A simple tubular outlet illustrated at **90** may be used in the event that separation is not desired at that location. If separation is desired, the type of outlet illustrated at **20** in Figure 1 may be used.

Figure 4 shows still another modification having advantageous characteristics. The lower bend **92** is provided with accelerating nozzles indicated at **100**. In this figure the nozzles **100** are particularly arranged for the purpose of securing most effective loading and for this purpose are

provided with side passages 98 communicating with the outside of the bend 92. These passages 98 enter the nozzles, preferably at the vena contracta of each where they are subjected to very considerable suction. As a result of this arrangement the material circulating in the apparatus, and which may be introduced initially through a passage 94 by means of a nozzle 96, will be thrown outwardly centrifugally in the curved passage 92 and will then be sucked into the passage 98 to be reinjected into the apparatus by means of the nozzles 100. The recirculation thus produced at the nozzles themselves is extremely effective to produce grinding and also prevent the settling of material in dead spaces between the nozzles to which it may be thrown centrifugally. In the event that the material is of such nature as to tend to stick to the walls of the passages, the openings of the suction connections 98 may be made to occupy as much of the area of the bend as desired, with the result that a minimum of the material may find any quiescent region in the bend.

The bend 92 communicates with a converging passage 102 which leads into the tubular throat 104 terminating in an expanding diffuser passage 106 which discharges into the stack 110. Nozzles 108 may be provided in the throat of this Venturi or nozzle passage to produce added acceleration of the gases therethrough to effect results similar to those previously described. Inasmuch as this portion of the venturi is straight, it is very well suited for the reception of jets which may impinge on each other providing cross-flow conducive to the production of high velocity grinding and the effect of drying. At the upper end of the stack 110 there is a converging passage 112 which, in the present instance preferably provides a connection between the cylindrical tube 110 and an upper passage 114 of converging type and of rectangular cross-section. At the wide entrance end of this passage the cross-section may be square and in this modification gradually changes with reduction of cross-sectional area to a rectangular cross-section having its maximum dimension across the apparatus in a direction transverse to the plane of the paper. This passage reaches its narrowest portion at 119 from which the passage widens as indicated at 118 back to a square cross-section where it joins the transformation section 122 which changes from its entrance to its communication with the circular cylindrical stack 124 from a square to a circular cross-section. Communicating with the nozzle passage provided at 114, 119 and 116 and joining the flat face 119 of the portion 116 is the outlet 120 which communicates with the passage through an elongated slot as indicated. The change to the rectangular cross-section is primarily to secure the provision of this communicating slot in a plane rather than through an arc about a section of curved cross-section. In general it may be said that the sections of the passages are relatively immaterial, circular sections being generally used only because they are more readily constructed and more readily fitted to each other without difficulties. Where reference is made to passages of cylindrical type, the term "cylindrical" is intended to be interpreted in its broad mathematical sense, and where a passage is said to be of substantially uniform cross-sectional area, it will be understood that the actual cross-section may be changed throughout such passage while the area remains substantially constant. With this explanation it will be obvious that the different stacks in the various modifications heretofore described may have any desired cross-sectional shapes, but are of substantially constant cross-sectional areas, the same being true of the curved or straight throat portions of Venturi or nozzle passages. The various converging or diverging passages may vary along their lengths in their cross-sectional shapes, the increases or decreases in area being designed to effect the proper thermodynamic transformations involving pressure, velocity and temperature changes.

In a case where the maximum of grinding is to occur in a minimum of space, and where separation of particles of different sizes is not particularly important, the type of apparatus illustrated in Figure 5 may be adopted. In this modification, there are joined end to end a series of venturis or nozzle passages, indicated at 126, 128, 130 and 132. An outlet from the last of the series may be provided, as indicated at 134, some crude separation being provided by causing the outlet to extend in a direction reversed with respect to flow through the passage. Material may be introduced at 136 under pressure or by atomization in any of the fashions described, and is accelerated through the apparatus by the various sets of nozzles 138, 140, 142 and 144, preferably directed to provide intersecting jets which extend generally in the direction of flow through the throats of the passages. Semi-spherical junctions are provided between the nozzle sections of the apparatus, providing proper terminations to the diverging passages and proper entrances to the throats of the nozzles. With an apparatus of this type, not only is intense centrifugal action set up at the sharp bends, but additionally in the Venturi or nozzle passages there are accelerations followed by decelerations in such fashion as to secure violent changes in the relative particles of different sizes. In addition a great deal of turbulence is created by means of the supply gas nozzles. The result is a compact apparatus in which, though only crude separation is possible, there is a maximum of grinding, though at the expense of the provision of considerable amount of accelerating gases.

