United States Patent

[11] 3,584,792

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[21] Appl. No. 817,370
[22] Filed Apr. 18, 1969
[45] Patented June 15, 1971
[73] Assignee Patent and Development of N.C., Inc.
Raleigh, N.C.
Continuation-in-part of application Ser. No. 787,974, Dec. 30, 1968.

[54] **DEVICE FOR LIQUID ATOMIZATION AND FLUID BLENDING**
11 Claims, 21 Drawing Figs.

[52] U.S. Cl. 239/424, 239/338, 239/433, 239/566, 239/568
[51] Int. Cl. B05b 7/06
[50] Field of Search 239/318, 358, 312, 337, 338, 418, 566, 421, 424, 433, 568; 261/29, 30, 78, 120, 116

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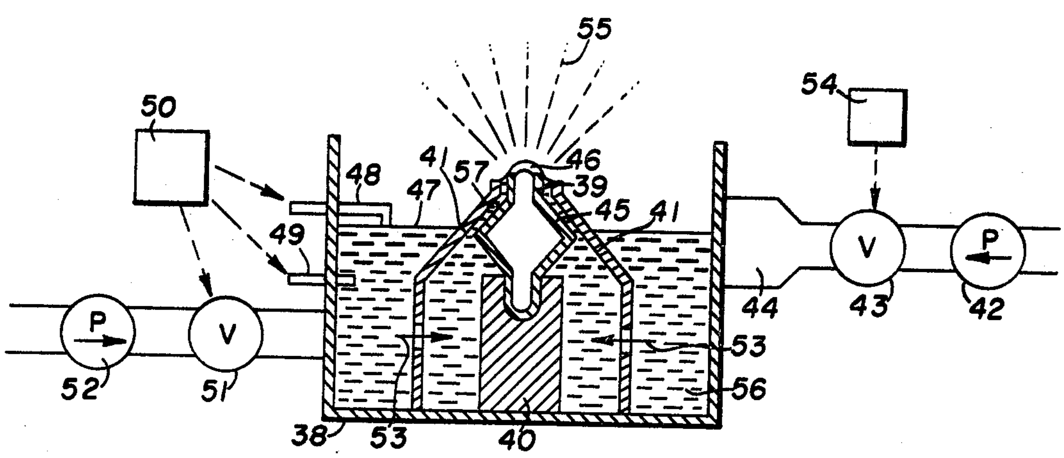
Primary Examiner—Lloyd L. King
Assistant Examiner—John J. Love
Attorney—Munson H. Lane

ABSTRACT: This disclosure relates to a method and a device for efficiently atomizing liquids into extremely fine cloudlike particles by discharging fluid thru one or more apertures located, preferably between 1 mm. and 100 mm., above a controllable free surface of the liquid to be atomized. The area adjacent to the fluid-discharging aperture is linked to the liquid by at least two distinct wettable surface means. In operation the liquid, at least partially due to pressure differential, adhesion, cohesion, surface tension and capillarity, rises to and surrounds completely the apertures. These factors and means, along with a means of achieving a wide flat-fan fluid dispersion and a means of varying the number of apertures, produce a uniformly fine, highly stressed film on all sides of the apertures and results in excellent metering control, uniform atomization, efficient dispersion and atomization, and clogfree operation. Secondary blending of the emitting fluid with atomized liquid in the vicinity of the aperture by the removal of one or more of the said liquid wettable surface means, permitting certain apertures to emit only fluid while the remainder are emitting atomized liquid, provides added efficiency and control.



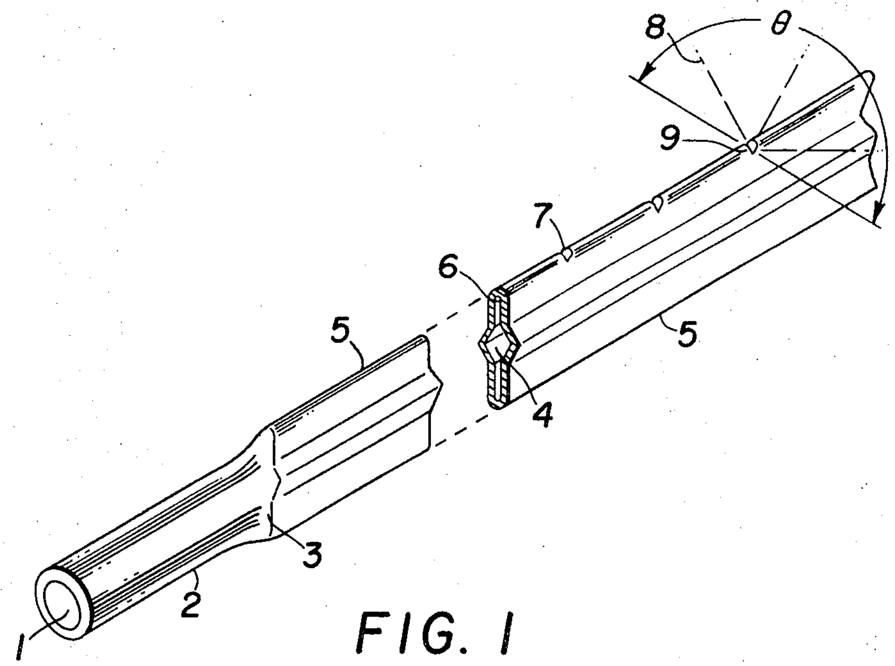


FIG. 1

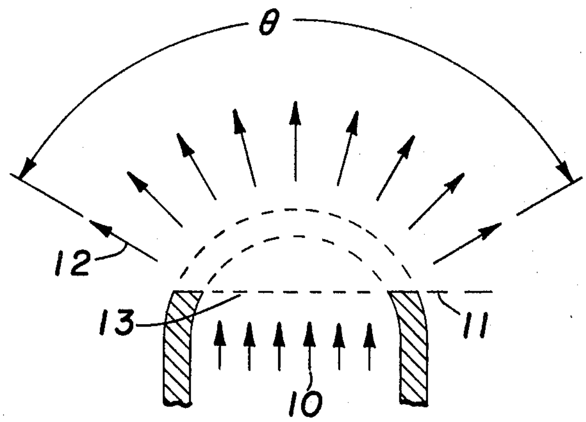


FIG. 2

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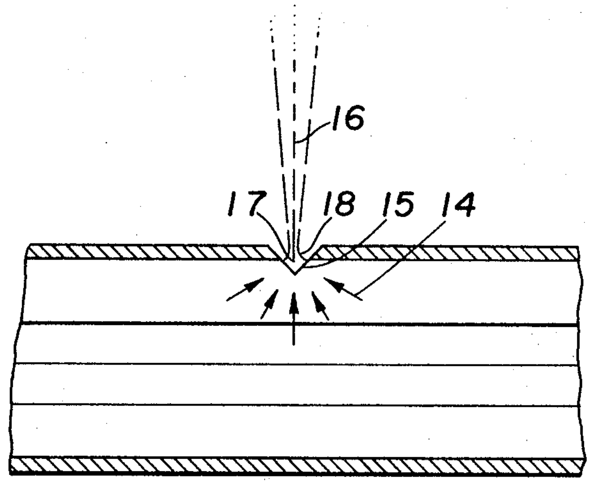

