

April 9, 1963

J. B. JONES ETAL

3,084,874

METHOD AND APPARATUS FOR GENERATING AEROSOLS

Filed Aug. 12, 1959

2 Sheets-Sheet 1

FIG. 1

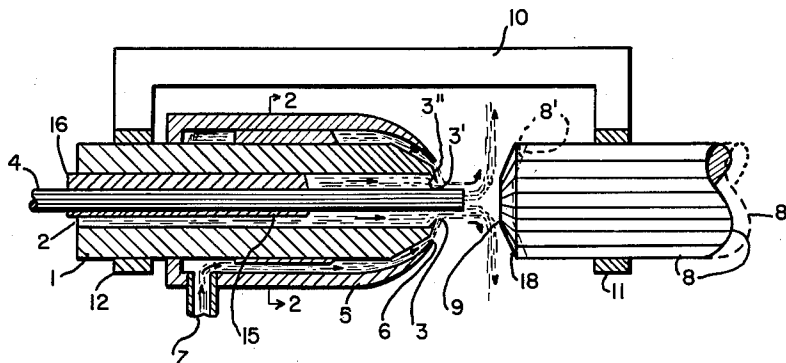


FIG. 2

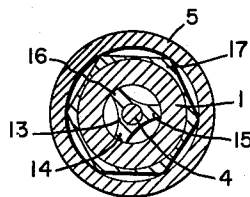
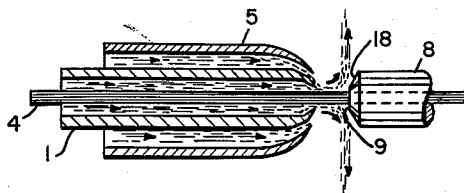


FIG. 3



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2 Sheets-Sheet 2

FIG. 4

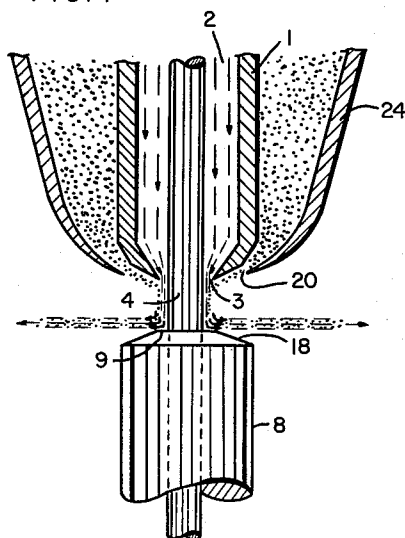
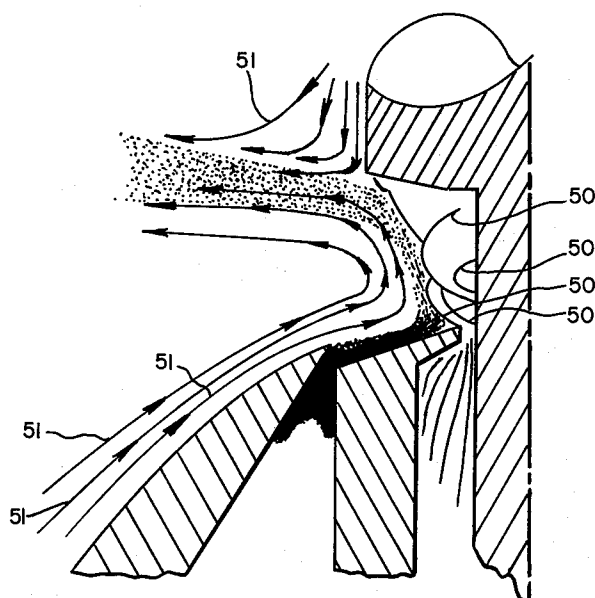


FIG. 5



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3,084,874

METHOD AND APPARATUS FOR GENERATING AEROSOLS

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Filed Aug. 12, 1959, Ser. No. 833,361
11 claims. (Cl. 239-424)

This invention relates to the atomization of materials, and more particularly to an apparatus and to a method for forming gaseous disperse systems and especially suspended liquid or solid particulate matter such as aerosols.

This application is a continuation-in-part of United States patent application Serial No. 539,381, filed October 10, 1955, and now abandoned, in the names of James Byron Jones and Kenneth H. Yocom, entitled "Method and Apparatus for Generating Aerosols."

Aerosols are stable suspensions of finely divided liquids, solids, or mixtures thereof in a gaseous medium, e.g., suspensions in air, such as natural fog, screening smokes, contrails from jet engines, and the like, and, in accordance with the present invention include particles having dimensions less than those produced by ordinary sprayers and dusters.

This invention has as an object the provision of a novel process for generating aerosols.

This invention has as another object the provision of a process for generating particles of a size difficult or impossible to achieve by prior processes and apparatus.

This invention has as yet another object the provision of a process for producing aerosols in which at least a major percentage of the particles comprise particles of very small size, such as below 15 microns diameter or below 10 microns diameter.

This invention has as a still further object the provision of a process for producing aerosols comprising small size particles having a narrow size range distribution.

This invention has as a different object the provision of a method for producing small size aerosol particles from liquids, slurries, and powdered solids at a relatively rapid rate.

This invention has as yet a different object the provision of a method for forming aerosol particles at a relatively low gas consumption.

This invention has as a further object the provision of apparatus for forming aerosol particles of small sizes.

This invention has as a yet further object the provision of apparatus for converting large amounts of liquids, slurries, and powdered solids into aerosol particles at a relatively rapid rate.

This invention has as yet another object the provision of apparatus for producing aerosol particles of diameters less than 10 microns.

This invention has as a still further object the provision of apparatus for producing small size aerosol particles within a relatively narrow size range.

Other objects will appear hereinafter.