For convenience of reference, Venturi passages have been mentioned throughout the specification. In engineering practice, a Venturi passage generally implies a passage arranged for smooth flow without breaking away of the gas from the walls of the passage. It will be noted, however, that where the term is here used it is used in the more general sense to refer to a passage having converging throat and diverging portions, but in which there may be abrupt changes in the walls or over-expansion or the like, resulting in the gas's breaking away from the walls, thus producing turbulence, which, in the case of the type of apparatus herein described, is desirable rather than objectionable.

It will be obvious that the various features of the invention described above may be embodied in other modifications of the apparatus, and accordingly the invention is not to be considered restricted, except as defined by the following claims.

What I claim and desire to protect by Letters Patent is:

1. Apparatus for the treatment of material in comminuted form comprising a casing providing an endless tubular passage, a plurality of portions of said passage being in the form of Venturi passages, means for feeding material to said

tubular passage, and means for inducing a high velocity flow of elastic fluid through said tubular passage to maintain particles of the material continuously in suspension and recirculating through said tubular passage.

2. Apparatus for the treatment of material in comminuted form comprising a passage through which the material may flow in gaseous suspension, means for feeding material to said passage, means for inducing high velocity flow through the passage, and an outlet passage communicating with the first named passage and arranged at a backward angle with respect to the first named passage so that material entering the outlet passage must undergo a substantial change of direction of flow of more than 90° and be thereby subjected to a centrifugal separating force, and means for adjusting the width of the entrance to said outlet in the direction of flow through the passage, so that the centrifugal separating action may be modified.

3. Apparatus for the treatment of material in comminuted form comprising an endless passage through which the material may recirculate in gaseous suspension, means for feeding material to said passage, means for inducing high velocity flow through the passage, and an outlet passage communicating with the first named passage and arranged at a backward angle with respect to the first named passage so that material entering the outlet passage must undergo a substantial change of direction of flow of more than 90° and be thereby subjected to a centrifugal separating force, with the result that centrifugally separated material will continue to move in the recirculating flow through the first named passage, said outlet passage communicating with the first named passage through a slot elongated in a direction transverse to the direction of flow through the first named passage.

4. Apparatus for the treatment of material in comminuted form comprising a passage through which the material may flow in gaseous suspension, means for feeding material to said passage, means for inducing high velocity flow through the passage, and an outlet passage communicating with the first named passage and arranged at a backward angle with respect to the first named passage so that material entering the outlet passage must undergo a substantial change of direction of flow of more than 90° and be thereby subjected to a centrifugal separating force, and means for adjustably controlling the radius of curvature of the gas path as it flows from the first named passage into said outlet passage.

5. Apparatus for the treatment of material in comminuted form comprising a casing providing an upright endless tubular passage, means for feeding material to said passage, means for introducing suspending elastic fluid for said material at high velocity at the bottom of said passage, means for removing said material at the upper portion of said passage, and means providing a reduction in cross-sectional area of said passage for accelerating the suspended material in the vicinity of and past said removing means to cause heavier particles to pass without entering the removing means.

6. Apparatus for the treatment of material in comminuted form comprising an upright unobstructed stack of substantial length and cross-sectional area, means for feeding material in gaseous suspension into the apparatus, and means for producing an upward flow of said material in gaseous suspension in said stack and a region of reverse flow in at least the bottom of the stack, said means directing gaseous fluid upwardly into said stack in a direction at an acute angle with at least a portion of the wall thereof to produce thereat a partial vacuum into which said reverse flow occurs, and said means for feeding material introducing it into said region of reverse flow.