FIG. 3

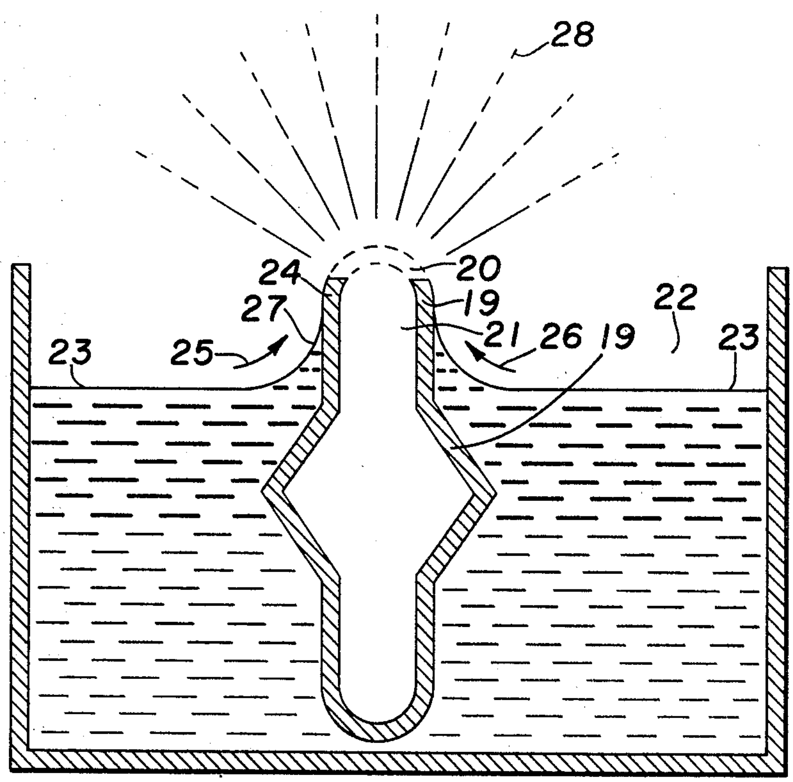

FIG. 4

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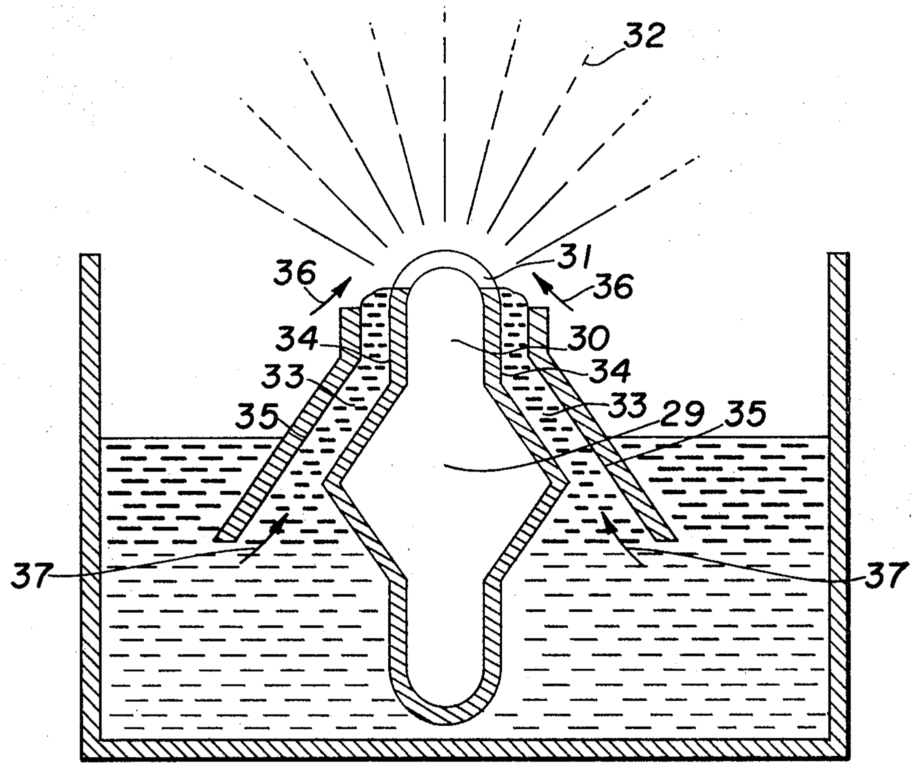

FIG. 5

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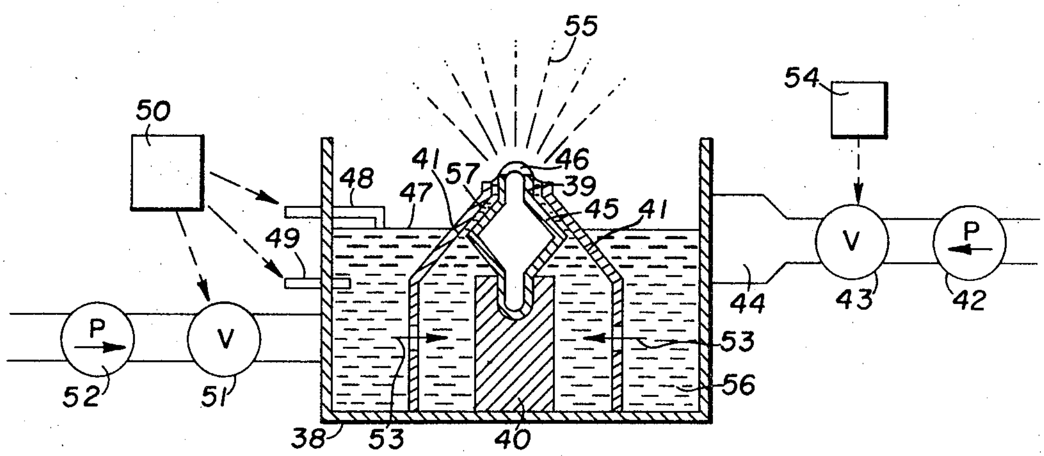