For the purpose of illustrating the invention forms are shown in the drawings which are presently preferred, it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

Referring to the drawings wherein like reference characters refer to like elements:

FIGURE 1 is a partly elevational and partly sectional view of an embodiment of the apparatus of the present invention.

FIGURE 2 is a cross-sectional view taken on line 2-2 of FIGURE 1.

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FIGURE 3 is a partly elevational and partly sectional view of another embodiment of the apparatus of the present invention.

FIGURE 4 is a partly elevational and partly sectional view of yet another embodiment of the apparatus of the present invention.

FIGURE 5 is a diagram showing the dispersion mechanism of the aerosol generator of the present invention.

Dispersion methods which have been used by industry to produce particles comprise three principal types: pneumatic (or two-fluid or air-blast or aerodynamic) atomizers (in which compressed air or other gas is used to break up liquid emerging from a nozzle); centrifugal action atomizers (wherein liquid is fed onto the center of a rotating disk, cone, or top and centrifuged off the edge); and hydraulic (or hydrodynamic or pressure) atomizers (such as swirl chamber atomizers, in which liquid alone is forced through a nozzle under pressure and breaks up into droplets, usually in a cone spray pattern, this type of atomizer being commonly used in spray drying, agricultural spraying equipment, oil-fired furnaces, internal combustion engines, etc.).

Swirl atomizers handle a wide range of liquid capacities and small swirl atomizers give finer atomization than large ones, but the spray produced by the smallest practicable swirl nozzle is still coarse by comparison with the product of pneumatic atomizers. Spinning disks give a spray of nearly uniform droplets in a comparatively large size range, rotational speeds becoming excessive for small particle production. Pneumatic atomizers, while they produce a very small percentage of fine droplets, are characterized by a very wide range of droplet size, trapping devices sometimes being resorted to in an effort to narrow the range by removing the very large percentage of large droplets and recycling them to the feed, only a small percentage of the bulk fluid being converted into droplets in the size range below about 15 microns in diameter. Pneumatic atomizers are also of low capacity, accomplishing the production of particles at an exceedingly low rate, which is generally suitable for inhalation purposes although not adequate for many other uses, and this is particularly true if the liquid or slurry has a high surface tension or high viscosity; they also require for their operation substantially large quantities of compressed gas. For example, it has been reported that commercial pneumatic atomization of molten aluminum presently produces less than two percent of the weight passing through the atomizer into a particle size range of 8 microns average diameter.

Pneumatic nozzles, wherein a liquid jet is disintegrated by an air or other gas stream whose velocity is high relative to that of the liquid at the region where the liquid encounters the gas jet, either discharge the liquid into the center of the gas stream (as by injection of a smaller-diameter liquid jet along the axis of a high-velocity gas stream in a Venturi throat) or atomize the liquid at the region of discharge from the nozzle, sometimes with internal mixing of the streams before they leave the nozzle but often with external mixing just after they leave their respective conduits. Pneumatic nozzles, when they do not have both gas and liquid in the same conduit, present the gas stream exteriorly of the material stream either axially thereof or perpendicularly or otherwise tangentially to the material stream as it leaves the material conduit, all pneumatic atomization so far as is known being directed toward this conventional positioning.

The aerosol generator of the present invention is a new type of atomizer which is characterized by not only fine-particle production but also production of such fine particles in a narrow size range, being a range in a region previously inaccessible by utilization of commercially-

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available devices of the dispersion type, as may be seen by reference to the following table wherein is shown the aerosol size range produced by the present invention as compared with the particle size range of particles common in nature and the range of particle sizes usually produced by conventional dispersion-type atomizers. It should be noted that the particle size produced by various atomizers can be described in a number of ways. Determination of the suitability of particles for use in particular applications, however, is generally based on weight or mass and therefore the mass median diameter is a more valuable criterion in judging acceptability than, for example, the number median which tends to emphasize the number of small particles while glossing over the presence of the usually large quantity of material in large particles. The mass median diameter is of particular interest for practical purposes, since it indicates the diameter above which and below which there is 50 percent of the mass, i.e., 50 percent of the weight of the material will have a smaller particle size diameter than the specified mass median diameter and 50 percent of the weight of the material will have a larger particle size diameter than the specified mass median diameter. The mass median diameter is accordingly used in the table to show, for purposes of comparison, the usual mass median diameter ranges commonly achievable in each case, the information having been obtained from the published literature and, in the case of the output of the present invention, from our experimental data.

	Mass Median Particle Diameter	
	Microns	Inches
Common Small Particles:		
Rain.....	500 to 5,000.....	0.0197 to 0.197.
Mist.....	30 to 500.....	0.001182 to 0.0197.
Fog.....	1 to 30.....	0.0000394 to 0.001182.
Pollens.....	20 to 60.....	0.000788 to 0.002364.
Plant Spores.....	10 to 30.....	0.000394 to 0.001182.
Bacteria.....	1 to 10.5.....	0.0000394 to 0.0004137.
Usual Product of Dispersion-Type Atomizers:		
Rotating Disk.....	200 to 600.....	0.00788 to 0.02364.
Pressure Nozzle.....	60 to 600.....	0.002364 to 0.02364.
Pneumatic Atomizer.....	25 to 150.....	0.000985 to 0.00591.
Usual Product of Aerosol Generator of Present Invention.....	1.5 to 10.....	0.0000591 to 0.000394.

The aerosol generator of the present invention also operates with relatively low power consumption and with a lesser influence of viscosity of the material being aerosolized on performance. The means and method of the present invention result in the generation of aerosols at a relatively high rate, with a high percentage of bulk fluid, for example, being broken down into droplets of small size, i.e., below about 10 microns diameter, with relatively low gas-to-liquid ratios and without resort to excessive gas and fluid pressures.

