Dec. 31, 1946. N. N. STEPHANOFF 2,413,420

METHOD AND APPARATUS FOR DISPERSING OR DRYING FLUENT MATERIAL IN HIGH VELOCITY ELASTIC FLUID JETS

Filed Feb. 26, 1940 5 Sheets-Sheet 1

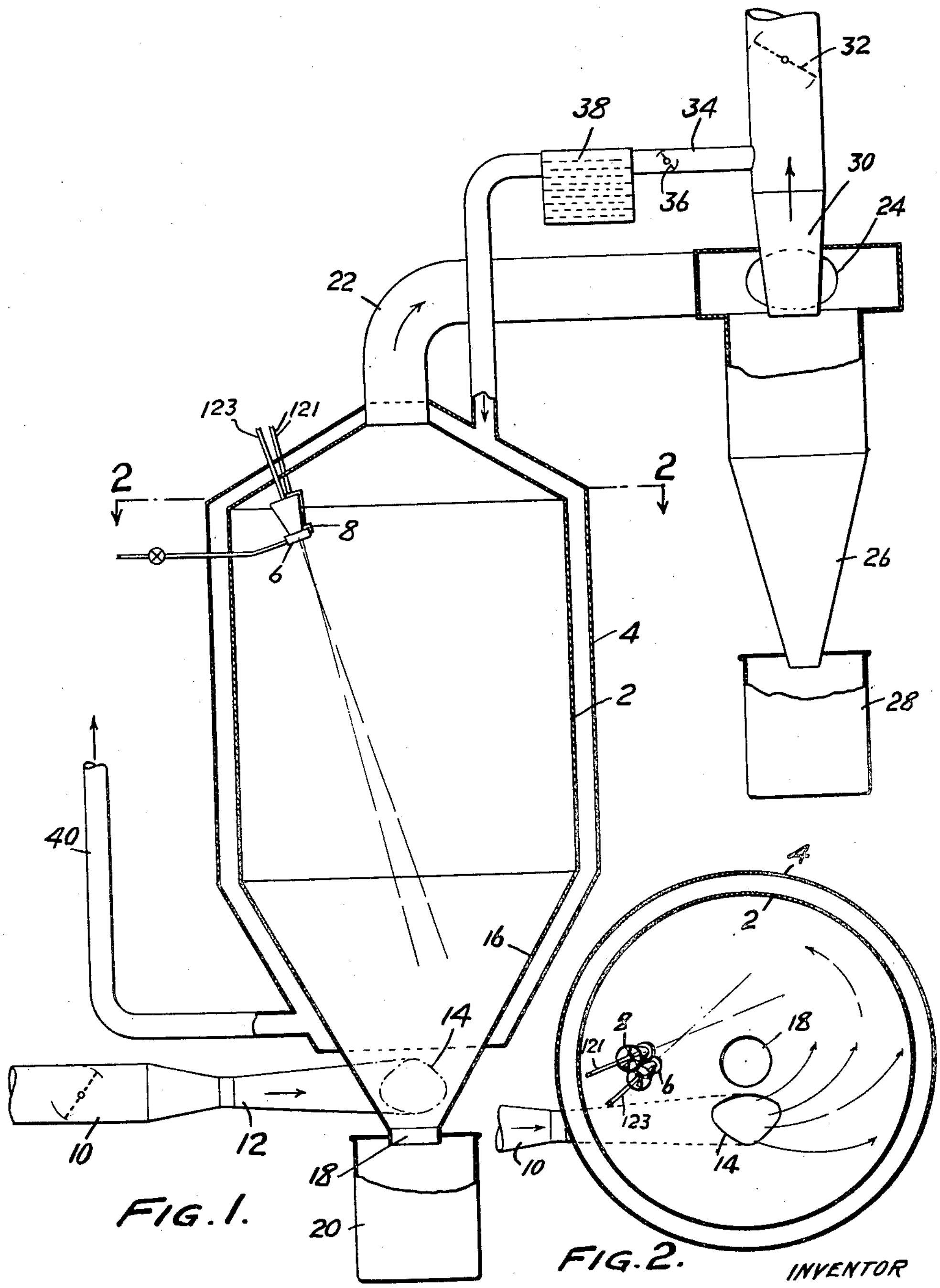

FIG. 1.

FIG. 2.

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METHOD AND APPARATUS FOR DISPERSING OR DRYING FLUENT MATERIAL IN HIGH VELOCITY ELASTIC FLUID JETS

Filed Feb. 26, 1940 5 Sheets-Sheet 2

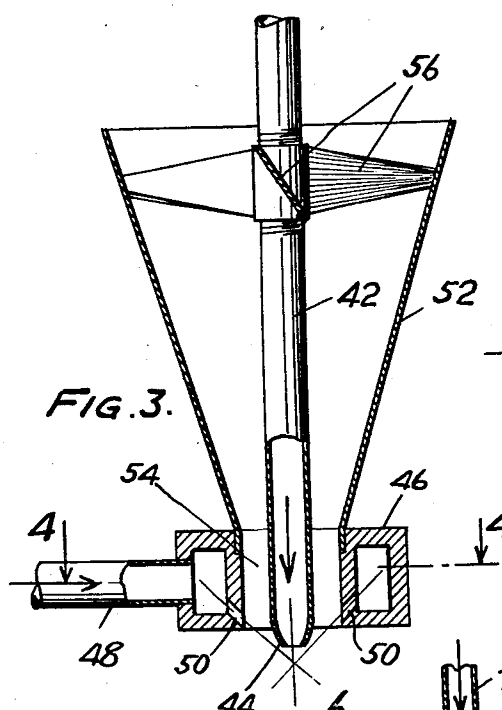

FIG. 3.

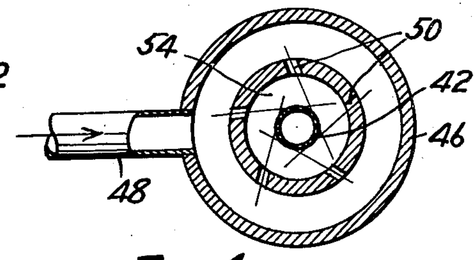

FIG. 4.

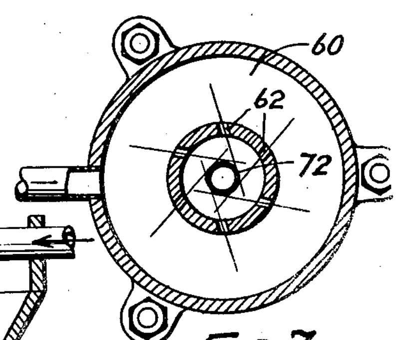

FIG. 7.

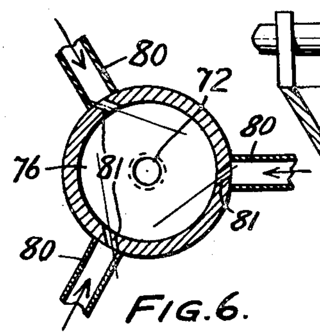

FIG. 6.

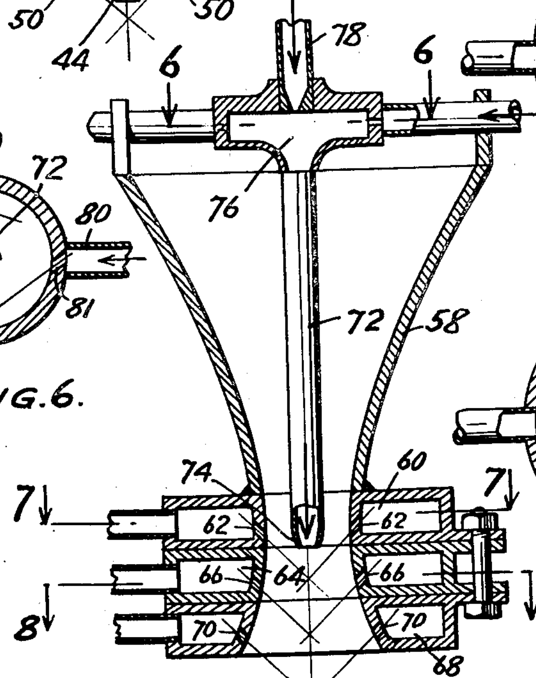

FIG. 5.

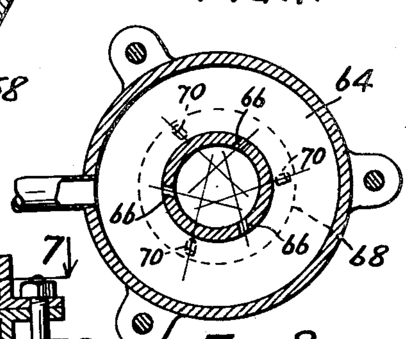

FIG. 8.