FIG. 6

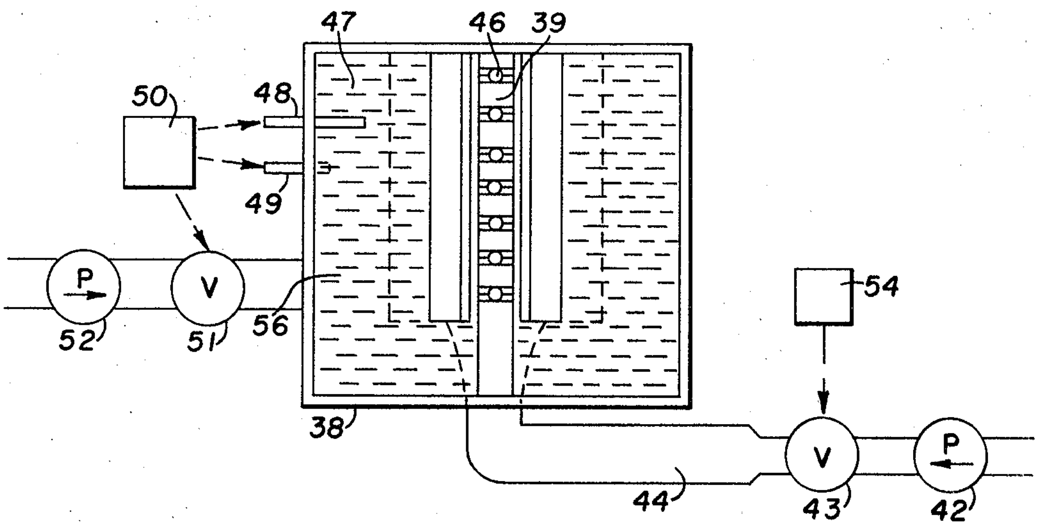

FIG. 7

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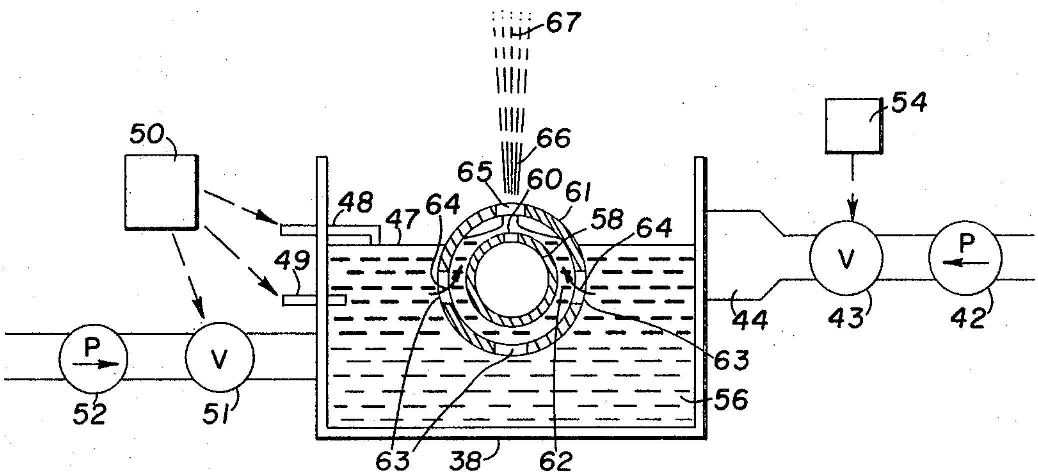

FIG. 8

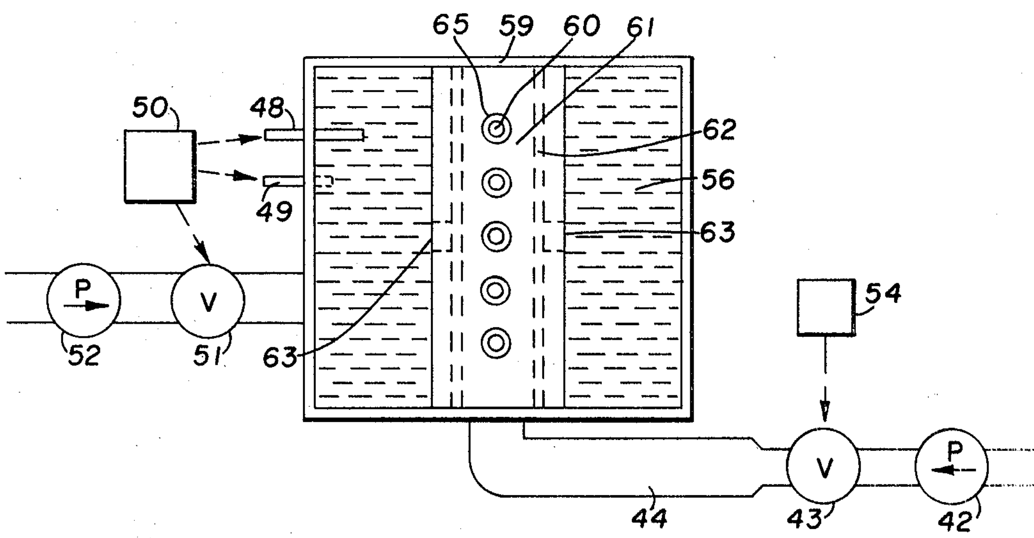

FIG. 9

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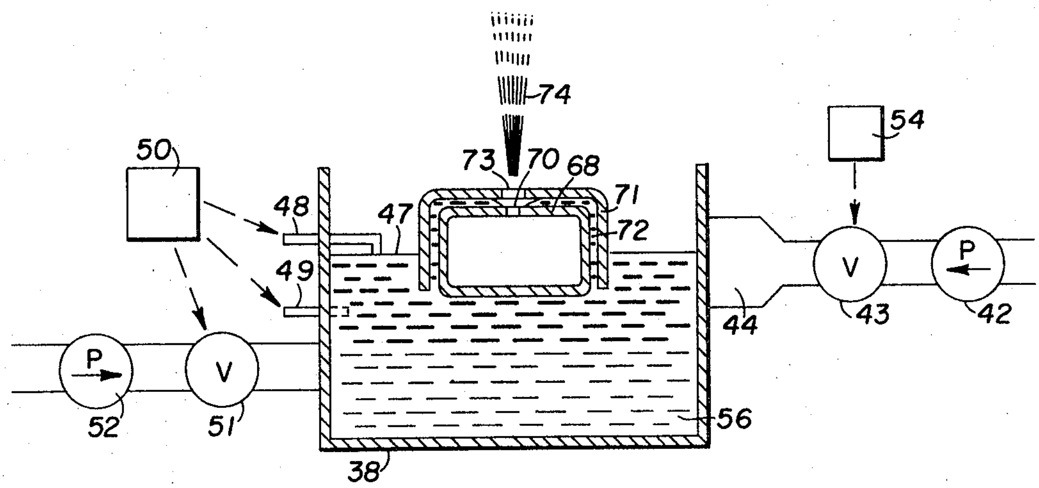

