March 22, 1960 J. B. JONES 2,929,563

PROCESS FOR GENERATING AEROSOL AND APPARATUS THEREFOR

Filed Jan. 3, 1957

Fig. 1

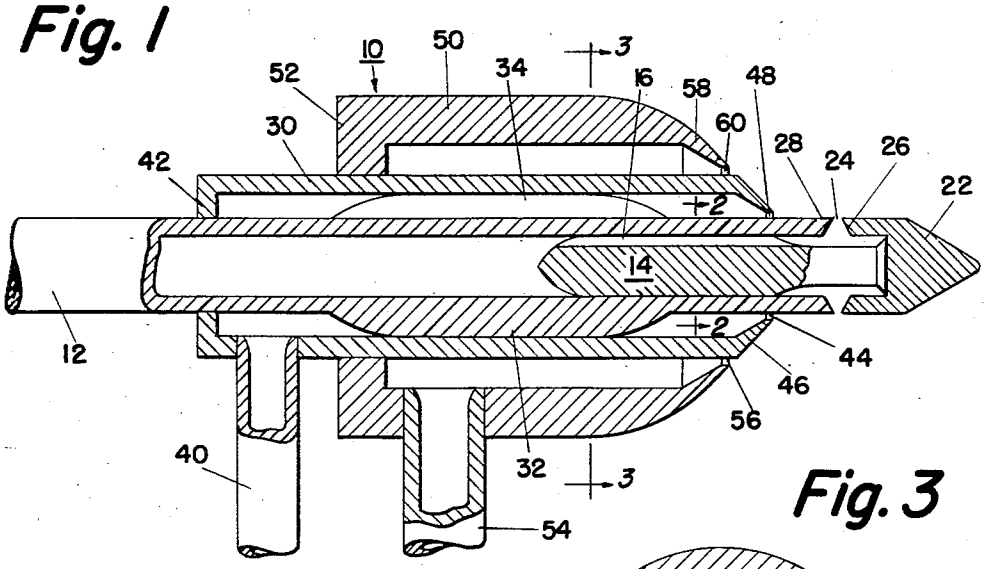


Fig. 3

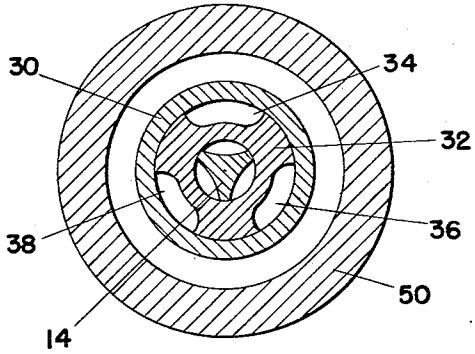


Fig. 2

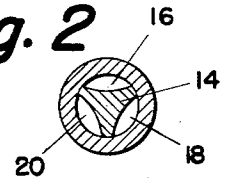
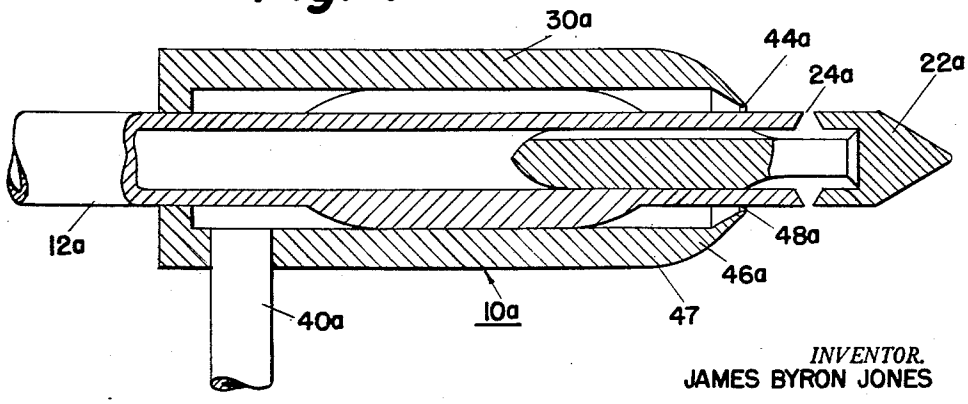


Fig. 4



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United States Patent Office 2,929,563 Patented Mar. 22, 1960

2,929,563

PROCESS FOR GENERATING AEROSOL AND APPARATUS THEREFOR

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Application January 3, 1957, Serial No. 632,332

8 Claims. (Cl. 239—8)

The present invention relates to a process for generating aerosols and apparatus therefor, and more particularly to a process for generating aerosols within a selected particle size range, in which the distribution of various particle sizes is maintained within narrow limits; and to a nozzle for producing such aerosolized particles.