The present invention produces aerosols from aerosolizable substances such as liquids and slurries. It may also be used to atomize coarsely powdered solid particles, with relatively minor modifications in configuration, such as a larger feed annulus for solids than that used for liquids and/or incorporating a venturi feeder to aid fluidization and feeding of the powdered solids. Clumps of finely divided solid particles ordinarily de-agglomerate under the influence of the subject invention, and particle size reduction is accomplished when larger particles are disseminated, aerosol particles being achieved which will remain airborne for extended periods of time.

Aerosol particles are produced from liquids, meltable solids, and slurries by the means and method of the present invention in the form of tiny microspheres discharged from the generator in an essentially-flat pancake-shaped plume.

While the common method of obtaining aerosols or fog-like particles for insecticide bombs, for example, is to spray a dilute solution of the material through a paint-

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spray-type atomizer so as to atomize into particles in the 25 to 150 microns size range and depend on extensive evaporation to reduce the particle size down to that desired, the means and method of the subject invention can produce particles directly from the material itself in the smaller size range without the necessity for use of the solvent. However, it is possible to produce even finer particles of some materials with the subject invention by utilizing an evaporative technique in conjunction therewith, wherein the volatile solutions are aerosolized into 1.5 to 10 micron mass median diameter size particles and are allowed to evaporate to sub-micron particle size.

Furthermore, when desired, it is possible to increase the size of the particles produced by the present invention through modification of the ratio of liquid-to-gas operating rates without substantial broadening of the size range produced.

Moreover, it is possible by use of the subject invention to aerosolize materials difficult or impossible to aerosolize by other means, such as materials which are insoluble in a volatile solvent.

The subject invention may be utilized under room temperature conditions or under other temperature conditions, such as with elevated temperature of the gas and/or material streams.

Evaluation of performance of atomizer nozzles, or of aerosol generators such as that of the present invention, is perhaps best considered on the basis of a figure of merit, which takes into account the mass of material passed through the nozzle which was atomized into a certain size range per unit of driving gas required for the nozzle. This Figure of Merit rating may be described by means of the following equation:

$$\text{Figure of merit} = \frac{10(w/o R_{60})(V_1)}{V_g}$$

where $w/o R_{60}$ is mass percent recovery after 60 minutes sedimentation in test cell, V_1 is the volume of liquid dispersed in (milliliters), and V_g is the volume of gas used to disperse 1 milliliter of liquid (in cubic feet). Ascertaining the quantity of aerosol produced which remains airborne after 60 minutes' stirred sedimentation, by a technique described in an article by William B. Tarpley, Jr., entitled "The Significance and Determination of Droplet Particle Size for the Aerosol Field," Aerosol Age, vol. 2, No. 12 (December 1957), pages 38-42, 112-113, it has been found that the figure of merit covering performance of an aerosol generator such as that disclosed in United States patent application Serial No. 441,039, filed July 2, 1954, in the name of James Byron Jones, entitled "Apparatus and Method for Generating Aerosols," is about 20, while that of the aerosol generator of the present invention is 47. Information from the published literature indicates that commercial paint-spraying nozzles and similar devices would have figures of merit in the region of 10 or below.

With conventional spray nozzles there is a marked influence of viscosity on aerosol particle size, as Nukiyama and Tanasawa have shown (Trans. Soc. Mech. Engrs. (Japan), vol. 4, No. 14 (1938), S-13 to S-16; vol. 4, No. 15 (1938), S-24 to S-26; vol. 5, No. 18 (1939), S-14 to S-17; vol. 6, No. 22 (1940), S-7 and S-8; vol. 6, No. 23 (1940), S-10), since viscosity appears as a higher power in the equation for droplet size. Following is a correlation of physical properties which fits the data obtained with applicants' apparatus and method over a wide range of fluids:

$$\text{Log}_{10} w/o R_{60} = 1.165 - 0.01\eta^{0.3}\gamma^{0.8}$$

where η is viscosity (in centipoises), γ is surface tension (in dynes per centimeter), $w/o R_{60}$ is weight percent recovery at 60 minutes in standard test cell, a measure of particle concentration in approximately the <5 micron size range. This indicates a dependence on viscosity to a much lower extent; in fact, surface tension and viscosity appear in the equation to approximately the same degree.

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This indicates that a different mechanism is involved in the break-up of liquid into fine droplets than that for conventional nozzles represented by the Nukiyama-Tanasawa expression.

Referring now to the drawings and particularly to FIGURE 1, wherein an embodiment of the aerosol generator of the present invention is shown in detail, the generator comprises a pair of concentrically-spaced conduits, the inner or gas conduit, conduit 1, having an inlet 2 and an outlet 3, and the outer or feed conduit containing the aerosolizable material, conduit 5, having an inlet 7 and an outlet 6. Conduit 1 has its outlet 3 axially projecting beyond the outlet 6 of the outer conduit 5. A cylindrical member 4 extends axially through the central portion of the inner conduit. A flat-faced barrier member 8, in the form of a frustum of a cone which is integrally and axially joined to a cylinder, is axially spaced from and juxtaposed to the outlet 3 of the inner conduit 1.

The outlet 3 of inner conduit 1 is formed by a constricted or inwardly converging lip having a sharp edge. Thus, the interior portion of the inner conduit adjacent to the lip region is of uniform cross-section whereas the interior of the lip region of the inner conduit decreases in cross-section from said uniform cross-section to the approximately pointed edge of the lip, thereby forming a constricted exit.

We have found that this construction provides a gas passage which minimizes obstructions, rapid changes in direction, sudden reductions or expansions in cross-sectional area (except at the gas conduit outlet region), and provides for a sudden constriction or "pinching" of the gas stream at the outlet after which the gas is able to suddenly expand into the environmental gas. The gas stream, compressed as for example at a pressure of above about 1.9 atmospheres gauge or from about 28 to 200 pounds per square inch gauge, attains supersonic velocity upon its issuance from the outlet and shock wave patterns with associated high-turbulence zones are formed adjacent to the barrier member.