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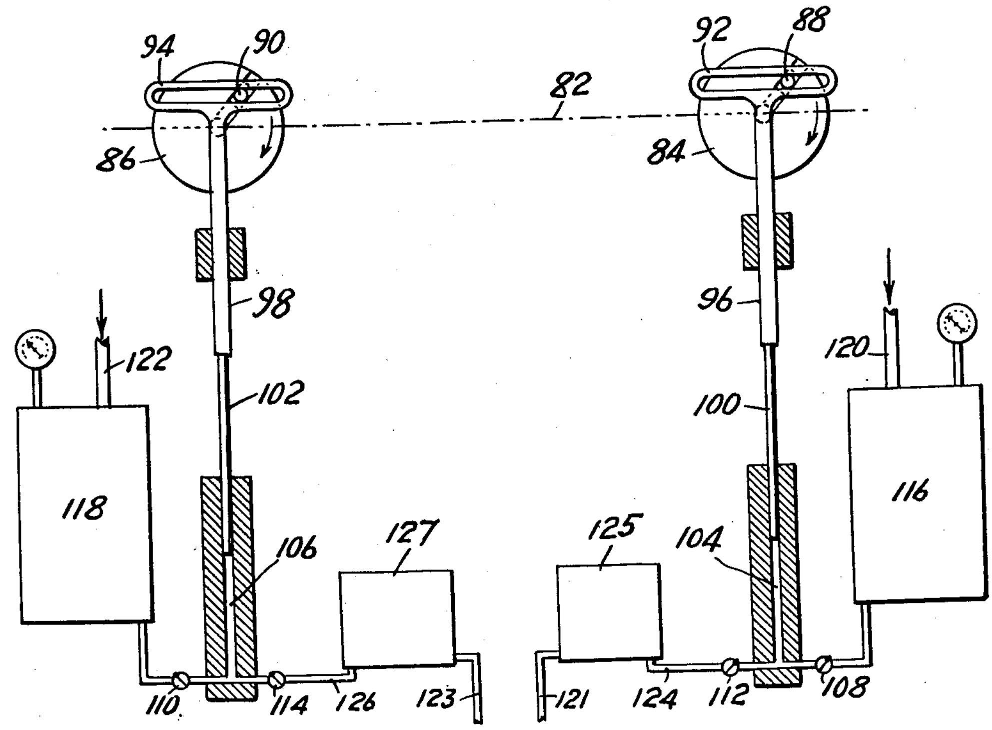

FIG. 9.

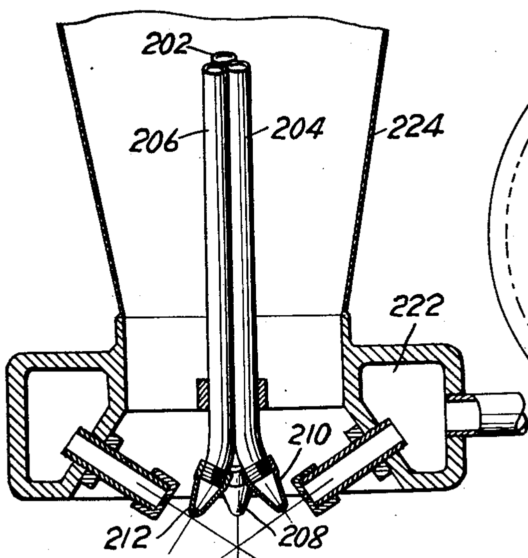

FIG. 10.

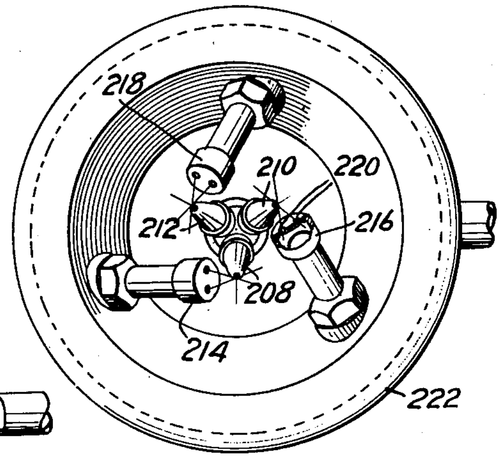

FIG. 11.

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METHOD AND APPARATUS FOR DISPERSING OR DRYING FLUENT MATERIAL IN HIGH VELOCITY ELASTIC FLUID JETS

Filed Feb. 26, 1940 5 Sheets-Sheet 4

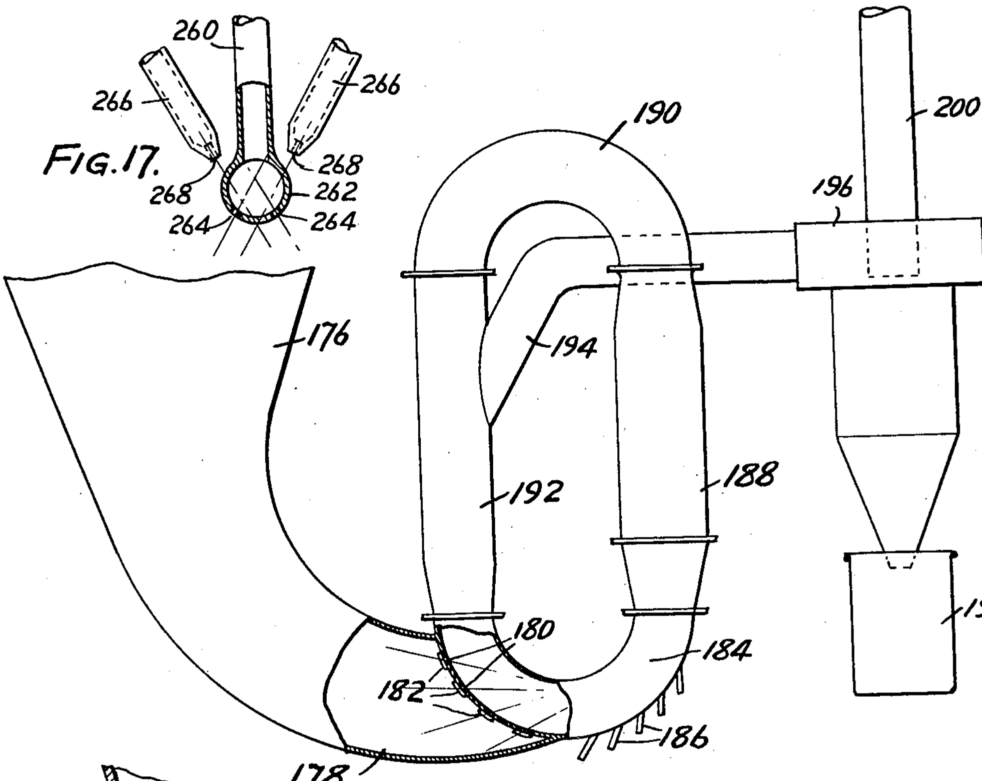

FIG. 17.

FIG. 16.

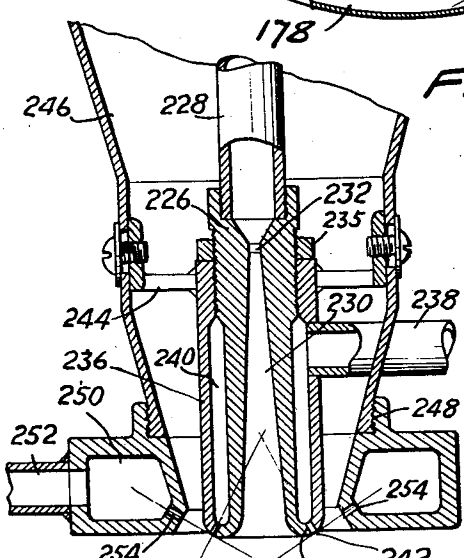

FIG. 12.

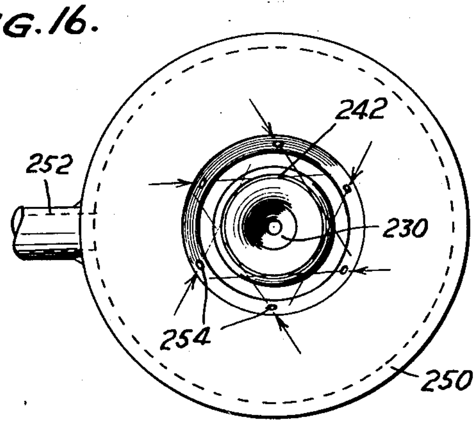

FIG. 13.