A variety of processes for generating aerosols and aerosolization equipment have heretofore been suggested. It is, however, very difficult to produce aerosols in which substantially all of the particles are characterized by dimensions smaller than a diameter of about ten microns. Furthermore, it is most difficult with most prior processes and apparatus to obtain small size aerosol particles within a relatively narrow size distribution range.

In particular, substantially all prior aerosol generators capable of handling liquids or slurries at a bulk liquid velocity in excess of about one milliliter per second are incapable of delivering such relatively large volumes in the form of aerosols having a major weight percentage of aerosolized droplets of a diameter of below ten microns.

Prior equipment has been developed by me capable of producing aerosol droplets having a particle size of ten microns diameter or less in high yield and within a relatively small size range distribution. Such equipment comprises a multiple orifice nozzle having a barrier spaced from and facing at least the centermost orifice.

While the aforesaid barrier type nozzle constitutes one of the most efficient forms of aerosol generators yet developed, if not the most efficient aerosol generator yet developed, it suffers from certain handicaps in certain areas of use. These handicaps arise due to the necessity for positioning the barrier in respect to the orifices by means of struts which extend from the housing comprising the orifices to the barrier.

For example, when the use of the generator is to aerosolize a combustible liquid, as for example fuel oil or the like, which is to be burnt while in the aerosolized state, the struts adversely affect the resultant flame due to their action as impingement surfaces in respect to the aerosol droplets. Thus, the struts serve as surfaces upon which coke or other carbonaceous materials deposit. These coke and carbonaceous materials act as secondary combustion centers and adversely affect the nature of the flame developed by the aerosol particles. Moreover, the presence of the struts within the combustion chamber frequently leads to the conflagrant or corrosive consumption of the struts with attendant shutdowns for repairs.

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 liquids, or other aerosolizable substances, or slurries of a size difficult 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 weight percentage of the droplets comprise particles of very small size, such as below twenty microns or below ten microns.

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 of liquid, or slurries, at a relatively rapid rate.

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

This invention has as a further object the provision of apparatus for converting large amounts of a liquid, or slurry 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 ten 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 there is shown in the drawings forms 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 longitudinal sectional view through one embodiment of the apparatus of the present invention.

Figure 2 is a cross sectional view taken on line 2—2 of Figure 1.

Figure 3 is a cross sectional view taken on line 3—3 of Figure 1.

Figure 4 is a longitudinal sectional view of another embodiment of the apparatus of the present invention.

Referring initially to Figures 1, 2 and 3, wherein the preferred embodiment of the present invention is shown, the apparatus of the present invention is designated generally as 10. The apparatus 10 comprises a nozzle which in accordance with the process of the present invention should discharge into the open atmosphere, or into a gaseous atmosphere, if the process is conducted under conditions where air or oxygen is to be excluded. Thus, as will be more fully explained below, the aspiration of gas from the surrounding atmosphere through the material being aerosolized is desirable and preferable for the proper functioning of the apparatus 10.

The apparatus 10 includes a center conduit 12. The outermost end portion of center conduit 12 is provided with internal splines 14 which segregate the interior of center conduit 12 into a plurality of channels 16, 18 and 20 (see, in particular, Figure 2). While three channels 16, 18, and 20 are shown in the drawings, it is to be understood that a larger or smaller number of such channels may be utilized.

The splines 14 are press-fitted into center conduit 12 and are preferably integral with a cap 22 which is longitudinally disposed to conduit 12. The outer end of cap 22 is preferably streamlined, e.g. tapered or generally conical, to permit aspiration circulation of gas from the surrounding atmosphere, as will be more fully explained below. As will be seen from Figure 1, the cap 22 faces and blocks the channels 16, 18 and 20.

An annular aperture 24 is positioned intermediate the free edge 26 of cap 22 and the free edge 28 of center conduit 12.

I have found that the size dimensioning of the annular

aperture 24 is critical if satisfactory aerosolization is to be accomplished. In particular, I have found that the narrowest part of the annular aperture 24 should be maintained within the size range 0.0005 to 0.030 inch. The annular aperture 24 should not vary substantially about its 360 degrees of circularity so that an annular discharge of uniform configuration will be had.

The center conduit 12 is concentrically disposed within a conduit 30 (see Figures 1 and 3). The disposition of center conduit 12 in respect to conduit 30 is maintained by splines 32, which are external and which are for convenience integral with conduit 12.