FIG. 10

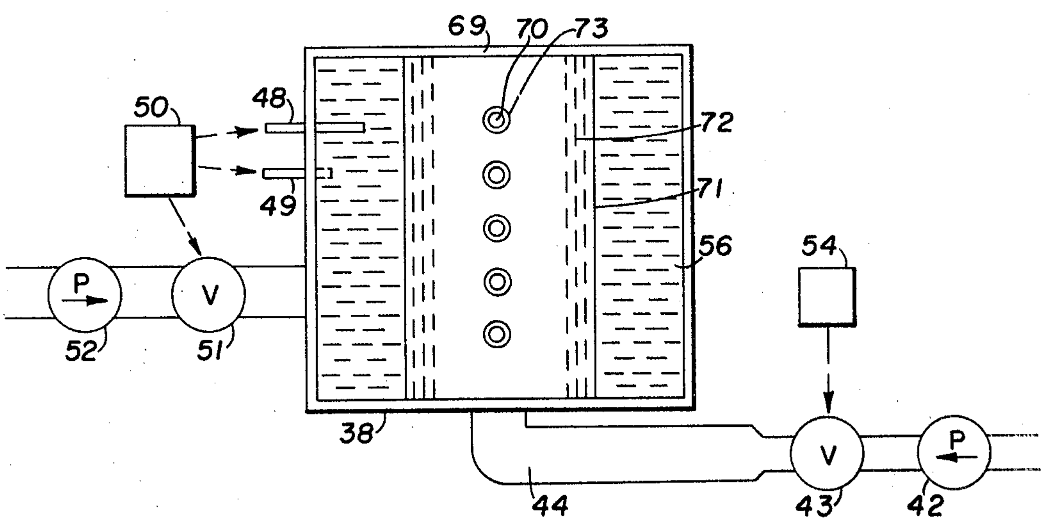

FIG. 11

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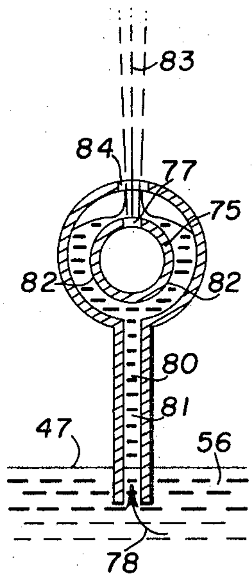

FIG. 12

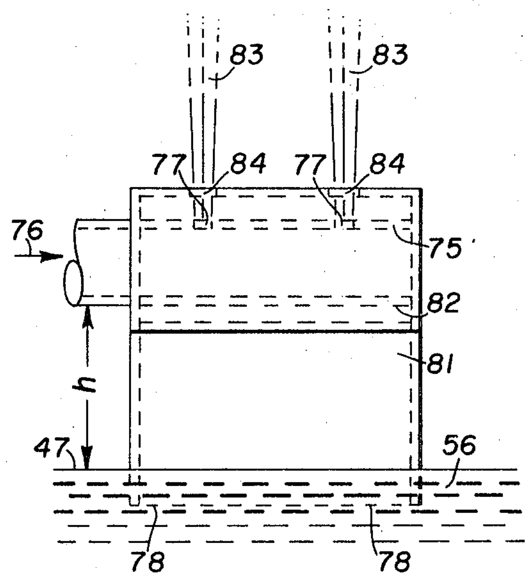

FIG. 13

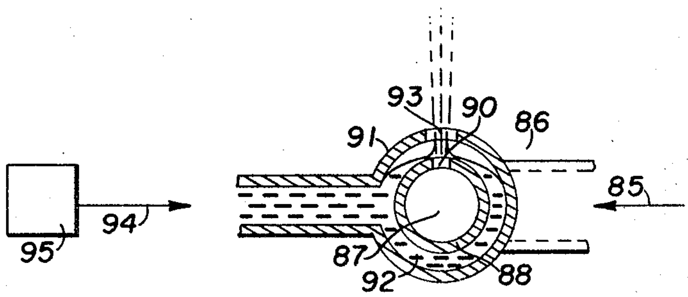

FIG. 14

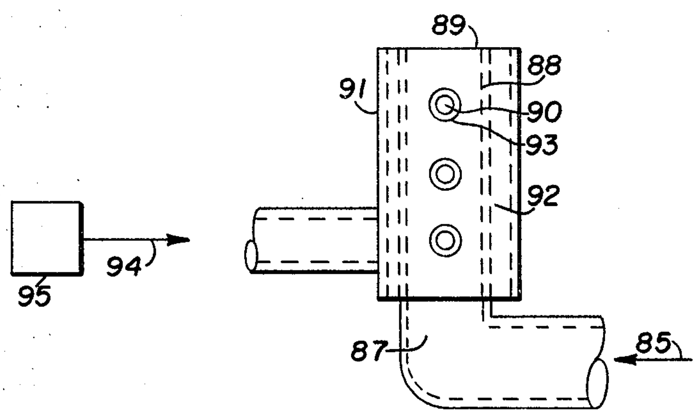

FIG. 15

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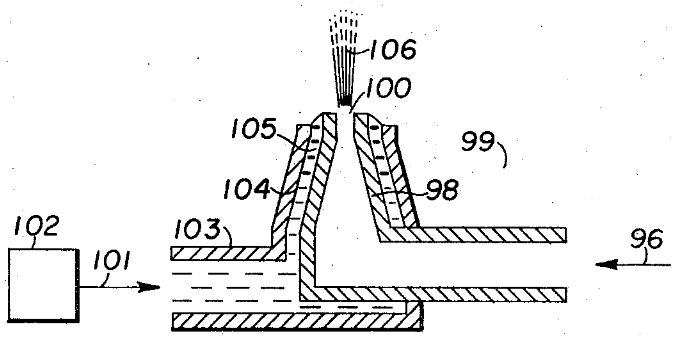