Such construction is in contrast to that of conventional pneumatic nozzles of the type having a channel- or bore-type approach to the orifice, often having a relatively small-diameter bore coming after the relatively large-diameter bore of the remainder of the inner conduit which is usually a liquid conduit instead of a gas conduit. Such combination of large- and small-diameter bores provides a sharp shoulder at the region of entrance to the smaller bore which contributes to internal losses and lowered efficiency of performance.

We have found that, for efficient performance such as we have described, the gas stream must issue from its orifice at supersonic velocity. When only nearly-supersonic velocity is attained, such as might be achieved by pressurizing the gas at, for example, a pressure of below 1.9 atmospheres gauge such as 1.5 atmospheres gauge or 23 pounds per square inch gauge, a correspondingly less efficient performance is obtained. Thus, at subsonic gas flow, a still lower performance has been observed.

The approximately pointed edge of the gas conduit lip has been found to be essential to optimum operation. Thus it has been found that gradually decreasing performance is obtained as the orifice land width (edge) is increased from zero to 0.005 to 0.015 inch. However, in view of the impracticality of making a knife-edge lip which is sturdy, an orifice land width (edge) of from 0.005 to 0.007 inch has been found to be satisfactory. The effect of orifice land width becomes more pronounced with higher driving gas pressure.

The outer surface of the lip region and the region proximate the lip region, wherein the interior cross-section of the gas conduit 1 is decreasing toward the lip region of outlet 3, is inwardly converging so as to provide, in effect, a shoulder over which the aerosolizable material flows smoothly from outlet 6 toward the gas issuing from conduit outlet 3, flowing in a more or less

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uniform layer across the said shoulder, as shown in FIGURE 5. That is, the fluid must flow in a uniform pattern rather than in rivulets and must not be introduced above or too close to the inner conduit outlet so as to cause flooding. The location and conformation of the shoulder are also important in connection with the need for good flow of secondary-air aspirated from the environmental air in the region rearwardly of the outlet region (see FIGURE 5), to assist in the acceleration of the liquid and permit of aerosol plume stability and good aerosolization. It has been found, for example, that when the distance which the fluid must flow is too great the fluid flow will not be optimum. The protrusion of the outlet lip of the inner conduit beyond the smallest liquid exit cross-section defined at 6, i.e., the angle of the jet shoulder, should not exceed a 20-degree angle measured from the horizontal for optimum performance. The width of the jet shoulder should not exceed 0.5-inch for good performance and is preferably smaller, and the liquid feed should be introduced in such a way that the maximum unconfined depth on the jet shoulder as defined by the position of the feed conduit 5 and its outlet 6 does not exceed 0.005 to 0.015 inch for optimum performance as aforesaid. Other reasons for defining this configuration include directing the fluid toward the gas jet and promoting smooth secondary-air flow commensurate with good liquid feeding.

The outlet 6 of the outer or feed conduit 5 is directed toward the discharge path of the inner conduit 1 and is preferably directed toward the periphery of the outlet 3 of the inner conduit 1, while the outer surface of the shoulder of conduit 5 forms with the outer surface of the shoulder of conduit 1 axially projecting beyond outer conduit outlet 6 a generally ogive configuration. Said outlet 6 has the form of an annulus whose discharging width is from 0.5 to 20 times the distance from the wall of the core 4 to the lip of the gas discharge orifice 3 but should not exceed 0.020-inch for best performance, for reasons of maintenance of uniform liquid feed. In any event, the distance from the outer conduit outlet 6 to the inner conduit outlet 3 must not be such that the liquid layer or film must travel a distance more than about 0.5-inch for optimum performance unless the liquid is substantially pressurized.

Again, as with the inner or gas conduit 1, the outer or feed conduit 5 is formed from a conduit which is uniform in cross-section until it decreases in cross-section near the outlet region so as to form a constricted exit having a sharp edge.

It should be noted that the liquid need not be supplied at any pressure (such as may be found in conventional nozzles) since the liquid can actually be made to aspirate from the feed conduit and a slight negative pressure is always observed in the dissemination zone. This places certain restrictions on the characteristics of the liquid feed, however. If the annular orifice is excessively large, aspiration of the flow will occur at a rate controlled by aspiration rather than by feed rate to the nozzle, and a decrease in efficiency of performance associated with an undesirable balance between gas and liquid flow will be attained. One of the difficulties associated with conventional nozzles which do not restrict liquid flow is that liquid will first aspirate from the entire feed conduit in the region nearest the outlet, then there will be a lag period while this is filled, then there is another pulse, etc.; during such pulses, atomization is taking place at a larger "local" liquid flow rate than is being controlled by the feed device up the liquid stream.

The outer surface of the outer conduit 5 is likewise inwardly converging toward its outlet 6, so as to form with the outer surface of the inner conduit 1 in the region just back of the jet shoulder an approximately streamlined configuration conducive to good flow of aspirated secondary air.

It has been found, in this connection, that an object

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below the outlet region, i.e., rearwardly thereof, should not protrude beyond the envelope defined by a 30-degree cone having its apex approximately at the discharge orifices in view of the serious influence on the stability and symmetry of the aerosol plume resulting from non-uniformity of the flow of secondary or aspirated air.

The barrier member 8 is positioned with its flat face at a distance beyond the outlet 3 of inner conduit 1, the optimum positioning of the barrier member face having a relation to plume stability, which is related to the barrier member geometry. If, for example, the slope distance away from the barrier member face is too sharp or the barrier member face is located too far from the gas jet, the aerosol plume will tend to close up and embrace the barrier member which will not separate the formed aerosol particles as rapidly as possible, thus leading to reagglomeration.