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METHOD AND APPARATUS FOR DISPERSING OR DRYING FLUENT MATERIAL IN HIGH VELOCITY ELASTIC FLUID JETS

Filed Feb. 26, 1940 5 Sheets-Sheet 5

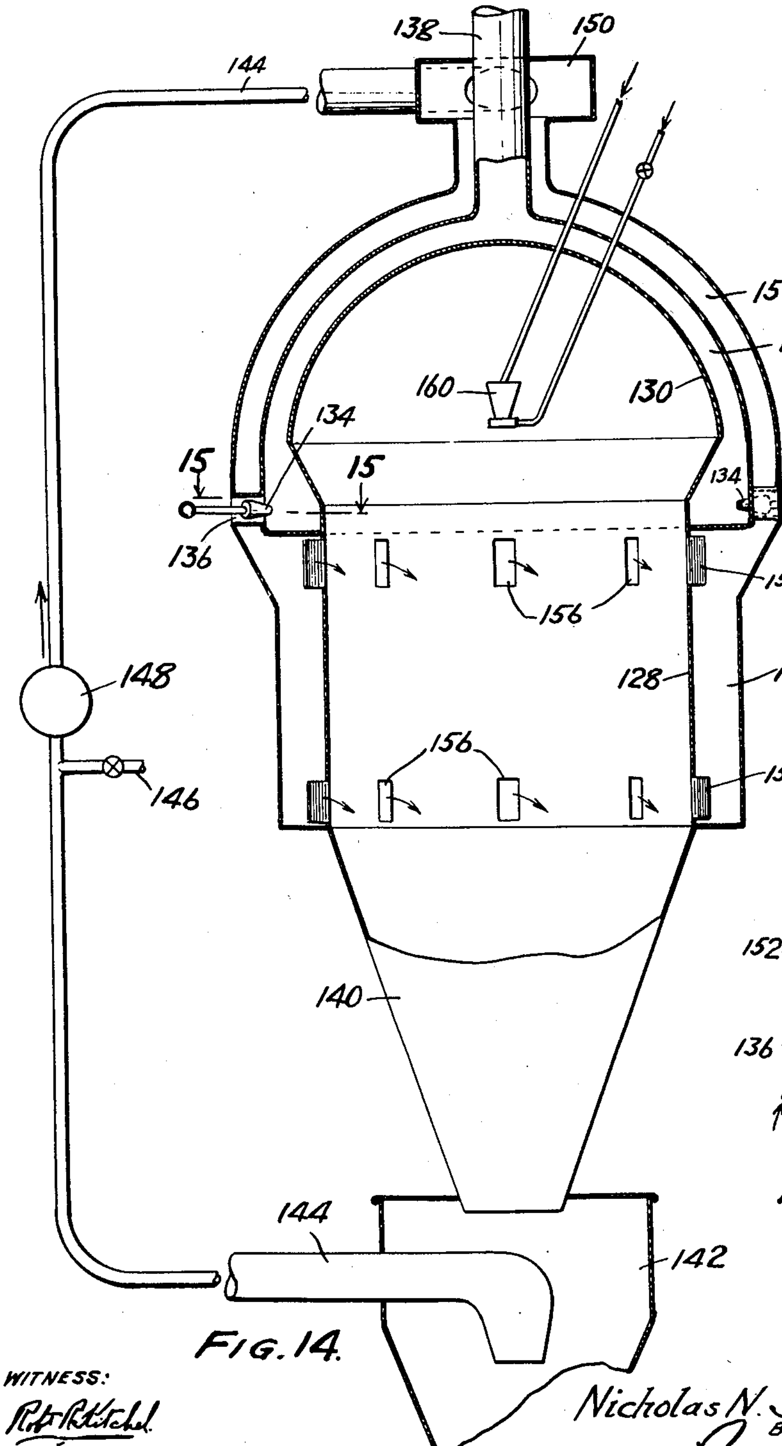

FIG. 14.

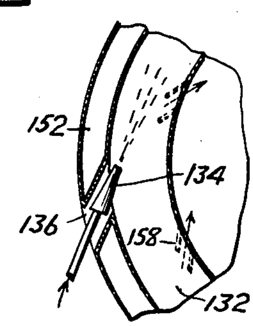

FIG. 15.

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Patented Dec. 31, 1946

2,413,420

UNITED STATES PATENT OFFICE

2,413,420

METHOD AND APPARATUS FOR DISPERSING OR DRYING FLUENT MATERIAL IN HIGH VELOCITY ELASTIC FLUID JETS

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Application February 26, 1940, Serial No. 320,788

15 Claims. (Cl. 34—10)

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This invention relates to a method and apparatus for drying, in a broad sense, material in the form of droplets or particles and, more particularly, to a method and apparatus for effecting such drying by the atomization of the material to be dried in a high velocity gas or vapor jet or jets.

In my application Serial No. 199,687, filed April 2, 1938, now Patent No. 2,297,726, there is described the drying, in a broad sense, of material by atomization in high velocity gas or vapor jets. As pointed out in said application, in accordance with its disclosure drying and comminution of materials may be effected to secure extremely minute particles. The present invention is concerned with improvements in the methods and apparatus described in said prior application; and for the broad action of high velocity jets and other broader features of this method reference may be made thereto.

The present invention is concerned primarily with particular problems arising in effecting the results described in said prior application, more particularly with quite low pressure jets and economy of heat and gas. One of the objects of the present invention, for example, is the provision of improved nozzle arrangements whereby deposition of dried or partially dried materials is prevented in the vicinity of the nozzles. They are, in effect, what might be designated "self-cleaning." Another related object of the invention is the provision of an apparatus on the walls of which deposition of material does not occur, particularly in the handling of highly viscous materials relatively difficult to dry.

A further specific object of the present invention is the provision of a method and apparatus for the more effective handling of highly viscous materials of the nature of the filter cakes produced in the manufacture of pigments, such as, for example, titanium dioxide. In accordance with the present invention, these pigments may be extruded into high velocity jets which effect not only the drying, but the disintegration of the pigment as well to produce an extremely fine product. This involves, furthermore, an improved method of obtaining the final product directly from a filter cake without going through a preliminary drying of the filter cake prior to grinding. When drying is effected in conventional fashion, agglomeration takes place, and the resultant dried material is ground only with considerable difficulty. By the application of the present method, the grinding or disintegration is effected before the agglomeration can take

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place, and a superior product of very uniform nature is thereby secured.

In accordance with the present invention, the drying and/or grinding is effected while the material in comminuted form is maintained in a relatively restricted zone. Under such circumstances, it may be subjected to radiant heat, in the form of infra-red or heat rays, which, in the case of a wet material in comminuted form, is very effective for applying heat thereto. By the use of radiant heat, a desired rise in temperature to facilitate drying may be secured more efficiently than through heating by the gas utilized for the drying. By an extension of the application of heat, actual calcination may be effected for the production of particular materials, such as pigments which involve calcination to bring them into final form. Under such circumstances, there may be produced in a single apparatus drying, fine grinding and calcination with direct collection of the final product.

In accordance with the arrangement described hereafter, wet grinding of particles can be effected with subsequent drying, as well as mere drying of solutions or suspensions of sufficiently fine particles requiring no further grinding.

A further object of the invention is the production of chemical reactions while one or more of the reacting materials is in a fine atomized state. A material undergoing drying, grinding and/or heating may be reacted with a gas included in or forming an atmosphere into which it is directed or, in fact, with the gas which may be used in whole or in part for its drying and comminution. More important, however, is the securing of reaction between two non-gaseous substances by their intimate admixture in finely comminuted state. Specifically, in accordance with the present invention, the two materials in suspension or solution in liquid or even in a moderately finely powdered dry state, may be projected in finely comminuted form and in accurately regulated proportions into a common zone wherein violent admixture is effected and reaction accomplished. It will be evident that, since reaction time is dependent upon contact, reactions taking place relatively slowly or necessarily in relatively dilute solutions under ordinary circumstances can be caused to take place with great rapidity, and, if desired, finely comminuted solid products may be secured directly without going through the usual separate filtering, drying and grinding steps. As an example, lithopone may be produced by feeding into the apparatus zinc sulphate in the form of a relatively thick paste with a similar paste of barium sulphide. These two materials, finely atomized, are brought together in a common zone, where reaction may take place simultaneously with drying and grinding. After drying is accomplished, the temperature may be raised while the material is still in suspension to produce calcination and thereafter chilling and collection of the final product. By proper proportioning of the reacting materials the reaction will be complete with substantially no proportion of either of the original materials remaining. Thus in a single step there may be secured the production of the final product normally requiring a number of individual steps.

In the types of apparatus described herein, there may also be accomplished the admixture of materials involving, for example, coating of one material with another, as described in said application.