FIG. 16

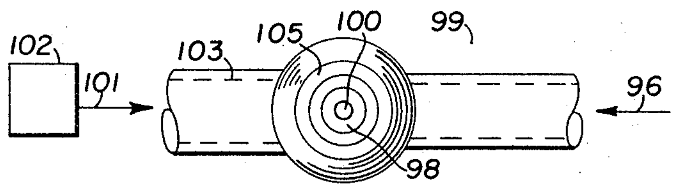

FIG. 17

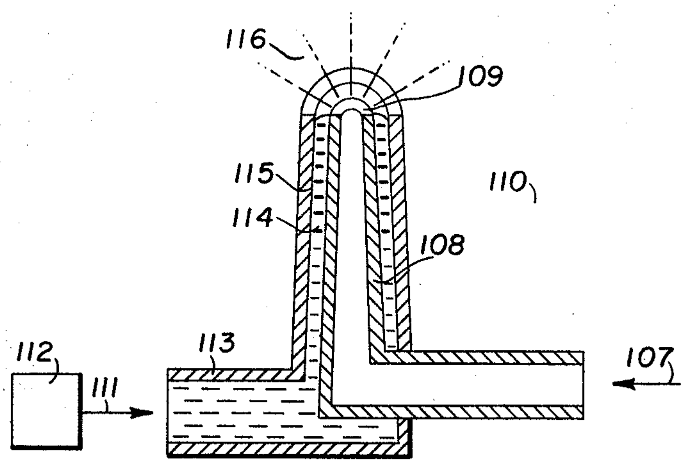

FIG. 18

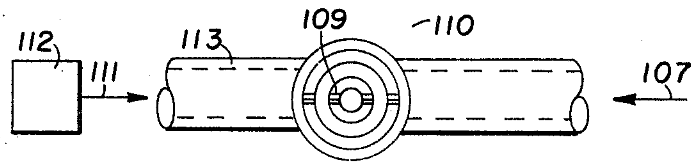

FIG. 19

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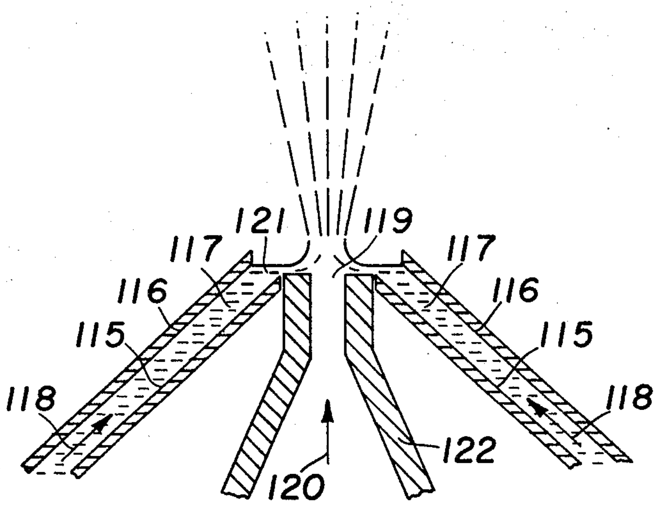

FIG. 20.

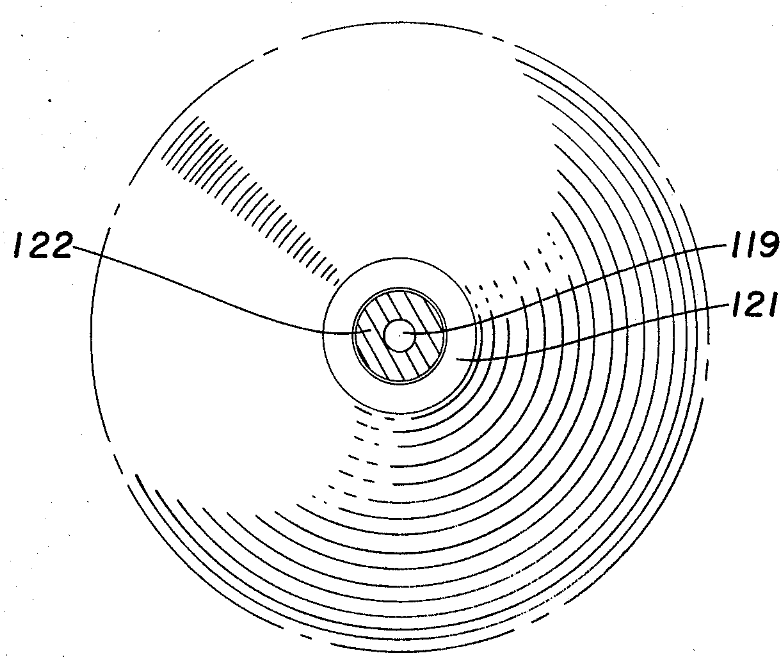

FIG. 21

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DEVICE FOR LIQUID ATOMIZATION AND FLUID BLENDING

The present application is a continuation-in-part of my copending application Ser. No. 787,974, filed Dec. 30, 1968.

The present invention relates to an improved apparatus for atomizing liquids into an emitting fluid medium, particularly gaseous but not restricted thereto. More particularly, the invention relates to a device for achieving unusually uniform and fine atomization of a liquid in a highly efficient and simple fashion. Furthermore, the invention achieves these two features, uniform and fine atomization, over a wide range of volumetric capacity. Utilizing the momentum of a fluid external to an aperture to effect liquid feed and atomization, additional advantages of control simplicity and dependable nonclogging operation become apparent. In addition, secondary blending is easily accomplished by preventing the feeding of liquid to one or more of a series of fluid-dispersing apertures.

In carrying out this invention, particular reference is made but not restricted to a fluid dispersion nozzle disclosed and claimed in the copending application of William H. Johnson, on "Fluid dispersion nozzle and method of making the same," Ser. No. 787,974 filed Dec. 30, 1968. This nozzle as disclosed pertains to a unique design for achieving wide angle, flat-fan dispersion of both liquids and gases uniformly and over a wide range of capacity and pressure. In operation, a single fluid such as a liquid or a gas is dispersed more completely than was heretofore possible because of combined advantages in minimizing the orifice (aperture) area while maximizing the dispersion angle. By utilizing this nozzle in combination with auxiliary apparatus, the present invention makes possible superior liquid atomization by forcing a fluid through the aforesaid nozzle which in turn provides controlled liquid dispersion and atomization.

The invention lends itself admirably to many applications where it is desired to efficiently disperse and atomize a liquid into a fluid medium, particularly gaseous. The usual applications of air humidification, insecticide fogging, fuel atomization, spray drying, etc. and numerous industrial operations could advantageously employ the present invention. For example, home humidification systems and greenhouses need fine atomization and dispersion with little or no liquid fall out. Combustion processes also need effective atomization and dispersion. In all cases uniformity and efficiency of atomization are important considerations. Efficiency is defined as the pounds of liquid atomized per pound of gaseous fluid.

In order that a liquid remain dispersed in a gaseous medium for a long time or until evaporation occurs, the drop size should be small. For example water drops of 20 micron diameter fall at a speed of 1 cm./sec. whereas drops of 200 micron diameter fall at 76 cm./sec. These and other points on drop size in relation to fall speed and evaporation rate are discussed by Louis J. Battan in "Cloud Physics and Cloud Seeding," published by Doubleday and Company, Inc. Garden City, New York, 1962. Battan discusses rather thoroughly investigations in measuring particle size distribution in clouds and fogs and states that particles range from a few microns to about 50 microns in diameter. The invention herein disclosed accomplishes excellent liquid atomization with particle size of about 50 microns diameter or less, that is with a particle size distribution approximately that of a cloud or fog.