The flat face of the barrier member preferably subtends the driving gas stream and its embracing stream of aerosolizable material but should not be so wide as to interfere with the adequate flow of secondary air. The slope distance or bevel width 18 of the barrier member 8 should not exceed about 0.5-inch for optimum performance, again for reasons of good secondary air flow. If the face of the barrier member is too large, the aerosol plume will no longer be essentially flat but will be bent back upon the conduit members and finally embrace them with resultant undesirable effects on particle size performance. The angle of the beveled portion of the barrier member does not reflect directly on performance but relates to aerosol plume stability and hence to stable performance and indirectly to nozzle performance. The utilization of a frustum-of-a-cone-shaped barrier member provides for a sharp turn of the gas stream at the barrier member such as is essential to good performance. A beveled slope on the barrier member is superior to other configurations such as spherical, conical, or flat configurations.

The barrier face 9 of the barrier member 8 is spaced axially of the outlet 3 of the inner conduit 1, preferably at a distance of from between 0.03- and 0.50-inch from said outlet, depending upon the gas used and its pressure and the size of the barrier member face. Accordingly, at least one of said barrier members and said inner conduit may, but need not necessarily, be axially adjustable with respect to each other as at 8' for providing an optimum spacing within the range.

The cylindrical member 4 which is positioned internally of the inner conduit 1 and extends axially through the central portion of the inner conduit 1 extends outwardly of the outlet 3. The cylindrical member or core 4 has two purposes: the support of the barrier member, when desired, and the primary purpose of channeling the driving gas into a coreless annular ring which subsequently interacts with the material being aerosolized.

Thus we have found that a simple cylindrical gas jet does not utilize the entire jet cross-section efficiently, and that only the peripheral volume of gas in the jet operates to disrupt the surrounding sleeve of aerosolizable material into fine aerosols. In accordance with the invention, therefore, the central portion of the gas jet is effectively eliminated and its place taken by a solid core or plug, such as a metal plug, making an annulus of the issuing jet of gas. Such a solid core, plug, or pin not only affords economies in gas consumption but may, when desirable as has been said, support the barrier member and thereby make the generator more economical to manufacture than if the gas and feed conduits were connected to the barrier member by strut-type or other conventional supporting means. Also, there is considerably less tendency toward impaction losses of particles on nozzle parts such as supports of the barrier member. In addition, by utilization of such a solid core, a greater plume stability (favoring efficient aerosolization) is achieved through the symmetrical disposition of the upper and lower parts of the con-

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duit-barrier member construction without the interference of supporting structures such as struts. The core or pin must be sufficiently sturdy that it will not oscillate in the gas stream at the orifice region, but otherwise its diameter is important only insofar as it determines the width of the annular gas outlet orifice. However, positioning of the core within the gas conduit must be concentric, to avoid heavier flow of driving gas on one side which will tend to distort the plume and make for less efficient operation. Practical considerations define the width of the annulus formed by insertion of the core member 4 within the inner gas conduit 1 and its outlet 3 at the outlet 3 at approximately 0.001-inch minimum to about 0.025-inch, although if gas consumption is not a factor larger annular widths may be used. Those skilled in the art who are concerned with gas economy may work out the annulus area in terms of a gas-to-liquid ratio as desired, according to production needs.

While the core 4 may be positioned and axially supported within the conduit 1 in any suitable manner, the core 4, in accordance with FIGURE 2, is supported by means of a spline-like member 13 concentric with the core 4 and having its circumferentially-spaced projecting legs or flutes 14, 15, and 16, contacting the inner walls of the conduit 1, said flutes being preferably press-fitted into said conduit 1, whereby channels are provided in inner conduit 1 for the passage of the driving gas.

Likewise, conduit 1 may be similarly supported within conduit 5 by means of hexagonal member 17, whereby channels are provided in the outer conduit 5 for the passage of aerosolizable material such as a liquid or a slurry.

It will be apparent that spline-like member 13 and core 4 and likewise hexagonal member 17 and conduit 1, although illustrated as separate parts, may be and preferably are for machining purposes fashioned as single units.

In connection with the flutes which support the core 4, these are preferably streamlined, although minor turbulence such as would be associated with non-streamlined flutes can be tolerated with a reduction in efficiency of utilization of the driving gas stream. As has been said, positioning of the core member 4 within the inner conduit 1 must be concentric, or a heavier flow of driving gas on one side will distort the aerosol plume and make for inefficient operation. It is also desirable for optimum performance that the supporting flutes are not extended to the edge of the gas conduit outlet, in order that there may be provided a concentric supply chamber between the ends of the flutes and the gas outlet orifice so as to reduce turbulence.

A supporting means, for example in the form of a supporting bridge 10, connects the conduit 1 and the barrier member 8 in axial alignment with each other, e.g., by means of intermediate collars 11 and 12 embracing said conduit and barrier. However, separate supports (not shown) for each of said barrier member 8 and said conduit 1 may serve as supporting means. Also, when desired, the core member 4 may be extended through the intervening axial spacing between the gas outlet 3 and barrier member 8 with the barrier member 8 being supported on said core (see FIGURE 3).

The manner of operation of the apparatus embodiments of FIGURES 1 and 3 is as follows: The driving gas (compressed as aforesaid at a pressure of above about 1.9 atmospheres gauge or from about 28 to 200 pounds per square inch gauge) flows from the gas conduit outlet 3 at supersonic velocity, impinges upon the juxtaposed flat portion of the barrier member 8, and is thereby diverted from its original direction to a direction essentially normal to the axis of the gas and feed conduits so as to flow outwardly and radially in a disk-like flow. The action of this rapidly-moving gas-flow pattern aspirates environmental secondary air from both above and below the disk-like flow, which aspiration is aided and abetted by the configuration of the barrier member and the outer surfaces of the inner and outer conduits in the region of

their outlets. When the barrier member region away from its flat face is beveled in the manner shown and described and when the outer surfaces of the outer and inner conduits in the region of their outlets are formed as shown and described, an even streamlined flow is produced without significant energy losses due to turbulent eddies or stagnation and the secondary air flow serves to decelerate and mix with and dilute the disk-like pattern.