The interior of conduit 30 is provided with a plurality of channels 34, 36, and 38 defined by splines 32. While three channels 34, 36 and 38 are shown in the drawings, it is to be understood that a larger or smaller number of channels may be utilized within conduit 30.

The conduit 30 is provided with an inlet 40, preferably tangential as shown in the drawings, positioned in back of splines 32. The rear portion 42 of conduit 30 extends radially inwardly and is secured to center conduit 12.

Conduit 30 discharges forwardly through annular orifice 44 defined by an inwardly directed lip 46. As with the annular aperture 24, the dimensioning of annular orifice 44 is critical and should, in all cases, be between 0.0005 and 0.030 inch. The annular orifice 44 should not vary substantially about its 360 degrees of circularity so that an annular discharge of uniform configuration will be had. Moreover, it is desirable that the inwardly directed lip 46 of conduit 30 be provided at its innermost edge 48 with as narrow a land as possible, e.g. approximate a circular knife edge. Practical machining operations prevent a satisfactory edge 48 for most materials of less than 0.008 to 0.010 inch, but where possible, this land dimension should not be exceeded.

The longitudinal spacing between the innermost edge 28 of annular aperture 24 and the innermost edge 48 of annular orifice 44 is critical to achieve optimum operation of apparatus 10. I have found that with most, if not all materials, this distance between the land of 48 and the nearest edge of annular orifice 24 should be in the range of one-fifth to three times the diameter of lip 46 at the edge 48.

As will be more fully explained below, the outer surface of the lip 46 of conduit 30 should be conical or streamlined in the manner shown in the drawings.

A conduit 50 is concentrically dispised in respect to conduit 30 and center conduit 12. The disposition of conduit 50 in respect to conduit 30 is maintained by securing the rear portion 52 of conduit 50 to the outer surface of conduit 30. The conduit 50 is provided with an inlet 54, preferably a tangential inlet, as shown in the drawings.

The discharge orifice for conduit 50 comprises annular orifice 56 defined by an inwardly directed lip 58. The annular orifice 56 is spaced to the rear of annular orifice 44. The size of the opening of annular orifice 56 should be controlled, and the narrowest portion thereof should preferably be within the range 0.0005 inch to about 0.050 inch. As a general rule, for liquids of very low viscosity or low surface tension the smaller size for orifice 56 is to be preferred, whereas for very viscous liquids the larger size for orifice 56 is to be preferred. The annular orifice 56 should not vary substantially about its 360 degrees of circularity so that an annular discharge of uniform configuration will be had. It is desirable that the innermost edge 60 of lip 58 should be maintained as small as possible, but as with the innermost edge 48, it is difficult in practice to maintain an innermost edge having dimensions of less than 0.008 to 0.010 inch.

The outermost surface of the lip 58 should be curved, with a gentle gradual curve provided between the outer surface of the main portion of conduit 50 and the outer surface of the lip 58. The curvature of lip 46 should comprise a continuation of the curvature of lip 58 or a conical tangent thereto.

The curvature of the lips 46 and 58 in the manner set forth above provides for the facile passage of gas from the ambient atmosphere due to aspiration by the streams discharged from the annular orifice 44 and the annular aperture 24. I have found that the presence of a sharp corner intermediate the outer surface of conduit 50 and lip 58 or a discontinuous noncurved or irregular outer surface of the lip 46 or lip 58 interferes with the optimum performance of the apparatus 10.

The operation of the apparatus 10 of the present invention is as follows:

Propellant gas is introduced into center conduit 12 and from inlet 40 into conduit 30. It is essential for superior performance that at least one of the gas streams, namely the gas stream discharged from center conduit 12 or the gas stream discharged from conduit 30 be moving at a supersonic velocity when it leaves the conduit. In a preferred embodiment, both the gas stream discharged from annular aperture 24 of center conduit 12 and the gas stream discharged from annular orifice 44 of conduit 30 are discharged at supersonic velocities. In order to achieve supersonic velocities for the discharged gas stream in the apparatus 10, it is necessary that the gas from center conduit 12 and/or conduit 30 (depending upon whether one or both of the discharge streams from the conduits are moving at supersonic velocity) be pressurized at a pressure of 1.5 atmospheres or more within the conduit.

The material to be aerosolized is preferably introduced through inlet 54 into conduit 50 and discharged through annular orifice 56 of conduit 50. The material introduced through inlet 54 may comprise a liquid, or a slurry comprising finely divided solids dispersed within a liquid.