Several liquid atomizing devices are commercially available. Although they may achieve satisfactory atomization, they generally have certain disadvantages or limitations either in construction complexity, operation or application. High-speed rotary atomizers for example give capability of high capacity output with dependable, nonclogging operation; however they are expensive, have limited applicability and do not permit easy control of the dispersion volume. On the other hand two-fluid atomizers such as water-air devices are complex in construction, have fine openings for liquid metering, are expensive per unit of liquid atomized, are of low capacity, and are not applicable to all liquids because of clogging problems.

The problem of clogging of the liquid channels cannot be overemphasized. In many applications it is not possible, nor feasible, to have a perfect liquid solution with no contaminants or fine solid particles in suspension. For example, in spray drying it may be desirable to form a fine slurry which is atomized and dispersed in a drying environment. This problem is generally handled by utilizing rotary atomizers wherein the liquid slurry does not pass through a small orifice. The present invention has the advantage over present two-fluid atomizers by providing designs such that the liquid or slurry is not necessarily required to pass through a fine orifice, hence it is virtually nonclogging in operation. This advantage is realized in any application where small solid particles in the liquid may pose a problem.

A further problem common to two-fluid atomizers is that of proper metering of the liquid to achieve the desired degree and uniformity of atomization and with high efficiency. With a given gaseous flow, the liquid flow must be controlled rather critically to maintain a given degree of atomization. An increased liquid flow relative to a given gaseous flow causes larger particles. These problems are overcome in the present invention since liquid metering and atomization are both easily controlled. Also secondary blending can be provided in a simple manner.

While the invention has its greatest usefulness in atomizing liquid into a gaseous fluid medium emitting from an aperture, it is not restricted thereto. Other emitting fluids such as water or kerosene can be used, in which case the liquid to be atomized is simply blended into the discharging liquid and results in the same advantages such as uniformity and control. Hereafter gas as the emitting fluid will be used mainly to describe and illustrate this invention.

In view of the above considerations, it is an object of this invention to provide an improved apparatus for wide dispersion and fine uniform atomization of a liquid into a gaseous medium.

Another object of the invention is to provide liquid dispersion and atomization wherein the liquid is uniformly and efficiently entrained into a moving fluid. This is highly important in applications where liquid flow should be responsive to an intermittent fluid flow.

An additional object of the invention is to provide an improved apparatus for liquid atomization wherein the liquid feed rate is controlled by the difference in pressure of the free liquid surface and the liquid at the orifice. Uniform and efficient atomization over a wide range of operating conditions is further provided by the control of the emitting fluid.

Another object of the invention is to provide an improved means for achieving uniform, easily controlled secondary blending of a fluid into the atomized liquid.

A further object of the invention is to provide an improved apparatus for liquid atomization which virtually eliminate the problem of clogging common to nonrotational atomizers. The feature of nonclogging opens up many new areas of application for a nonrotational device.

These and other objects and advantages of the invention will become apparent in the following discussion of the method and apparatus and in reference to the attached illustrations.

In the drawings:

FIG. 1 is a diagrammatic view partially in longitudinal section of a multiple orifice nozzle means as disclosed and claimed in my copending application, Ser. No. 787,974.

FIG. 2 is a diagrammatic sectional view of a suitably curved nozzle end portion having a slot therein and illustrates how to maximize the dispersion angle, that is to achieve up to at least 180°.

FIG. 3 is a vertical cross-sectional view of the nozzle of FIG. 1 and illustrates convergence of fluid within the nozzle.

FIG. 4 is a cross-sectional view of the nozzle of FIG. 1 and illustrates how liquid is lifted from a lower level to be entrained in the gaseous medium.

FIG. 5 is a sectional view, partly diagrammatic, of the nozzle of FIG. 1 with the addition of liquid-feeding surfaces.

FIG. 6 is a vertical sectional view, partly diagrammatic, showing an apparatus which utilizes the nozzle means of FIG. 1 for suitably controlling liquid atomization such as in humidification.

FIG. 7 is a top view of the apparatus of FIG. 6, also partly diagrammatic.

FIG. 8 is a vertical sectional view, partly diagrammatic, illustrating a nozzle means, tubelike in structure and generally horizontally disposed, with apertures cut in the topmost portion thereof, and illustrating further a surrounding liquid-feeding surface having openings in the bottom and top.

FIG. 9 is a top view of the apparatus of FIG. 8, also partly diagrammatic.

FIG. 10 is a vertical sectional view, partly diagrammatic, illustrating another tubelike nozzle means whose top surface, or a portion thereof surrounding the apertures, is flat. As in FIG. 8 the liquid feeding surface generally conforms to the outer surface of the container and has openings at the top and bottom.

FIG. 11 is a top view of the apparatus of FIG. 10, also partly diagrammatic.

FIG. 12 is a vertical sectional view, partly diagrammatic, illustrating an atomization device in which the liquid is lifted from a free surface that is below the bottom of the nozzle means.

FIG. 13 is a longitudinal section of FIG. 12, also partly diagrammatic.

FIG. 14 is a vertical sectional view, partly diagrammatic, illustrating how the liquid can be remotely located, as in the case of combustible liquids, yet maintain its surface below the apertures, without affecting satisfactory performance.

FIG. 15 is a top view of the device of FIG. 14, also partly diagrammatic.

FIG. 16 is a vertical sectional view, partly diagrammatic, illustrating a design having a single circular orifice in the top of a tapered tubelike structure, positioned vertically and having the exterior surface of the nozzle means and the liquid-feeding surface converging like a cone, not necessarily circular in section.

FIG. 17 is a top view of the device of FIG. 16, also partly diagrammatic.

FIG. 18 is a vertical sectional view, partly diagrammatic, illustrating a nozzle means which is a vertical tubelike structure, dome shaped at the top with one aperture cut therein to give a flat-fan dispersion to the emitting gas.

FIG. 19 is a top view of the device of FIG. 18, also partly diagrammatic.

FIG. 20 is a vertical sectional view, partly diagrammatic, illustrating liquid-feeding surfaces physically independent of the nozzle means and therefore not dependent upon the external surface of the nozzle means for the lifting of the liquid.

FIG. 21 is a top view of the device of FIG. 20, also partly diagrammatic,

More efficient and uniform atomization, and wider dispersion, of liquid into a gaseous medium are accomplished by: (1) discharging upwardly and dispersing outwardly, a gas thru one or more discharge orifices or apertures located within the 180° top portion of a nozzle means, (2) locating said point of discharge above a liquid to be atomized (3) lifting said liquid by forces of adhesion, cohesion, surface tension, and differential pressure acting singly or in any combination thereof; the said liquid moving upwardly on more than one side of the nozzle means and converging from more than one direction to the region of the gaseous discharge from the aperture, (4) entraining the liquid into the said discharging gas along the greater portion of the aperture periphery, forming a stressed liquid film within the unconfined fluid; further stressing of the liquid film by dispersing and expanding the gas thru a narrow aperture whose inner edge is minutely curved and has a large included angle, (5) disrupting the liquid film surrounding the aperture periphery by shear forces resulting from differential velocities within the gas stream and between the gas and the liquid to form extremely fine cloudlike particles.