The standing shock waves produced in the region between the gas conduit of the orifice and the flat top of the barrier member appear in schlieren photographs to be essentially toroids arranged in the form of an inverted cone.

The annular sleeve of aerosolizable material (such as a liquid or a slurry) is introduced through the outer or feed conduit 5 and leaves it through the outlet 6 at essentially ambient pressure so as to be in close juxtaposition to the driving gas conduit outlet, the aerosolizable material flowing across the gas jet conduit shoulder and, along with the secondary aspirating air, creating a thin film maximizing the material's surface area. The attainment of this condition is important, since rivulet or uneven feed will provide locally high (and undesirable) liquid-to-gas ratios at the region of contact of the two coaxial streams, with a resulting lowered atomization efficiency and comparatively broad particle size distribution. The thin film traversing the gas conduit shoulder is simultaneously (as judged by high-speed photographs) drawn off the shoulder edge, diverted from its traversing direction and tremendously accelerated by the action of the internally-disposed supersonically-moving driving gas stream. It is also tremendously thinned, further increasing its surface area, while traveling towards the barrier member with the gas stream which it embraces. The sleeve of aerosolizable material, as it embraces the driving gas stream, takes on a roughened and filamentous appearance in which the filaments and threads appear to be in violent motion, and further break-up probably occurs because of the relative gas-liquid interfacial velocity. Interaction with secondary air aspirated by jet action also promotes break-up. Upon approaching the region of the barrier member, the liquid sleeve is diverted sharply outwardly, substantially without wetting of the barrier member, through an approximately 90-degree angle by interaction with the diverging gas stream, at the same time passing through a zone of high turbulence and shock-wave-pressure gradients which further contributes to the break-up of the aerosolizable material, to the end that the distance between individual particles is abruptly and greatly increased, thus minimizing reagglomeration and ending in the formation of an exceedingly fine aerosol product.

During the stage of this second sharp change in direction, which is produced if the proper shape of barrier member and outer conduit outlet surfaces has permitted an adequate flow of secondary air, small droplets which can follow the flow lines appear to be carried away in the disk-shaped gas-flow pattern, while large droplets (which can penetrate further into the driving gas stream) appear to be given rotational components as well as relatively large shear action. Fibrils appear to be drawn out further and sheared off. This apparently selective action would account in some measure for the relatively-uniform size distribution produced by the subject invention through preferential break-up of larger droplets.

An essential feature of the output of the aerosol generator of the present invention is the stable plate-like discharge plume which is essentially normal to the axis of the generator, said plate-like discharge zone diverging and opening up as the distance from the axis of the nozzle increases. The disk-like pattern may be and usually is slightly concave on the barrier member, as can be observed in FIGURE 5. This flow pattern permits aerosolized particles to move rapidly away from one another along radii in the disk, together with the mixing in and

diuting of particles with secondary air in the region outwardly of and remote from the barrier region.

This dissemination action is in sharp contrast to the acute conical flow pattern produced by some conventional nozzles and those nozzles which do not operate with supersonic velocity of the driving gas stream, and which consequently provide ineffective utilization of the energy available in a compressed gas stream and insufficient dilution to increase the individual particle spacing with resultant permission of rapid reagglomeration due to high concentration. In some cases, improper and turbulent secondary air flow, such as is present in nozzles which direct flow in acute conical patterns, will cause severe impingement of material on the nozzle parts so as to clog the parts and reduce operating efficiency; this is a serious problem in spray drying. The aerosol plume produced by the nozzle of the present invention, however, is of a generally-flat disk-like character slightly concave on the barrier member side as aforesaid, with particles decelerating a short distance after dissemination and rising in a dense cloud-like pattern, a sign of fine-particle production.

In the aerosolization of solids with the apparatus and method of the present invention, the exact mechanism by which such break-up occurs is not altogether clear. However, the same essentially-flat disk- or pancake-like configuration for the discharge plume of particles emerging from the nozzle is indicated as optimum in order to prevent particle reagglomeration and to insure immediate separation of the aerosolized particles. The solids may be introduced sometimes under pressure or by aspiration as with a venturi. The use of a venturi for aspirating the solids into the feed supply to the feed conduit 5 apparently serves simply as a means of fluidizing the feed of aerosolizable substance, in which case air or gas is associated with the aerosolizable substance within conduit 5.

We have found that, when aerosolizable substances are treated in the above manner by the apparatus and method of the present invention, exceedingly fine aerosols are generated and produced in substantially large quantities at substantially high rates, i.e., up to 30 pounds per hour for small nozzles and as high as 300 pounds per hour for large ones, at low gas consumption and at low gas pressures as aforesaid.

It will be appreciated that similar or different substances may be simultaneously introduced to the periphery of the gas stream issuing from the inner conduit, as for purposes of effecting increased aerosol generation rate, for producing an aerosol mixture of different substances, or for providing an aerosol product influenced by the combined substances.

FIGURE 4 illustrates another modification of the invention, wherein conduit 5, the feed conduit of FIGURES 1 and 3, has been replaced with a modified form of feed conduit, conduit 24, still having the characteristic constricted or inwardly converging lip having a sharp edge, but with the inlet region of the outer conduit upstream of the conduit outlet being broadened so as to provide a more convenient reservoir for the less-easily-flowable powdered solid substances which may be aerosolized by means of the present invention.

FIGURE 5, which illustrates diagrammatically the dispersion mechanism of the aerosol generator of the subject invention, shows especially the shock wave formation 50 and the path of the aspirated secondary air 51.