The above and other objects of the invention, particularly relating to details of the method and apparatus, will become apparent from the following description, read in conjunction with the accompanying drawings, in which:

Figure 1 is a diagrammatic sectional view through one form of apparatus designed for carrying out the objects of the invention;

Figure 2 is a transverse section of the apparatus of Figure 1 taken on the plane indicated at 2—2 in said figure;

Figure 3 is a vertical sectional view through one of the nozzle assemblies illustrated in Figure 1;

Figure 4 is a transverse section taken on the plane indicated at 4—4 in Figure 3;

Figure 5 is a vertical sectional view of an alternative form of nozzle assembly particularly adapted for the more thorough grinding of materials than that illustrated in Figure 3 and for the handling of extremely viscous materials;

Figure 6 is a section taken on the plane indicated at 6—6 in Figure 5;

Figure 7 is a section taken on the plane indicated at 7—7 in Figure 5;

Figure 8 is a section taken on the plane indicated at 8—8 in Figure 5;

Figure 9 is a diagrammatic view illustrating a material proportioning apparatus designed for feeding materials to the dryer of Figure 1, and particularly materials of highly viscous nature;

Figure 10 is a vertical section through still another form of nozzle assembly, particularly designed for the intimate admixture of reacting materials from the moment of their initial atomization;

Figure 11 is an inverted plan view of the nozzle assembly of Figure 10, illustrating particularly the relationships between the material feeding nozzles and the disintegrating jets;

Figure 12 is a vertical section through another form of nozzle assembly for dispersing materials embodying possibility of ready adjustment;

Figure 13 is a bottom plan view of the assembly of Figure 12;

Figure 14 is a sectional diagrammatic view illustrating an alternative form of dryer, particularly designed for the utilization of radiant heat;

Figure 15 is a fragmentary sectional view taken on the plane indicated at 15—15 in Figure 14;

Figure 16 is a diagrammatic view, partially in section, showing an auxiliary grinding attachment applicable to the dryers of the preceding figures; and

Figure 17 is a sectional view illustrating an alternative nozzle assembly desirably used in certain cases.

In the following description and claims it will be understood that where the term "gas" or "air" is used it is generally to be regarded as synonymous with "elastic fluid," i. e., it includes the vapor state of a substance below its critical temperature. As pointed out in said prior application, evaporation of a liquid, such as water, may be carried out not only in a fixed gas, such as air, but in a vapor, including the vapor of the liquid to be evaporated in a superheated or reduced pressure state, e. g., steam. Vapors as well as fixed gases may also be used in producing chemical reactions as described hereafter. Superheated steam is a thoroughly effective drying medium for materials wetted with water or other liquids and, in fact, the desirable effects of distillation in steam may be used to produce low temperature drying of high boiling liquids which are immiscible with water. To simplify the description, reference may be made hereafter to specific gases or vapors with the understanding that the terms used are to be broadly construed. Where "drying" is referred to herein, it will be understood that there is included the transition from a liquid to a solid or semisolid state, though that may not occur by evaporation of a liquid. For example, drying in this broad sense may occur by polymerization of a liquid, as the result of chemical reaction, or by chilling of a molten liquid.

Referring first to Figures 1 and 2, there is disclosed therein an apparatus adapted, in the form illustrated, for drying and comminution and, in addition, for performing chemical reactions. By slight modifications, as will be apparent hereafter, involving, primarily, different nozzle constructions, it may be applied for other purposes.

The apparatus comprises a shell 2 preferably having a cone-shaped lower end, indicated at 16, and surrounded by a jacket 4 for heating purposes, as described hereafter. Located within the upper portion of the shell 2 are a pair of dispersing nozzle assemblies 6 and 8. These are directed within the shell, preferably as indicated in the construction lines in the figures, i. e., they are located close together and have their axes directed convergently toward each other (preferably so as to intersect not far from the assemblies) and somewhat eccentrically with respect to the lower conical portion of the shell in a direction opposite the direction of flow of air having a general flow countercurrent to the streams produced by the nozzles. This air is introduced through a controlled pipe 10 and a venturi 12 which communicates through the opening 14 with the lower portion of the cone 16. By reason of the provision of the venturi, a smooth high velocity flow of air into the cone is produced, and by reason of the peripheral entrance it acquires a vortical motion to flow upwardly through the apparatus. By reason of the centrifugal action which occurs, it tends to flow along the walls as it progresses upwardly. The gas introduced at the bottom of the apparatus may be hot waste gas under low pressure. The heat of this gas may be primarily relied upon for the drying, the dispersing nozzle gas being cold or only moderately heated.

The lower portion of the cone 16 communicates at 18 with a receiver 20. In most normal operations of the device, nothing passes into this receiver 20, but it appears to form a gas cushion serving to smooth out irregularities in flow, while it is also present to receive any material which might happen to reach it. But if the velocities in the shell are properly adjusted, centrifugal separation may be caused to occur in the cone 16 with collection of the dried product in the receiver 20.

From the upper, preferably conical, end of the shell there extends the outlet passage 22, which communicates peripherally at 24 with the upper portion of a dust separator and collector, indicated at 26. The final product separated in 26 is collected in the receptacle 28, while the outflowing gas and vapor may escape through the passage 30 controlled by a damper 32. A side pipe 34, controlled by a damper 36 is adapted to lead a controlled amount of the escaping fluid through the heater 38 to the jacket 4, whereby heating of the shell is accomplished with most effective utilization of the residual heat of the waste gases. The jacket may discharge these gases through the pipe 40. In the event that they contain vapors desired to be recovered, suitable condensation may follow.

Referring to Figures 3 and 4, there is illustrated therein a form which the nozzles 6 and 8 may take which is found to be highly satisfactory. A tube 42 is provided for the feed of the material which is to be dispersed. While the arrangement is capable of dispersing substantially any type of material, it is particularly adapted for the dispersion of highly viscous material such as wet press cake, which may have to be extruded from the tube 42 under considerable pressure. The lower end of this tube is preferably rounded and restricted somewhat, as indicated, to secure a cleaning action, as will be described.

About the lower end of the tube 42 is located a chest 46 arranged to be fed with steam, air or other vapor or gas at high pressure, and, usually, high temperature. Nozzles 50 are provided in this chest and are directed as will be evident from consideration of the lines indicating their axes in Figures 3 and 4, i. e., these axes are so directed as to just miss the tip of the tube 42 and be substantially tangent to the lower end of the tube. From this arrangement it will be evident that a swirling array of jets will be provided.

It has been stated that the axes of the nozzles just miss the lower end of the tube 42. This, however, does not mean that the jets from the nozzles completely miss the tube 42, but actually the adjustment is preferably such that the jets at their upper sides engage the tube at its tip. As a result of this, a violent disturbance is set up at the tip of the tube and extends in the jet in the form of a wake made up of vortices, and the wiping of the tube by the jets prevents any possibility of having the material leaving the tube cake its outer side or pass upwardly within the annular chest 46.

Above the chest 46 there is provided a conical enclosure, indicated at 52, converging down to a throat at the position of the chest. By reason of the direction of the jets of gas from the chest, a high degree of vacuum is produced in the cone, and by reason of its Venturi action, a high velocity of downward flow of gas within the throat is produced. Desirably the cone may be supported by means of directing vanes 56, giving to the gas flowing through the cone a swirl which may be in the direction of, or opposite, the swirl produced by the jets from the nozzles 50, depending upon the action which is desired. In the event that it is desired to confine the dispersion which is produced, the rotations thus secured may be in opposite directions. If spreading is desired, rotations in the same directions are desirable. The divergence of the dispersed cone of material may also be controlled to a substantial extent by direction of the jets 50 so as to be tangent to circles of greater or less diameter.

The jets produced should conform to the conditions described in my prior application Serial No. 199,687; i. e., the nozzles should be so formed as to produce at least acoustic velocities of the gas or vapor in these jets. It is generally desirable that the nozzles be of abrupt type to secure a maximum of turbulence to promote comminution or grinding, though smoother flow may be desirable (secured by convergent and properly divergent nozzles) if drying only is desired with a minimum of grinding, i. e., if the particles are not desired to be of too small size. As pointed out in said prior application, acoustic velocities may be secured by the use of abrupt nozzles and superacoustic velocities by the use of convergent-divergent nozzles. The acoustic velocities correspond to the temperature and pressure conditions in the jet. When intensive grinding is to be accomplished, the jets from the nozzles 50 are preferably caused to be tangent to a smaller circle than that indicated, so that they impinge upon each other. In fact, they may be made to intersect substantially at the axis of the tube 42, in which case a maximum of turbulence and grinding is secured.