Numerous tests and observations have been conducted to study the atomization phenomenon and the significance of various forces involved in causing liquid movement from a liquid surface to the exit aperture. Several liquids and types of surface have been utilized which indicate broad applicability of the method. In most of the discussion, reference will be made, for illustrative purposes only, to water as the liquid to be atomized and air as the fluid-dispersing medium.

Reference to FIGS. 1 to 5 will permit a more complete understanding of the method and will set the stage for the subsequent discussions on specific apparatus for carrying out the method.

The nozzle shown in FIG. 1, and for which my copending application, Ser. No. 787,974 supra, has been filed, has particular advantages in permitting the formation of an arbitrarily small orifice inner cavity while maximizing up to at least 180° the angle of fluid dispersion. This illustration is shown and discussed to emphasize the nature of fluid dispersion from an orifice and to point out the unique advantages of this design in accomplishing the present invention. A fluid, either liquid or gas, enters the nozzle 1 and travels through the tube section 2 into the main nozzle section beginning at 3. The nozzle section was originally a straight length of circular tubing and has been brought to the desired shape by pressure operations to form a central elongated feed cavity or conduit 4 and at least one elongated corona discharge portion or wing 5. As shown the central feed cavity 4 is relatively large in cross section as compared with the smaller cross section of the discharge wing portion 5 fluidly communicating therewith. Two such wings are shown in FIG. 1. Each wing contains within its surface a corona orifice cavity 6, fluidly connected to said feed cavity 4. The wing and its cavity was referred to in the copending application, Ser. No. 787,974 supra, as corona in that they are crownlike and protrude outwardly. In this application the main feed cavity, corona orifice cavity and aperture cut therein are referred to as a nozzle means or a fluid-dispensing container. Fluid moves unrestrictedly along the main feed cavity 4 until finally terminating at a closed end. From the main feed cavity, the fluid moves within the corona discharge wing 5 to its corona orifice 7 formed by intersection of a surface slit with the corona orifice cavity 6. The shape of the corona orifice cavity at its outer extremity, as revealed by a cutting plane at right angles to the longitudinal axis of the structure at my point, preferably an arc of a circle of about 150° to 190° or approximately a semicircle. Convergence of fluid flow at the orifices establishes a fan dispersion pattern 8 as shown generally at orifice 9. The angle of dispersion θ is determined by the degree of intersection of the curves portion of the inner cavity 6 by the surface slit. In the case of the present invention, air is forced through the nozzle where wide-angle fan dispersion occurs at each discharge orifice or aperture 7.

As shown for example in FIG. 1 a plurality of widely spaced slits 7 are provided, the slits being spaced apart a sufficient distance so that the orifice cavity is unslitted on either side of any orifice for a distance greater than the diameter of the orifice cavity, which as more fully set forth in my copending application Ser. No. 787,974 is an important feature from the standpoint of ensuring uniform flow of fluid.

FIG. 2 illustrates how uniform dispersion is achieved by intersection of the curved surface of the corona discharge wing with a slit. The entering fluid 10 is dispersed through the angle θ depending on the depth to which the surface slit 11 which forms the discharge orifice intersects the corona cavity. The emerging fluid 12 is discharged in a diverging fan pattern with exceptional uniformity. It is to be noted that the diameter 13 of the orifice at the line of intersection 11 can be made arbitrarily small down to 0.001 inch. This feature, in combination with wide angle dispersion, as more fully set forth in my copending application Ser. No. 787,974, has particular importance to the present invention in giving maximum dispersion per unit volume of discharged gaseous substance. This will become evident in subsequent discussions.

Consider now FIG. 3 which illustrates convergence of fluid within a nozzle, necessary for the formation of a fan discharge pattern. Fluid flow **14** converges to the surface slit **15** and produces a fan discharge pattern **16**, shown from the side, by nature of change in fluid momentum within the orifice. The fluid at **17** is rapidly changing direction near the center of the orifice and accelerating outwardly. This action produces by entrainment low-pressure regions **18** along either side of the fan pattern. It is in fact this low-pressure region, in combination with rapidly accelerating and diverging gaseous flow, which permits certain unique advantages to be achieved in the present invention. In tests in which air was forced through the orifice at 30 p.s.i., suction pressures of 45 cm. water column were observed at the low-pressure regions **18**, utilizing a hypodermic needle carefully positioned from the side. The suction pressure provides the capability for lifting a liquid from a lower liquid level in a feed system wherein the liquid is external to the orifice. FIGS. **1**, **2** and **3** are more fully described and claimed in my copending application Ser. No. 787,974 **and their application to the present invention will now be more fully described.**

FIG. **4** is a cross-sectional view of the nozzle of FIG. **1** located with partial immersion in a liquid. As discussed above, a gaseous substance such as air is forced through the nozzle means **19** and is dispersed in a fan pattern by fluid behavior at the orifice **20**. Air within the corona orifice cavity or discharge orifice portion **21** is under a higher pressure than the outside ambient pressure **22**. FIG. **4** illustrates the manner by which a liquid such as water may be lifted from a lower level **23** and caused to rise upward along the outer surface of the corona discharge wing **24** to the orifice **20** where entrainment and atomization by the air stream occur. The suction pressures along the side of the discharge orifice or aperture **20** induce air movement **25** and **26** over the liquid surface **23**, the air moving in the direction of the orifice from both sides of the exposed nozzle portion **19**. Low pressure and air movement along the sides of the exposed nozzle portion **19** provides a lifting effect which aids movement of liquid to the orifice.