7. Apparatus for the treatment of material in comminuted form comprising an endless tube including a plurality of Venturi passages in series with each other, each including a throat and a diverging diffuser discharge portion provided by restricted and enlarged portions of said tube, and having free unobstructed communication between them, means for feeding material into said tube, and means for inducing a continuously forward flow of elastic fluid recirculating through said endless tube and in series through said passages at sufficient velocity to maintain the particles of material in suspension throughout said passages.

8. Apparatus for the treatment of material in comminuted form comprising an endless tubular passage for the flow of material in suspension in elastic fluid, means for introducing material into said passage, at least one nozzle connected with and discharging elastic fluid into said passage in the direction of the axis of said passage and effecting recirculation of said fluid through said endless passage, and a second connection between said nozzle and said passage through which the nozzle aspirates material from the passage to return it to the passage in the nozzle jet.

9. Apparatus for the treatment of material in comminuted form comprising an endless tubular curved passage adapted to impose centrifugal forces on material flowing therethrough in suspension in elastic fluid, means for introducing material into said passage, at least one nozzle connected with and discharging elastic fluid into said passage in the direction of the axis of said passage and effecting recirculation of said fluid through said endless passage, and a second connection between said nozzle and said passage through which the nozzle aspirates centrifugally separated material from the passage to return it to the passage in the nozzle jets.

10. Apparatus for the treatment of material in comminuted form in suspension in elastic fluid to produce a finely divided substantially solid product comprising a tubular passage having a curved axis and adapted to impose centrifugal forces on material flowing therethrough, means for introducing material thereto, a diverging passage arranged to receive material from said curved passage while it is flowing under the influence of said centrifugal forces so as to be directed towards a side of said diverging passage, an enlarged unobstructed elongated substantially straight tubular member into which said diverging passage discharges, means for inducing high velocities of flow through said curved passage comprising at least one nozzle arranged to discharge fluid in the direction of flow therethrough, means for returning elastic fluid from said straight tubular member to the first mentioned tubular passage for recirculation therethrough, and means for removing said product from the last mentioned means, said means for returning elastic fluid including a Venturi-like passage within which the fluid is accelerated above its velocity in said enlarged straight tubular member.

11. Apparatus for the treatment of material in comminuted form in suspension in elastic fluid to

produce a finely divided substantially solid product comprising a tubular passage having a curved axis and adapted to impose centrifugal forces on material flowing therethrough and to discharge said material upwardly, means for introducing material thereto, a diverging passage arranged to receive material from said curved passage while it is flowing under the influence of said centrifugal forces so as to be directed towards a side of said diverging passage, an enlarged unobstructed elongated substantially straight upright tubular member into which said diverging passage discharges upwardly, which has a cross-sectional area at least as great as that of the diverging passage, and in which gravity separation of heavier particles may occur, means for inducing high velocities of flow through said curved passage comprising at least one nozzle arranged to discharge fluid in the direction of flow therethrough, means for returning elastic fluid from said straight tubular member to the first mentioned tubular passage for recirculation therethrough, and means for removing said product from the last mentioned means, said means for returning elastic fluid including a Venturi-like passage within which the fluid is accelerated above its velocity in said enlarged straight tubular member.

12. Apparatus for the comminution of material and its treatment in comminuted form in suspension in elastic fluid to produce a finely divided substantially solid product comprising a Venturi-like passage including a throat and a diverging upwardly opening discharge portion, an upright substantially straight elongated stack having a substantially uniform and unobstructed cross-section substantially that of the discharge mouth of said Venturi-like passage, said stack extending upwardly from said discharge mouth and providing a region in which velocities of flow are reduced so that gravity separation of heavier particles may occur, means for introducing material into said Venturi-like passage for flow in suspension therethrough, means comprising at least one nozzle directed into said Venturi-like passage for inducing high velocity turbulent flow of elastic fluid through said Venturi-like passage, means for supplying high pressure elastic fluid to said nozzle to produce a jet having a velocity at least that of sound, means for returning elastic fluid from said stack to said Venturi-like passage for recirculation therethrough, and means for removing said product from the last-mentioned means, the elastic fluid supplied to said nozzle being additional to that returned from said stack to said Venturi-like passage, said means for returning elastic fluid including a Venturi-like passage within which the fluid is accelerated.