The action of a single nozzle assembly just described within the arrangement of Figure 1 is to produce along the general line of the axis of the nozzle assembly an extremely fine dispersion of the material passing through the tube 42. This dispersion is bounded by a surrounding atmosphere of gas passing at relatively low pressure and in large quantity through the cone 52 and is thus prevented from impinging upon the walls of the shell. Before the dispersion can reach the lower portion of the shell toward which the axis of the assembly is directed, the expanding dispersion, now slowing down, will have met the outflowing gas from the opening 14, which, in the lower portion of the cone, has a relatively high velocity, slowing up as it enters the central portion of the shell. Here again, a protective layer of helically moving gas keeps the dispersion from reaching the walls of the shell, and by the time sufficient diffusion can have occurred to bring any of the material in contact with the shell, it will have been dried and in such a fine state that deposit on the shell does not occur. As the helix of flowing gas changes to a spiral approaching the outlet 22, its linear velocity will be maintained which means that, with reduction of radius, the centrifugal forces on particles increase. Thus if larger incompletely dried particles reach this region, there will be a tendency to reject them from the outlet with a probability that in their circulation they will be drawn into a nozzle assembly cone 52 to be recirculated into the lower portion of the drier.

In the securing of drying of materials, it is desirable first to have as long a period of contact of the material to be dried with the drying atmosphere as possible, and consequently a relative movement of the material to be dried and the drying atmosphere. Both of these ends are achieved in the present apparatus, which involves both countercurrent and concurrent drying. The downwardly flowing dispersion has relative movement with the upwardly flowing spirally moving gas and the path of a particle in contact with a drying atmosphere is from the dispersing assembly to a lower portion of the apparatus and then extends helically upwardly toward the outlet. Throughout this entire path, relative motion is produced, as by the meeting of the downwardly moving particles or droplets with the upwardly flowing gas, and secondly by reason of the turbulence set up by centrifugal action in the helical flow. It may be pointed out, furthermore, that larger particles will have greater inertia and hence will reach the lowermost portions of the shell which are not reached by the smaller particles or droplets. In this fashion, the larger particles or droplets are brought into contact with the upwardly flowing gas before it becomes even partially saturated by evaporation of liquid from the finer particles or droplets. Uniform effective drying is thereby promoted.

This action is described for a single nozzle assembly only, as would be used for ordinary drying. In the case of two nozzle assemblies, as illustrated, whether for mere drying or for the production of chemical reaction or coating, the action so far as the shell is concerned is quite similar, though the dispersions may be caused to merge closely adjacent the assemblies. The matter of reactions will be referred to in greater detail hereafter.

In Figure 5 there is illustrated another form of nozzle assembly particularly desirable where viscous material rather than a mobile solution or suspension is to be dispersed. In this assembly a Venturi entrance passage 58 is assembled to a group of gas chests 60, 64 and 68, the inner surfaces of which continue the Venturi passage begun by the entrance 58. The gas chests are respectively provided with nozzles 62, 66 and 70, of which, for example, as indicated in Figures 7 and 8, the nozzles 62 and 70 may be directed to produce a rotation of the gas in a clockwise direction, viewed from above, and nozzle 66 may tend to produce rotation in a counter-clockwise direction. The axes of these nozzles are disposed as indicated in the figures, and if reverse directions of rotation are imparted by the successive sets, intense turbulence and comminution of the material to be dispersed is effected.

A central tube 72 is provided for the introduction of the material, this tube being restricted, as indicated at 74, at its lower end. The material enters this tube from the chamber 76, to which entrance is afforded through the central tube 78 and a group of tubes 80 communicating with the chamber 76 through eccentrically directed passages, indicated at 81 in Figure 6. This arrangement provides considerable flexibility for use with various types of materials. If the material to be introduced is plastic in nature but flows comparatively readily, it may be forced into the chamber 76 through either the axial or peripheral entrances and extruded therefrom through the tube 72 into the region of the jets issuing from the gas nozzles. In such case of extrusion, it is not necessary to have the upper jets wipe the lower end of the tube, as illustrated in Figure 3, the extruded rod of material meeting the jets and being broken up by them as it projects thereinto. If the material is more viscous, so as to be desirably diluted with gas as it leaves the tube 72, the material may be forced into the chamber 76 at 78, there to meet jets of gas issuing from the passages or nozzles 81, so that there will emerge from the tube 72 at high velocity the material already substantially suspended in the gas. Liquid for its dilution may be introduced instead of the gas. Alternatively, the material to be dispersed may be introduced through the peripheral tubes and gas introduced through the central tube 78 tending to force it directly through the tube 72. The approach of the tube 72 to the dispersing jets may be varied to secure the most desirable action, depending upon the nature and particularly the viscosity of the material to be dispersed. In the case of low viscosity material it may be located to be wiped by the uppermost jets as in the modification of Figure 3 to produce suction and turbulence. It may be noted that even if the jet is of smooth flow characteristics, such as a jet of superacoustic velocity produced by a De Laval nozzle, turbulence will result as it breaks away from a surface at the feed tube tip in contact with which it flows.

As in the case of the modification of Figure 3, a high velocity of flow takes place through the venturi approach, cleaning out of the passages any material which might tend to pass upwardly and forming, in effect, a sheath of gas about the dispersion promoting evaporation and preventing its deposition in wet state upon the walls of the apparatus.

To secure most intense grinding in the type of assembly illustrated in Figure 5, the jets are caused to impinge upon each other to a maximum degree. The material so ground in the wet state, then in a finely dispersed form, is dried in the region through which it subsequently travels.

It will be evident that with the use of single dispersing nozzle assemblies in the apparatus of Figure 1 or the use of a plurality of such assemblies handling the same materials, not only may drying be effected, as indicated above, but reactions with gas may be produced if the gas entering the casing 2 at 14 and/or the gas used for dispersion is adapted to react with the material dispersed. Thus, for example, vapors of formaldehyde may be caused to react with phenolic substances to form plastics recovered directly in a finely divided form suitable for introduction into molds. Similarly, other vapors or gases, such as ammonia, other aldehydes, etc., may be reacted with sprayed liquids.

More important than the reactions with gases, however, are the reactions achieved between materials fed selectively through a plurality of nozzle assemblies or dispersed individually in a single assembly, as described in greater detail below. The speed of chemical reaction is dependent largely upon the surface contact of the reacting materials, particularly in organic reactions which are frequently very slow when occurring between liquids, liquids and solids, or solids and solids in solutions or suspensions. If such materials are finely dispersed, and, in such state, admixed, or, alternatively, partially or completely admixed and then immediately dispersed, the reactions are greatly accelerated. The speeding up of reactions, however, is not the sole advantage. If a reaction, for example between two salts, results in the formation of a precipitate, the final product may only be secured from a reaction in solution through the medium of filtration, washing and drying; and if a finely comminuted product is required, this drying is generally necessarily followed by grinding because, in the precipitation in solution and in the filtration, agglomeration occurs. If the materials are brought together in finely comminuted form, however, while wet (either in solution or suspension) the reactions will take place with the formation of products in finely comminuted form. If drying then occurs, a fine powder is produced which, unlike precipitates, even if thereafter wetted, will not agglomerate. Since agglomeration is a matter of time, it is possible usually to achieve similar results by causing reaction to occur, and then, before agglomeration may happen, dispersing the product. If there is produced in this reaction no material which need be washed from the solid product, the result is the direct production of an extremely fine powder. If, on the other hand, a soluble salt remains which must be washed out, the dried powder can be subjected to washing and can then be filtered, washed and dried, generally without further agglomeration, since it has already passed into a stable physical state, nonconducive to the further growth of the particles. Such a wet washed powder can be dried by a subsequent operation in the machine illustrated.

Generally, in reactions in which one material is not a gas, it is necessary for economy, if not for the obtaining of a desired final product, that the reacting materials be fed in rather closely related proportions. These proportions need not necessarily be chemical equivalents but may involve predetermined excesses of one or more materials to secure most effective reaction in accordance with the law of mass action. In conventional batch processes or even continuous processes in which the time of reaction is indefinitely long and thorough intermixture may be leisurely caused to occur, it is sufficient that the materials be measured out in desired proportions and mixed together either at one time or progressively. In the described apparatus, however, it will be evident that a particular small amount of material passing from one nozzle assembly will be completely out of the reaction zone in a time of the order of a fraction of a second to not more than a few seconds, and hence it is necessary to feed the materials continuously in continuously closely regulated proportions to insure that the reaction will be completed or have proceeded to the desired extent before drying occurs and, at any rate, while the materials are in suspension, i. e., before they come to a condition in which agglomeration can occur in a separator or collector. To this end, there may be provided a proportioning apparatus of the type illustrated in Figure 9 for feeding the respective reacting materials to the nozzle assemblies 6 and 8 through the feed tubes 121 and 123.