As illustrations of the subject invention, there are set forth below the following examples:

Example I

The process heretofore described was effected on a non-evaporating fluid of viscosity 4.5, comprising a mixture of glycerine and water so adjusted as to be at equilibrium relative humidity and produced 79 percent of the mass of feed material in particles of below 8 microns in size and 60 percent in a size range smaller than 4

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microns. A paint-spray-type nozzle operated at the same flow rates with the same material produced only 21 percent in particles smaller than 4 microns.

Example II

Beta-propiolactone, a liquid produced by Celanese Corporation of America, was aerosolized in accordance with the subject invention at 76° F., with a flow rate of 50 milliliters per minute and an air pressure of 90 pounds per square inch, and 95 weight percent of the beta-propiolactone particles so produced were less than 7 microns in diameter.

Example III

Petronate-L, a sulfonated petroleum product sold by Sonneborne & Sons, Inc., New York City, was aerosolized in accordance with the subject invention, at an air pressure of 120 pounds per square inch, a liquid feed rate of 47 milliliters per minute, and an aerosolizing temperature of 76° F. The mass median diameter of the fog so produced was less than 10 microns.

Example IV

An alkyl-aryl sulfonate of anionic surfactant character, designated G-3300 and sold by the Atlas Powder Company, Wilmington, Delaware, was aerosolized in accordance with the subject invention at a liquid feed rate of 47 milliliters per minute at 76° F. with a driving air pressure of 110 pounds per square inch. The mass median diameter of the product was less than 8 microns.

Example V

In a series of experiments, Type 200 Silicone oils manufactured by the Dow Corning Corporation, Midland, Michigan, having viscosities ranging from 5 to 50 centistokes were aerosolized in accordance with the subject invention with air pressure of 100 pounds per square inch, liquid flow rate of 50 milliliters per minute, and liquid temperature of 76° F., the products having the following measured size distributions:

Viscosity	Weight Percent Less Than—		
	8 microns	5 microns	4 microns
5 cs.-----	76	62	47
10 cs.-----	68	45	35
50 cs.-----	48	31	23

Example VI

Lauryl alcohol, designated Dytol B-35 and obtained from Rohm & Haas Company, Philadelphia, Pa., was aerosolized in accordance with the subject invention, utilizing a feed rate of 50 milliliters per minute, a driving air pressure of 125 pounds per square inch, and a liquid temperature of 100° F. The resultant aerosol showed a persistent fog after over two hours' settling time.

Example VII

A chlorinated naphthalene derivative containing an average of 26 percent chlorine, manufactured by the Bakelite Company, New York City, under the trademark Halowax Oil, was aerosolized in accordance with the subject invention under the following conditions: 150 pounds per square inch driving air pressure, 80° F., 50 milliliters per minute feed rate, resulting in a product having a mass median diameter of 9 microns.

Example VIII

An oil-water-type emulsion of olive oil in a non-volatile 40 - weight - percent - glycerine - 60 - weight - percent-water solution was prepared by stirring in a Waring Blendor. This emulsion was aerosolized with a driving air pressure of 110 pounds per square inch, at 76° F., and a liquid feed rate of 47 milliliters per minute. The product consisted of tiny droplets of olive oil each surrounded

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by a spherical shell of the nonvolatile glycerine-water solution. The particle size of the product was 60 weight percent in the size range smaller than 4 microns.

Example IX

Cetyl alcohol, a low-melting solid, sold by the M. Michel Company, New York City, was melted and aerosolized at a liquid temperature of 160° F., an air pressure of 90 pounds per square inch and an air temperature of 250° F., and a feed rate of 33 milliliters per minute. The mass median diameter of the product was less than 5 microns.

Example X

An alloy of 38.4 weight percent bismuth, 30.8 weight percent lead, 15.4 weight percent tin, and 14.4 weight percent cadmium, having a melting point of 158° F., was aerosolized in accordance with the subject invention at a temperature of 300° F., using nitrogen at 100 pounds per square inch pressure as the driving gas at a temperature for the nitrogen of 400° F. The product gave an indicated size distribution of 90 weight percent of the particles having a diameter of less than 10 microns.

Example XI

A low-melting carbon paper ink based on iron blue pigment was prepared in the normal manner, melted, and aerosolized at a liquid temperature of 180° F. and a liquid feed rate of 33 milliliters per minute. The driving gas pressure was 100 pounds per square inch and the gas was heated to a temperature of 250° F. The resulting finely-divided aerosol was allowed to deposit by slow sedimentation on sample strips of carbon paper base stock, heat-set, and a superior one-time-use carbon paper sheet obtained. No blobs, blotches, or bleed-through to the back of the paper base was observed, and a product was obtained which was superior in uniformity to commercially-available material.

Example XII

An insecticide, hexachlorobenzene, was melted and heated to a temperature of 180° F., and aerosolized in accordance with the subject invention at a feed rate of 50 milliliters per minute, utilizing air at 120 pounds per square inch and a temperature of 250° F. The resulting fog of droplets had a particle size of which 90 weight percent of the particles had diameters of less than 5 microns.

Example XIII

A tranquilizer pharmaceutical, Meprobamate, prepared by the Wallace Laboratories, New Brunswick, New Jersey, was melted and aerosolized at a temperature of 190° F. and a feed rate of 30 milliliters per minute, utilizing a driving gas pressure of 125 pounds per square inch and a gas temperature of 350° F. The product consisted of round solid microspheres, 90 weight percent of the particles having diameters of less than 10 microns.

Example XIV

A slurry consisting of 40 percent alumina of 7 microns average diameter in castor wax of melting point 190° F. was prepared with an apparent viscosity of 300 centipoises. This material was atomized in accordance with the subject invention to produce a product consisting of individual 7-micron-diameter particles with a few 1- and 2-micron-diameter particle agglomerates surrounded by a solidified spheroidal layer of wax.