13. Apparatus for the comminution of material and its treatment in comminuted form in suspension in elastic fluid to produce a finely divided substantially solid product comprising a casing providing an endless unobstructed passage of tubular form throughout, a portion of said passage being in the form of a Venturi-like passage, means for feeding material to said tubular passage, means providing a plurality of high velocity elastic fluid jets each having a velocity at least that of sound directed into said Venturi-like portion in the direction of flow therethrough, arranged in succession in said direction of flow and inducing a high velocity turbulent flow of elastic fluid through said Venturi-like portion to maintain particles of the material continuously in suspension and recirculating through said tubular passage, means for supplying high pressure elastic fluid to form said jets, and means for diverting fluid carrying suspended material from a part of the tubular passage remote from said Venturi-like portion, the elastic fluid supplied to form said jets being in addition to that recirculated through said tubular passage, said endless tubular passage having a second Venturi-like portion adjacent said means for diverting fluid.

14. A method of pulverizing raw material comprising mixing the material with a stream of an elastic fluid moving at high speed, causing the mixture to circulate in an endless circuit elongated in the vertical direction, the upper portion of the circuit being curved and of a substantially larger cross-sectional area than the lower portion so that the flow velocities therein are substantially less than in said lower portion, separating heavier particles by the centrifugal forces thus created in said curved upper portion of the circuit, returning such heavier particles for further circulation in the circuit, and extracting finer particles at the inner side of the downflow portion of the circuit, said upper portion of the circuit having the form of a Venturi-like passage to accelerate the flow in the region of the aforesaid separation above that occurring in the portions of the circuit joining the upper and lower portions thereof.

15. A pulverizing apparatus comprising a casing forming an endless elongated tubular pulverizing chamber having its longer axis disposed substantially vertically, means to admit a raw material into the casing, means to admit an elastic fluid at high velocity into the lower portion of the casing in a direction to cause the fluid and the material to circulate through the casing, thereby separating heavier particles from the lighter particles by centrifugal force in curved portions thereof, the upper portion of the casing being of substantially larger cross-section than the lower portion so that flow velocities therein are substantially less than in said lower portion, and an exhaust duct for removing from the casing centrifugally separated particles, said upper portion of the casing having the form of a Venturi-like passage so that flow therethrough is at a higher velocity than in the portions of the casing joining the upper and lower portions thereof.

16. A method of pulverizing raw material comprising mixing the material with a stream of an elastic fluid moving at high speed, causing the mixture to circulate in an endless circuit disposed substantially in a vertical plane, the upper portion of the circuit being curved and of a larger cross-sectional area than the lower portion so that flow velocities therein are substantially less than in said lower portion, separating heavier particles by the centrifugal forces thus created in said curved upper portion of the circuit, returning such heavier particles for further circulation in the circuit, and extracting finer particles at the inner side of the downflow portion of the circuit, said upper portion of the circuit having the form of a Venturi-like passage so that flow therethrough is at a higher velocity than in the portions of the circuit joining the upper and lower portions thereof.

17. A pulverizing apparatus comprising a casing forming an endless tubular pulverizing chamber disposed substantially in a vertical plane, means to admit a raw material into the casing,

means to admit an elastic fluid at high velocity into the lower portion of the casing in a direction to cause the fluid and the material to circulate through the casing, thereby separating heavier particles from the lighter particles by centrifugal force in curved portions thereof, the upper portion of the casing being of substantially larger cross-section than the lower portion so that flow velocities therein are substantially less than in said lower portion, and an exhaust duct for removing from the casing centrifugally separated particles, said upper portion of the casing having the form of a Venturi-like passage so that flow therethrough is at a higher velocity than in the portions of the casing joining the upper and lower portions thereof.

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