In Figure 9 there is indicated at 82 a shaft suitably driven at a suitable high rate of speed and connected to discs 84 and 86, which carry radially adjustable crank pins 88 and 90, desirably in the same phase relationships, though this phase may be desirably adjustable, as indicated hereafter. These crank pins operate in slotted cross-heads 92 and 94, respectively, carried by plungers 96 and 98, which, at their lower ends, are reduced to provide pistons 100 and 102, working in cylinders 104 and 106. These cylinders receive, respectively, through connections including check valves 108 and 110, materials from supply tanks 116 and 118. If highly viscous materials are being handled, gas pressures may be maintained on the materials in these tanks through the medium of connections 120 and 122. In such case, the rate of feed may be controlled by control of the pressures, as indicated by suitable gauges, to insure that on the upstroke of each piston the corresponding cylinder will be filled with material and not have therein spaces in which may exist partial vacuum. Stirring means may be present in tanks 116 and 118 to maintain uniform suspensions or mixtures therein.

The cylinders discharge through connections 124 and 126, containing discharge check valves 112 and 114 (sufficiently resisting direct passage of material due to pressure in tanks 116 and 118) into containers 125 and 127, in the nature of air domes to smooth out the fluctuations, and from these cylinders there extend connecting tubes 121 and 123 to the nozzle assemblies such as 6 and 8 of Figure 1.

By the use of this apparatus and the proper adjustment of crank pins 88 and 90 radially, and with a suitable high velocity of rotation of the shaft 82, coupled with small size of cylinders 104 and 106, there can be insured a carefully controlled delivery of proportionate amounts of materials through the assemblies, the amounts being so proportioned as to secure the desired reaction. Substantially continuous streams of materials in finely suspended form will issue from the nozzle assemblies at an accurately predetermined rate in the case of each to insure complete reaction in the limited zone afforded by the flow through the apparatus. If materials of different viscosities are fed, then to insure simultaneous delivery of portions corresponding to strokes of the pistons it may be desirable to adjust the phase relationship of the crank pins because of slight lags occurring in passage of the more viscous material to its nozzle assembly due to elastic effects in the feed line.

As an example of the type of chemical reaction which may be produced, there may be mentioned the production of lithopone by the spraying into a common reaction zone of an aqueous paste of zinc sulphate and an aqueous paste of barium sulphide. In the feeding of these materials, stirring may be used to maintain the material fed of uniform composition and adjustment of feeding means such as that of Figure 9 made upon analysis of the materials to insure their feed in equivalent quantities. The reaction between the two constituents will take place with great rapidity, in view of the large surfaces offered for reaction by the droplets or particles, and the result will be a dry cloud of fine particles composed of zinc sulphide and barium sulphate. This cloud may be passed through a calcining zone provided either in a separate apparatus or by the introduction of sufficiently hot gases, for example, in the bottom of the apparatus of Figure 1. If chilling of the particles is desired, large quantities of air at ordinary temperature may be admixed with the suspension prior to its reaching the separator. It will be evident that the reaction may take place in inert gas or in a reducing gas if the temperatures used are such that detrimental oxidation might possibly take place in air. In the case of chemical reactions, not only can there be removed by evaporation liquid solvent, but there may also be removed volatile solid products of a reaction if the temperature required is not too high to cause damage to the other particles. For example, in the precipitation of chemical bases by the use of ammonium hydroxide, the resulting ammonium salt may be volatilized together with the water used for solution or suspension and the base in a dry form and free of ammonium salt recovered. In such case, the volatilizing temperature must be maintained through the dust collector, and the spent vapors may be fractionally or wholly condensed to recover material of value such as, in the example just mentioned, ammonium salts. Evaporation or volatilization of products of many reactions will cause them to approach substantial completion according to the law of mass action.

In the operation of the apparatus in Figure 1 in accomplishing a chemical reaction, the proportioned amounts of materials intermix in the region about the dash lines indicated in that figure. Generally speaking, the materials will be initially moist with aqueous or other suspending liquid or solvent, though, of course, either or both may be completely in solution. As the reaction proceeds, evaporation of the solvent or suspending liquid simultaneously occurs and this evaporation may be substantially complete before the suspended material reaches the cone 16. At this point its velocity in a downward direction will be greatly reduced, and as it meets the relatively high velocity vortical flow in the cone the direction of movement of the suspension will be upward in a spiral direction adjacent the walls. The adjustment should be such that, before any particles can reach the walls 2 they will have been dried so as not to adhere thereto. The suspension carried upwardly, with centrifugal separation and recirculation of large particles through cones such as 52, will pass out through connection 22 to the separator 26. In some cases, some of the material will enter the receiver 20. More usually, if a fine product is desired, little or no material will reach this receiver.

Not only chemical reactions but physical admixture or coating and quasi-chemical reactions may be produced. For example, lakes may be formed by spraying together a metallic base and a dye solution, the resulting pigment in a fine state resulting directly as a product. Or particles intended to form the disperse phase of an emulsion may be coated with a dispersing agent, such as a soap, to produce a fine powder which forms an emulsion directly upon introduction into a liquid.

Polymerizations may also be effected, for example, the catalytic polymerization of liquid isobutylene, by dispersing it into admixture with a catalyst such as aluminum chloride or boron fluoride at a low temperature (0° F. to —40° F.). The viscous resulting product may be admixed with other materials while in the dispersed state and before it may engage and stick to the walls of the apparatus.

In the case of reactions of materials with gas, a similar action takes place, and a similar flow of suspended material occurs also in the case of ordinary drying, in which there may be used only a single nozzle assembly. Similar actions occur in the use of the other nozzle assemblies heretofore described.

In the case of the nozzle assembly of Figure 5, it will be evident that great freedom of choice in the admixture of materials may be had. Partial admixture may occur in chamber 76 and tube 72 accompanied by partial reaction. Dispersion may occur before any agglomeration can take place. Reacting gas or gases may be introduced through one or more of the nozzle groups 62, 66 and 70.

While heating may be accomplished by the introduction of hot gases for atomization through the nozzle assemblies in Figure 1 and by the introduction of hot gas through the passage 12, and by reason of the provision of a hot jacket indicated at 4, materials in fine suspension are adapted to be quite efficiently heated by the use of radiant heat. The use of radiant heat for directly heating suspensions eliminates the losses involved in first heating a drying atmosphere of gas, passing this to a drier and then producing a heat interchange between the gas and the material to be dried. By the direct application of radiant heat to the suspension, losses are avoided, and the heat may be more efficiently utilized, since it must not be brought to the liquid to be evaporated through the medium of a gas of low specific heat and poor heat absorbing qualities such as air. Radiant heat is readily absorbed by dispersions, particularly when they contain solid particles. In the formation of dispersions as described herein, temperature drops generally occur at the nozzles due to expansion, and radiant heat may be utilized directly at these points to raise the temperature of the dispersion to the proper degree.

In the apparatus of Figure 14, the arrangement is such as to impart heat to a material being dried, or to materials undergoing chemical reaction, by means of radiant heat to a primary extent. Such chemical reaction may be between two materials or may consist of polymerization of a single material. For example the polymerization of styrene may be started while the styrene is in a dispersed state to form polystyrene resin in a finely comminuted form. In the case of an exothermic reaction such as this polymerization, the application of the radiant heat is localized so that the dispersion rapidly passes from the region of its application, and into a cooler region.

In the apparatus of Figure 14, there is provided a shell 128 having a dome shaped top 130 surrounded by a combustion gas chamber 132, within which is burned fuel such as oil from burners 134, receiving their air through passages 136. These products of combustion may raise the dome 130 to a temperature desired to secure the necessary amount of infra red or heat radiation. The products of combustion may escape through the outlet 138.

The lower end of the shell has a conical shape 140 and communicates with a separator 142, of conventional type from which there extends the outlet 144. As indicated diagrammatically to the left of this figure, vapors or gases from which the solid material has been separated may be pumped by means of a pump or blower 148 into the top 150 of a jacket 152 surrounding the combustion chamber 132. This jacket 152 has a skirt portion 154 from which the gas and vapors heated by passage over the combustion chamber 132 may enter the shell through openings 156, being given a rotary flow by guide vanes 158, as illustrated. Inasmuch as increasing amounts of vapors are being continuously formed by the evaporation of liquid, a controlled escape 146 is provided to bleed from the apparatus the excess vapors. The material to be dried may be introduced through the nozzle assembly 160. If chemical reactions are to take place, a plurality of such assemblies may be provided as illustrated in Figure 1.