Example XV

A solution of cellulose nitrate, pyro grade, was prepared in a 75 percent di-isobutyl ketone 25 percent normal butyl alcohol solvent system and aerosolized in accordance with the subject invention at a temperature of 85° F. and a liquid feed rate of 50 milliliters per minute. Nitrogen gas at a pressure of 125 pounds per square inch and a temperature of 85° F. was used to drive the aerosol generator. The product consisted of solid microspheres

of nitrocellulose free of solvent and fibrils, and 90 weight percent of the product had particle diameters smaller than 20 microns.

Example XVI

An 0.127 percent aqueous solution of sodium chloride, disseminated through the aerosol generator of the present invention, produced 90 weight percent of the particles having diameters of less 1.7 microns, 75 percent with diameters less than 1 micron, and 50 percent with diameters less than 0.55-micron, when the generator was operated at 150 pounds per square inch driving gas pressure and a flow rate of 35 milliliters per minute.

Example VXII

Using a venturi-type feeder in conjunction with the outer feed conduit of an aerosol generator of the type shown in FIGURE 4, powdered instant coffee was disseminated and a slow-settling fog of powdered coffee dust was obtained, fracture of the hollow beads being noted in photomicrographs.

Example XVIII

Two lots of initially-different-particle-size dried *Serratia marcescens* were disseminated through a nozzle of the present invention under conditions which produced virtually complete deagglomeration; namely, 40 pounds per square inch driving gas pressure; and under conditions which produced particulate fracture as well as deagglomeration; namely, 160 pounds per square inch driving gas pressure, with the following results:

Particle Size Prior to Dissemination (Mass Median Diameter, Measured by Whitby Centrifuge Technique)	Particle Size in Cloud (Mass Median Diameter) With Gas Pressure	
	40 p.s.i.g.	160 p.s.i.g.
	Microns	Microns
Coarse (14.1 microns)-----	17.0	5.5
Fine (3.9 microns)-----	5.4	3.9

Example XIX

Acid Orange XX dye mixed with Alconox, a detergent, was disseminated through a nozzle of the present invention under conditions to produce particle fracture (160 pounds per square inch driving gas pressure), with the result that 22 percent of the mass of dye remained airborne in a small particle size range after one hour of stirred settling.

Example XX

When the aerosol generator of the present invention was operated under conditions of liquid flow rate: 300 milliliters per minute, driving gas pressure: 100 pounds per square inch gauge, the mass median diameter of particles obtained when aerosolizing Atmul 84, a hard glycerine monostearate obtained from Atlas Powder Company, Wilmington, Delaware, was 5 microns. When the feed rate was increased fourfold and the pressure of the gas reduced 70 percent, the mass median diameter of the resulting particles increased to 12 microns.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims rather than to the foregoing specification as indicating the scope of the invention.

We claim:

1. A process for generating aerosols which comprises continuously issuing an annular stream of pressurized gas from an orifice at supersonic velocity toward a barrier, forming shock waves adjacent the barrier, diverting the

gas stream approximately 90 degrees from the path of issuance of said annular gas stream so that it flows radially and outwardly from the path of issuance of the annular gas stream, aspirating environmental gas into the regions of the orifice and barrier, directing an annular film of aerosolizable substance from a region outwardly of the gas orifice towards the issuing gas stream orifice causing the film to embrace the annular gas stream which is interiorly of the film during the passage of both film and stream toward the barrier and to be diverted with and by the gas stream in the region of the barrier whereby the film of aerosolizable substance is broken up into aerosol particles.

2. A process in accordance with claim 1 in which the aerosolizable substance is a liquid.

3. A process in accordance with claim 1 in which the aerosolizable substance is a slurry.

4. A process in accordance with claim 1 in which the aerosolizable substance is a powdered solid.

5. A process in accordance with claim 1 which comprises heating to a temperature above ambient temperature the annular stream of pressurized gas prior to discharging the same from the orifice at supersonic velocity.

6. A process in accordance with claim 1 which comprises heating to a temperature above ambient temperature the aerosolizable substance prior to discharging it from the region outwardly of the gas orifice.

7. A process in accordance with claim 6 which comprises heating to a temperature above ambient temperature the annular stream of pressurized gas prior to discharging the same from the orifice at supersonic velocity.

8. Apparatus for generating aerosols comprising an outer tube having at one end an outlet orifice, an inner tube arranged within the outer tube and having an outlet orifice axially projecting beyond the outlet orifice of the outer tube, said outer tube constituting a feed passage for an aerosolizable substance and said inner tube constituting a feed passage for a pressurized gas, said outer tube outlet orifice being directed towards the discharge path of said inner tube outlet orifice, said outer tube outlet orifice and said inner tube outlet orifice being constricted orifices formed by converging the respective tube ends in the region of their respective outlets so as to form outlet shoulders rearwardly of the tube orifices, the outer surface of the shoulder of the outer tube forming with the outer surface of the shoulder of the inner tube axially projecting beyond the outer tube orifice a generally ogive configuration, said inner tube and outer tube outlet orifices having an approximately knife edge, a cylindrical member axially extending through the central portion of the inner tube, and a flat faced barrier member axially spaced from and juxtaposed to the outlet of the inner tube.

9. Apparatus for generating aerosols in accordance with claim 8 in which the barrier is fixedly secured to the cylindrical member.

10. Apparatus for generating aerosols in accordance with claim 8 in which the cylindrical member has a free end portion which projects through the inner conduit and is spaced from the face of the barrier.

11. Apparatus for generating aerosols in accordance with claim 8 in which the flat faced barrier is carried on the frustum of a cone which is integrally and axially joined to a cylinder.

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