The gas discharged from annular aperture 24 is directed radially in the illustrated embodiment. By varying the discharge nature of annular aperture 24, the form of pattern of the gas discharge may be varied, as to a radial pattern, or a more angularly deflected pattern. The gas discharged from annular orifice 44 impinges upon the umbrella-like pattern from the annular aperture 24, which serves as a gaseous barrier. The material being aerosolized from conduit 50 passes over the outer surface of lip 46 within and about the gaseous sleeve issuing from orifice 44 and is aspirated with the gas from conduit 30 along the outer surface of center conduit 12 until impingement with the pattern from annular aperture 24 is had.

Aerosolization of the material from conduit 50 is achieved due to a number of means, such as the drawing of the liquid from the surface of lip 46 into and about the gaseous stream issuing from orifice 44, thereby maximizing the surface area of the liquid. Further, the impingement of the liquid now mixed with or embracing the gaseaus stream from orifice 44 upon the high-velocity gaseous umbrella issuing from aperture 24 disrupts the liquid volume which has had its surface area maximized by embracement and mixing with the gas stream issuing from orifice 44 into an exceedingly fine aerosol.

Of importance to the resulting aerosolization achieved by the apparatus 10 of the present invention is the aspiration of gas from the ambient atmosphere into and through the material from conduit 50. Gas is aspirated into the material undergoing aerosolization from both sides of the pattern from annular aperture 24. The streamlined shape of cap 22 and the rounded surfaces of lips 58 and 46 provide for ease of access of the aspirated gas to the material being aerosolized. This aspirated gas acts to carry the discharging aerosol away from its relatively diminutive zone of generation into a greater volume, so that the formed aerosol particles are spaced further apart, and accordingly, have less tendency to reagglomerate.

The subject apparatus and process permit a marked degree of control. Thus, the velocity of the gas in the conduits **12** and **30** may be independently altered. In this manner, the shape of the pattern resulting from the combination of the discharges from annular aperture **24** and annular orifice **44** may be altered. This permits the subject apparatus and process to achieve resultant aerosolized particles of desired characteristics. Moreover, the shape of the pattern may be altered to conform to the shape of the container within which the apparatus **10** is positioned. For a narrow container, a conical pattern is normally most advantageous; whereas for a relatively broad container a pattern approximating a circular disc is advantageous. This control is also efficacious when the nozzle is located within a moving gas stream. Convenient adjustment of the pressures in conduits **12** and **40** can, for example, cause the discharging aerosol to mix thoroughyy with a gas moving axially of the nozzle in a duct or pipe, even to the extent when the gas is moving at velocities approaching the speed of sound.

In some cases, where exceptionally turbulent action is desired between the gas streams and the material undergoing aerosolization, as for example, when chemical reaction between the gas streams and the material undergoing aerosolization is desired, the material to be aerosolized may be introduced into conduit **30** from inlet **40** and discharged from annular orifice **44** thereof, while aerosolizing gas is introduced from center conduit **12** to be discharged from annular aperture **24** thereof and further aerosolizing gas is introduced from inlet **54** into conduit **50** and discharged through annular orifice **56** thereof. This mode of operation effects an exceptionally turbulent action in the zone of aerosolization.

In the apparatus embodiment shown in Figure 4, the apparatus **10***a* generally resembles that of Figures 1, 2 and 3 except that the conduit **50** is eliminated, and the lip **46***a* has a rounded corner **47** to provide for facile aspiration of gas from the ambient atmosphere into the discharge from annular orifice **44***a*.

In the embodiment of Figure 4, the material undergoing aerosolization such as the liquid, or slurry of finely dispersed particles is introduced along with gas through the conduit **30***a*. The combined gas and material mixture is discharged from annular orifice **44***a* and impinges upon the pattern from annular aperture **24***a*.

The operation of the apparatus embodiment **10***a* is therefore generally similar to the operation of the apparatus embodiment shown in Figures 1, 2 and 3. In the apparatus embodiment of Figure 4, either the gas stream from annular aperture **24***a* or the mixture stream from annular orifice **44***a*, or preferably both such streams, should be moving at supersonic velocities at their time of discharge. Moreover, the dimensioning of the aperture **24***a* and the orifice **44***a* should conform to the dimensions heretofore set forth for annular aperture **24** and annular orifice **44**, namely that the narrowest portion of annular aperture **24***a* should have a size of from 0.0005 inch to 0.030 inch and the narrowest portion of annular orifice **44***a* should have a size of from 0.0005 inch to 0.030 inch (the passage in each of these openings is substantially uniform about the entire 360 degrees of cicularity). In addition, a minimal thickness of the land at the edge **48***a* of lip **46***a* is desirable, and the distance between annular orifice **44** and annular aperture **24** should be maintained for the annular orifice **44***a* and the annular aperture **24***a*.