It will be evident that the material will be heated in this apparatus to a very substantial extent through the medium of radiant heat from the source surface 130. Further heating, of course, takes place by the introduction of the heated vapors and gas at 156. The dispersing gas or vapor may also be heated to a considerable extent. By the provision of the recirculating arrangement for the gaseous fluid, the efficiency of the apparatus is greatly increased, since the heat of the hot gases is not entirely lost. The heat from the escaping gases at 146 may be transferred through heat transfer apparatus to preheat the fluid used for the dispersing or to preheat the solutions or suspensions of materials to be dried or reacted.

By the use of the arrangement shown, dust and wet particles will not reach the radiating surface 130 and the dispersion or fog will have the radiation playing down upon it.

While radiant heat may be provided from a hot surface such as 130, it may be supplied, particularly if infra-red radiation is primarily desired, from infra-red electric bulbs located in a dome such as 130 along with suitable reflectors. Infra-red radiation is particularly effective for the heating of fogs which are deeply penetrated by it to secure thorough heating of a dispersion. Flames open to the drying region may also be used for supplying radiant heat without danger of contamination of the product with combustion gases if a pressure is maintained to drive the combustion gases away from the drying zone and to maintain the product of the drying away from the zone in which it can remain only by incorporation in a jet. For example, if open flames are provided in the location of the dome 130, and a slight excess of pressure is maintained therein, with suitable outlets for the products of combustion, this separation may be maintained. In many cases, however, separation is quite unnecessary, and in such case, the radiant heat of flames may be used as well as direct heating by the products of combustion which may pass with the evaporated vapors to the outlet and collector. Such an arrangement is particularly desirable where calcination of the product in a finely suspended state is desired, in which case flames may be projected directly into the dispersion. Heat may be quite locally applied, for example being focussed on the region in which a dispersion is being formed by the use of a heating bulb and reflector, when it is desired merely to start a reaction which is exothermic in character, as in the case of certain polymerizations.

The reaction may be exothermic to such extent that, after it begins, cooling should be effected. This may be done in the apparatus of Figure 1 by introducing cold, rather than hot gas at 14. Such introduction of cold gas is also used where the apparatus is used for the chilling of dispersed droplets of molten material. In the case of the latter procedure, if it is desired to prevent adherence of solidified droplets of bituminous or waxy materials, a suitable dust-laden atmosphere may be introduced from outside the apparatus by means of a conduit connected to one or more of the funnels such as 52. The dust will coat the particles of plastic material preventing their adhesion. The dust may consist of a dispersing material so that the final product when mixed with a liquid may form directly a dispersion or emulsion.

In the types of apparatus illustrated in Figures 1 and 14, the products of either drying or reaction will generally be in an extremely fine state, but sometimes the fineness will not be sufficient. Accordingly, a further grinding of the product may be desirable, and for this purpose there may be added the apparatus illustrated in Figure 16.

At 176 in this last figure, there is illustrated a cone which may be either the cone 16 of Figure 1 or the cone 140 of Figure 14, in either case designed to receive particles which are to be further ground. In the case of the apparatus of Figure 1, for example, the velocity of flow through the passage 12 may be so controlled that the upward flow within the chamber 2 is so low as to carry through the outlet 22 only very fine particles. In such case, the larger particles may settle down through the cone such as 176. The pressure within the apparatus is then also desirably increased (by restriction of the upper outlet) so that in the cone 176 will be secured a sufficient pressure to cause the gas therein and suspended particles to be forced through the extension 178 and nozzle openings 180 in an endless tubular passage, as illustrated. These nozzles may be controlled by gates indicated at 182, to secure greater or less velocity of entrance of materials into the passages 180 and to control the pressure drop.

It will be noted that evaporation of liquid will increase the pressure in the drying apparatus if the outlet is restricted and will furnish a considerable volume of gas to form the jets in the auxiliary grinding apparatus. The material is already entrained in the gas so that high velocity jets may be produced by nozzles 180 without regard to entrapment of material. Material which is originally quite wet is very effectively handled by this apparatus because of the large quantity of steam produced by evaporation in the drier which becomes available for the grinding jets.

The tubular apparatus comprises a lower bend 184 and an upper bend 190 connected by straight portions 188 and 192. An outlet 194 communicates with the inner side of the straight down flow passage 192 and serves to lead centrifugally separated fine material into the separator 196, communicating with the collector 198 and the outlet pipe 200. Within the tubular grinder the final comminution of the material takes place in the high velocity auxiliary jets issuing from nozzles 186. In the upper bend centrifugal separation takes place with the result that the heavier particles are thrown outwardly and hence caused to recirculate through the device, while the finely ground particles may be carried through the passage 194 of the separator. The operation of this tubular mill is described in my application Serial No. 235,139, filed October 15, 1938. The nature of the comminution occurring therein and the construction involved are described in said application.

For the purpose of securing a zone of reaction extended to the maximum, it is desirable that the reacting suspensions should be in intimate contact substantially from their initial dispersion. Accordingly, instead of having independent assemblies, such as 6 and 8, spraying their suspensions into reactive admixture, it is more desirable to utilize an arrangement such as that illustrated in Figure 10. In this figure a series of tubes, 202, 204 and 206, of any suitable number, terminate closely adjacent each other in outlets 208, 210 and 212. The material issuing from these outlets is engaged by high velocity jets issuing from nozzles 214, 216 and 218. In a preferred arrangement, the nozzle openings are duplicated in each of these, as indicated at 220, and are directed so as to converge substantially at the location of the outlets of the tubes 208, 210 and 212. Preferably, these high velocity jets should barely wipe these tips to secure the most effective dispersion of the materials. The directions of these jets are preferably as illustrated in Figures 10 and 11, i. e., downwardly and tangentially to a circle in which the openings of the tubes lie, so that a downward and spiral motion will be given to the dispersions, very substantially promoting their almost immediate intermixture. Additionally, as in the case of the nozzle assemblies already mentioned, a cone 224 is provided to form a Venturi approach, the throat of which is in the vicinity of the formation of the dispersion. Thus a large volume of gas sweeps downwardly tending to confine the dispersion and shield it as a dynamic barrier from the walls of the apparatus. The dispersing arrangement just described will, of course, take the place of the nozzle assemblies heretofore described.

For drying purposes, especially where attendant grinding is desired, a desirable form of nozzle assembly is that of Figures 12 and 13. In this modification, a central member 226 has an opening fed by a tube 228 with a suitable elastic fluid. The passage through 226 is preferably in the form of a nozzle having a throat 232 and a diverging outlet 230. At its outside the member 226 is formed as illustrated, with a conical lip at 234. Threaded to its exterior and securable in adjusted position by a lock nut 235 is a sleeve member 236 provided with an inner conical surface corresponding to the surface 234 and providing with it a conical shaped opening 242 which can be adjusted, as will be obvious, by axial movement of the sleeve 236 relative to member 226. Between the two members 226 and 236 there is provided the chamber 240 to which the material to be dispersed may be fed through connection 238. The sleeve 236 supports through the medium of arms 244 a cone 246 threaded at 248 to support the elastic fluid chest 250 adapted to receive the dispersing fluid through connection 252 and project it at high velocity through the nozzles 254. The direction of these nozzles may be understood by comparison of Figures 12 and 13, in which it will be noted that the axes of these nozzles are directed substantially tangential to the conical outlet 242 as viewed in inverted plan in Figure 13 and in a downward direction as viewed in Figure 12. The jets from these nozzles will wipe the metal walls bounding the opening 242 and, it will be noted, will strike all parts of the conical sheet of the material to be dispersed issuing from the opening 242. The gas drawn at high velocity through the cone 246, and received either from the interior of the apparatus or through a conduit communicating with the exterior atmosphere or a source of relatively low pressure gas, will again form an outer dynamic barrier while the gas flow through the nozzle 230 at high velocity will engage the inner face of the dispersed sheet, so that the result is a cone of dispersed material engaged both exteriorly and interiorly with gaseous fluid to produce a high rate of evaporation. In view of the conical nature of the dispersion produced by this nozzle, it is not so well adapted to the production of chemical reactions by association with another of similar type as are the nozzles discussed previously. However, if there is no objection to having the reacting materials intermixed immediately before dispersion, a mixture thereof may be formed in the chamber 240 and dispersion with proper reaction will then occur.

This dispersing assembly is particularly useful with heavy viscous materials because of the thin sheet presented essentially edgewise to the nozzles. In the case of feed of heavy rods of viscous and adherent material, for example from the nozzle of Figure 3, the impact of the jet with the material may use up so much of its energy that complete fine uniform dispersion may not occur. This difficulty is met in this last arrangement, in which the thin sheet of material is sheared edgewise.

The various dispersing assemblies described involve in common the direction of a plurality of high velocity jets at acute angles to a restricted region of a plane towards the same side thereof but with their axes in non-intersecting directions to form a dispersion of material flowing from said region in the fluid from the jets. The axes of these jets are preferably in the same skew direction relative to a line normal to said region.

In Figure 17 there is shown still another form of nozzle assembly designed for the effective dispersing of relatively low viscosity material. This comprises a tube 260 having a head 262 of smooth form, preferably spherical or ellipsoidal in nature. This head 262 is provided with a plurality of openings, indicated at 264. Directed toward the rearward portion of the head are nozzles 268 on the ends of tubes 266. Any suitable plurality of such nozzles may be provided, or even one may be used if completely symmetrical results are not required. Gas issuing from these nozzles tends to spread itself about the head 262 and then streams therefrom, carrying with it material which is pulled from the head by the suction in the vicinity of the openings 264 set up by the breaking away of the stream from the surface along which it flows. It may be remarked that this creation of suction to a considerably greater degree than in the preceding modifications makes this type of arrangement particularly attractive when it is not desired to feed the material to be dispersed under pressure.

In the case of all of the dispersing assemblies it is desirable to have one or more high velocity jets of elastic fluid wipe over a convex surface in the region of an opening in the surface through which there is introduced the material to be dispersed, so that the stream of fluid breaks from the surface in the vicinity of the opening to entrain and form a dispersion of the material. An exception is the apparatus of Figure 5 in which a highly viscous material such as filter cake may be projected into the path of jets by extrusion.

The gas nozzles in all the forms of the apparatus disclosed herein are desirably of the types described in detail in my application Serial No. 199,687, the particular forms used depending upon the type of flow required in the case at hand.

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

1. The method of drying material comprising passing material to be dried through an opening in a convex surface, and directing a high velocity jet of elastic fluid to wipe, subsequently to its formation, over said convex surface in a direction in which said surface has substantial curvature and in the vicinity of said opening so that the stream of fluid breaks from the curvature of said surface adjacent said opening to entrain and form a dispersion of the material in fluid from the jet.

2. Apparatus for forming a dispersion of material comprising a plurality of series of nozzles discharging into a relatively restricted passage, and means for feeding material to be dispersed to the nozzles of one of said series, all of said nozzles being directed in the same general direction in said passage, so that the dispersion formed by the first series passes in turn through the jets issuing from the nozzles of the subsequent series,

said series of nozzles being arranged to produce helical flow of the dispersion within said passage.

3. Apparatus for the dispersion of material comprising a receiver, means providing a converging fluid guiding region within said receiver and spaced at least in part from the walls thereof, both ends of said means being open to fluid within the receiver so that fluid leaving one end of said region may enter the other end thereof, means for producing in the vicinity of the throat of said region a high velocity jet of elastic fluid directed away from the enlarged entrance portion of said region and arranged to induce flow through said region, and means for introducing material to be dispersed into said jet.

4. Apparatus for forming a dispersion of material comprising means having a convex surface provided with an opening through which the material may emerge at a low speed, and a nozzle spaced from said surface for directing a high velocity free jet of elastic fluid having a substantially definite linear direction of flow to wipe over said convex surface in the vicinity of said opening, so that the stream of fluid breaks from said surface adjacent said opening to entrain and form a dispersion of the material in fluid from the jet.

5. Apparatus for drying material comprising a receiver having its upper end communicating centrally with a discharge passage, elastic fluid guiding means located inside the upper portion of said receiver at one side of the discharge passage, means for providing a dispersion of material flowing at high velocity in a downward direction from said elastic fluid guiding means and serving to induce flow therethrough, and means for providing a spirally ascending flow of elastic fluid through said receiver, said guiding means communicating at its upper end with the region in the upper portion of the receiver so that injection of fluid through the guiding means is effected from a portion thereof moving spirally inwardly towards said discharge passage.

6. The method of drying material comprising directing a plurality of high velocity jets of elastic fluid into a receiver, said jets being directed, convergently with respect to each other, at acute angles to a restricted region of a plane towards the same side thereof but with their axes in non-parallel and non-intersecting directions, and introducing into said jets material to be dried, thereby forming a dispersion of said material flowing from said region in fluid from the jets.

7. The method of drying material comprising directing a plurality of high velocity jets of elastic fluid into a receiver, said jets being directed, convergently with respect to each other, at acute angles to a restricted region of a plane towards the same side thereof but with their axes in non-parallel and non-intersecting directions and in the same skew direction relative to a line normal to said region, and introducing into said jets material to be dried, thereby forming a rotating dispersion of said material flowing from said region in fluid from the jets.

8. The method of drying material comprising directing a plurality of high velocity jets of elastic fluid into a receiver, said jets being directed, convergently with respect to each other, at acute angles to a restricted region of a plane towards the same side thereof but with their axes in non-parallel and non-intersecting directions, and introducing into said jets substantially in a zone of their maximum convergence material to be dried, thereby forming a dispersion of said material flowing from said region in fluid from the jets.

9. The method of drying material comprising directing a plurality of high velocity jets of elastic fluid into a receiver, said jets being directed, convergently with respect to each other, at acute angles to a restricted region of a plane towards the same side thereof but with their axes in non-parallel and non-intersecting directions and in the same skew direction relative to a line normal to said region, and introducing into said jets substantially in a zone of their maximum convergence material to be dried, thereby forming a rotating dispersion of said material flowing from said region in fluid from the jets.

10. Apparatus for drying material comprising a receiver, a nozzle arranged to discharge into the receiver, means for supplying to the nozzle an elastic fluid under pressure to produce a high velocity jet thereof from the nozzle, means for introducing into the jet material to be dried, and elastic fluid guiding means located inside said receiver, extending rearwardly from the vicinity of formation of said jet, open at both ends to the fluid in the receiver, spaced at least in part from the walls thereof, and constructed and arranged so as not to be engaged by said jet though subject to induction through it by the jet of high velocity flow of elastic fluid to carry the dispersion of material formed by the jet.

11. Apparatus for drying material comprising a receiver, a nozzle arranged to discharge into the receiver, means for supplying to the nozzle an elastic fluid under pressure to produce a high velocity jet thereof from the nozzle, means for introducing into the jet material to be dried, and elastic fluid guiding means located inside said receiver, extending rearwardly from the vicinity of formation of said jet, open at both ends to the fluid in the receiver, spaced at least in part from the walls thereof, and constructed and arranged so as not to be engaged by said jet though subject to induction through it by the jet of high velocity flow of elastic fluid to carry the dispersion of material formed by the jet, said guiding means having a restricted throat in the vicinity of formation of the jet.

12. Apparatus for drying material comprising a chamber of convex horizontal cross-section, means for introducing into a lower portion thereof a stream of elastic fluid, means for introducing a dispersion of the material into said stream, the last named means comprising material feeding means and means for subjecting the material to a jet of elastic fluid having in at least a portion thereof a velocity of flow at least equal to the velocity of sound in the fluid of the jet having the same pressure and temperature as said portion of the jet, thereby to provide a fine dispersion of the material, means providing a substantially closed region communicating with the lower portion of said chamber below the region of entrance of said elastic fluid, and a passage communicating with the upper portion of the chamber for removal of elastic fluid containing dried material.

13. Apparatus for drying material comprising a chamber of convex horizontal cross-section, means for introducing substantially tangentially into a lower portion thereof a stream of elastic fluid to provide a spirally rising current of fluid therein, means for introducing a dispersion of the material into said stream, the last named

means comprising material feeding means and means for subjecting the material to a jet of elastic fluid having in at least a portion thereof a velocity of flow at least equal to the velocity of sound in the fluid of the jet, having the same pressure and temperature as said portion of the jet, thereby to provide a fine dispersion of the material, means providing a substantially closed region communicating with the lower portion of said chamber below the region of entrance of said elastic fluid, and a passage communicating with the upper portion of the chamber for removal of elastic fluid containing dried material.

14. Apparatus for drying material comprising a receiver and means for providing a dispersion of the material in the receiver, said means comprising an enlarged mixing chamber, means for introducing into said mixing chamber said material and an elastic fluid, the latter in the form of a high velocity jet, to produce in said chamber an intimate mixture of the material and the elastic fluid, means for producing another high velocity jet of elastic fluid having in at least a portion thereof a velocity of flow at least equal to the velocity of sound in the fluid of the jet having the same pressure and temperature as said portion of the jet, and a tube for leading the mixture of material and fluid to said means for producing the second jet to be dispersed thereby.

15. The method of drying material of viscous nature comprising feeding into a mixing region said material and a high velocity jet of elastic fluid to produce turbulently an intimate mixture of said material and fluid having an average viscosity substantially lower than that of the material originally, and leading said mixture to another high velocity jet of elastic fluid to be dispersed thereby into a fine suspension, the second jet having in at least a portion thereof a velocity of flow at least equal to the velocity of sound in the fluid of the jet having the same pressure and temperature as said portion of the jet.

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