The apparatus **10** shown in Figures 1, 2, and 3 is to be preferred over the apparatus **10***a* shown in Figure 4 because of the greater degree of control which may be effected due to the regulation of the independent gas stream in the gas conduits **12** and **30**. This permits greater regulation of size and shape of spray pattern, and control of aerosol particle sizes.

An illustration of the results which may be achieved with the apparatus of the present invention, a mixture comprising 46 parts by weight of glycerol, 2 parts by weight of Brilliant Benzo blue dye (marketed by General Dyestuff Corporation, 123 South Second Street, Philadelphia, Penna.), and 52 parts by weight of water was aerosolized using the apparatus of Figures 1, 2, and 3 with air being discharged from both the conduits **12** and **30** at supersonic velocities. The aerosolization was effected with the temperature and humidity controlled so that the resultant aerosol particles would neither shrink in size nor grow in size on formation, and would thereby permit exact size measurement.

It was found that one hundred percent of the aerosolized liquid material was aerosolized to particles having a size less than 8 microns, the particle size ranges being distributed entirely within the size range of somewhat below 1 micron to 8 microns, with 42 weight percent of the particles having a size of less than 4 microns. The mean resultant aerosol particle size diameter was 4.6 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.

I claim:

1. A process for aerosolizing a material into very finely divided aerosol particles which comprises associating a rapidly moving annular stream of the material to be aerosolized with a first rapidly moving coaxial thin annular gas stream, the annular stream of the material to be aerosolized being of larger inside diameter than said first annular gas stream at the moment of association, impinging said mixed gas and material streams against an angularly directed rapidly moving annular gas stream, said angularly directed gas stream being angularly directed in respect to both the initial direction of movement of said first annular gas stream and also the initial direction of movement of the annular stream of material to be aerosolized, whereby aerosolized particles are formed, and minimizing the reagglomeration of the aerosolized particles by spacing such aerosolized particles away from each other through engagement with gas.

2. A process in accordance with claim 1 in which the process is effected in a gaseous atmosphere and in which simultaneously with the deflection of the material to be aerosolized and the first annular gas stream upon the angularly directed gas stream substantial amounts of gas from the surrounding gaseous atmosphere are aspirated into the streams.

3. A process in accordance with claim 1 in which at least one of the streams is initially moving at supersonic velocity.

4. A process in accordance with claim 3 in which each of the streams in the process is initially moving at a supersonic velocity.

5. Apparatus for forming aerosolized particles comprising at least three concentric tubes, one end of the innermost tube projecting beyond the end of the next adjacent concentric tube, said one of said innermost tube having a smaller outer diameter along the entire portion of its length which projects beyond the end of the next adjacent concentric tube than the smallest inside diameter of the next adjacent concentric tube to said innermost tube, a cap juxtaposed to said one end of said innermost tube, said cap having a smaller outside diameter along its entire length than the smallest inside diameter of the next adjacent concentric tube to said innermost tube, cap supporting means extending through said innermost tube, said cap supporting means joining together the inner wall of said innermost tube and said cap, at least one channel in said cap supporting means, an annular aperture intermediate said one end of said innermost tube and said cap, said channel being in communication with the in-

terior of said innermost tube and said annular aperture, with said next adjacent concentric tube to the innermost tube having an annular discharge orifice surrounding the outer surface of said innermost tube, said annular discharge orifice being spaced from the side of said annular aperture opposite to said cap by a distance equal to between one-fifth to three times the diameter of said annular discharge orifice, said annular discharge orifice discharging along the outer surface of the innermost tube parallel to the longitudinal axis of the innermost tube, the concentric tube which is disposed about the next adjacent concentric tube having an annular discharge opening surrounding the outer surface of said next adjacent concentric tube and discharging along the outer surface of said next adjacent concentric tube parallel to the longitudinal axis of the innermost tube.

6. Apparatus in accordance with claim 5 in which the outermost surface of the next adjacent concentric tube to the innermost tube and the outermost surface of the concentric tube which is disposed about the next adjacent concentric tube are both rounded in the region of their respective annular discharge orifice and annular discharge opening with such rounded surfaces being a continuation of each other.

7. Apparatus in accordance with claim 6 in which the annular discharge orifice of the next adjacent concentric tube in the annular discharge opening of the concentric tube which is disposed about the next adjacent concentric tube are both provided with inwardly directed lips whose outermost surfaces form the curved surfaces defined in claim 5.

8. Apparatus in accordance with claim 5 having tube support means joining together the inner wall of the next adjacent concentric tube to the innermost tube and the outer wall of the innermost tube with at least one channel extending through said tube support means.

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