A second factor which aids importantly in lifting the liquid to the aperture is related to adhesive and cohesive properties of a liquid. Surface phenomena and cohesive properties of liquids are discussed rather completely by G. Shortley and D. Williams in "Elements of Physics," published by Prentice-Hall, Inc., New York, 1955. Cohesive forces occur within liquids due to molecular attraction between like molecules. A free liquid surface as **23** in FIG. **4** tends to behave like a membrane stretched with constant tension per unit width because of cohesive forces. The surface tension varies for different liquids with mercury having a value of 0.465 joules/M^2 while water has a value of 0.072, both at 20° C. Surface tension becomes important for liquids which tend to "wet" a surface in accounting for the phenomenon of capillarity, or the tendency of a liquid to rise in a small tube or between closely spaced plate or surfaces. A liquid tends to wet or adhere to a surface when the liquid molecules at the interface are attracted more strongly by the solid than they are attracted back to the liquid. Liquid attraction forces with respect to the solid surface are called adhesive or surface action forces. The tendency of a liquid to wet a surface is often measured by the angle of contact with a vertical surface. When the contact angle is between 90° and 180°, the liquid does not wet the surface and the liquid tends to drop at the interface with a vertical surface. On the other hand when the contact angle is between 0° and 90°, the liquid wets the surface and the liquid tends to rise at the interface with a vertical surface. If the solid surface is inclined, of course, the tendency to rise also exists. As shown in FIG. **4** the liquid, for example water, wets the nozzle surface and tends to rise or climb up the outer upper exposed surface of the nozzle means **19**. The liquid surface **27** is shown curved upward as liquid approaches the liquid-solid interface. In the initial stages of operation the liquid is lifted by both adhesion forces and suction forces. When the liquid reaches the sides of the aperture **20**, it is almost instantaneously filmed along the sides of the discharging, fan-shaped gaseous fluid (air in this example) and is dispersed and atomized by entrainment into the high velocity air stream. It is important to note that divergence of gaseous fluid flow in the immediate vicinity of the orifice exit gives additional stressing and disruption of any liquid film carried upward by the gaseous fluid. The atomization so achieved **28** is exceptionally uniform in terms of particle size and distribution. Once the liquid is entrained by the air stream, continuous and uniform lifting is achieved by forces of suction at the aperture, cohesion forces within the liquid flowing up the sides of the nozzle, surface tension along the free surface of the liquid, and by surface action forces (adhesion) at the interface between the liquid and the solid surface of the nozzle.

The mode of action described above has been observed to provide satisfactory results for the liquids which wet the nozzle surface such that the orifice can be located about 1 mm. or more above the normal free surface level of the liquid. However, in the event the liquid material and the nozzle surface are such that a minute elevation difference is required to obtain feeding, say less than about 1 mm., the observations indicate that instability and irregular feeding may result due to turbulence in the liquid surface **23** or slight variations in the liquid level. To circumvent these problems, additional wettable surface means are employed. FIG. **5** illustrates the use of surfaces external to the nozzle means to direct the liquid upwardly. These are called surfaces because they are the outside part of a plate that has length, breadth, and thickness. And they feed liquid upwardly to the aperture. They are also wettable, as previously discussed. The term wettable surface means, also applies to the external surface of the nozzle means which also helps direct the liquid upwardly. The mode of operation is virtually the same as described for FIG. **4**, except that capillary forces are introduced and the liquid-feeding surfaces allow propagation of the suction pressure over a further distance to the lower liquid level. Considering air as the emitting fluid and water as the liquid, air is forced into the main feed cavity **29** from which it moves into the corona cavity **30** and is discharged through the orifice or aperture **31**, forming a fan pattern **32**. This latter cavity **30** with apertures **31** in the top most portion has heretofore been called a nozzle means. A more descriptive term is "fluid-dispensing container" in that it contains the gas and dispenses it thru an aperture. The emitting gas creates low pressure regions at either side of the fan as previously described. This suction pressure causes the water **37** to rise in the gaps **33** formed between the outer surfaces **34** of the fluid-dispensing container **30**, **31** and the wettable liquid-feeding surfaces **35**. With close spacing, capillarity with respect to these wettable surface means also causes the water to rise within the gaps **33**. Air **36** induced to flow laterally to the orifice **31** also aids in lifting the water by nature of frictional effects. From the top of the liquid directing plates **35** to the orifice, the water is additionally lifted by adhesion forces as the surface becomes "wet." When the water reaches the edge of the orifice, dispersion and atomization occurs as discussed previously.

The advantages of utilizing the wettable feeding surfaces **35** are (1) liquid may be lifted from one to several centimeters, (2) capillary forces can be utilized in certain applications to aid lifting of the liquid and to "hold" the liquid near the orifice for intermittent air operation, (3) operation of the device is not sensitive to the free surface level of the liquid and (4) apertures can be located within 90° of each side of the vertical axis thru the nozzle means or fluid dispensing container **30**, **31**.

The capillary action under certain applications is quite effective in aiding the initial lifting, even with a rather large gap. For example with water rising between two parallel glass plates, the following capillary rise is obtainable:

Gap spacing (mm.)	Rise (cm.)
.2	8. 2
.4	4. 1
.6	2. 8
.8	2. 0
1.0	1. 6
1.5	1. 1
2.0	. 8

The height of capillary rise between two vertical plates is directly proportional to surface tension and inversely proportional to the gap spacing, other factors being held constant. It is considered that the rise of sap in trees to great heights is largely attributable to capillary action. For liquid atomization, however, it is important to make the gap as large as practicable, especially where suspended particles are involved.

Once operation and atomization have started, continuous and uniform liquid feeding to the orifice occurs as previously described, with the exception that liquid moves into the gaps **33** from a subsurface location. Trash and fine particles floating on the surface are therefore no problem.

One additional, and unique advantage of the utilization of wettable feeding surfaces, such as **35** in FIG. **5**, is secondary blending. In a nozzle means having a series of apertures in line, the wettable feeding surfaces may be removed from one or more of the apertures, say alternate ones. Since the apertures **31** are located some distance above the free surface of the liquid, those with the surfaces removed will emit only gas. And this gas will blend with the gas and atomized liquid emitting from the remainder of the apertures. The method and device as described above therefore offers an effective additional control of the liquid to gas ratio.

The above discussion describes the method rather completely; however, general discussion related to specific operation and performance will illustrate the effectiveness and utility of the method. In numerous observations, the method has demonstrated excellent atomization over a wide range of operating conditions. The degree and uniformity of atomization are fairly easily observed visually by directing a bright light into the region of atomized particles with a dark background to offer contrast. Using air and water, excellent dispersion and atomization are achieved at air pressures as low as 0.5 p.s.i. At increasing air pressure and airflow through the orifice, the quantity of rate of liquid atomization does not appear to be appreciably changed. However, the fineness of atomization is noticeably increased with higher air discharge rate. Although elaborate, particle size distribution measurements have not been made, the effect can be visually observed by the increased volume of fog and smokelike particles at the higher discharge pressure and by measured efficiency. Apparently, the increased kinetic energy of the discharged air is utilized in producing finer atomization. Since surface energy of a given quantity of liquid is proportional to surface area, it is logical that a given quantity of more finely atomized particles, say 20 microns diameter, has considerably more surface energy than the same quantity of 50 microns diameter. Calculations show that the energy involved in atomizing 1 lb. of water to 50 micron diameter particles if 4.12 watts-sec; whereas for 20 micron diameter particles, the energy is 10.3 watts-sec. This information supports the experimental observations. The following data gives the effect of airflow rate on liquid atomization:

Orifice size	Air pressure (p.s.i.)	Air flow (s.c.f.m.)	Air flow (lb./min.)	Atomization flow (lb./min.)	Lb. air/lb. water
.014 in. average diameter	2	.1815	.0135	.082	.165
Do	10	.3808	.2084	.086	.330
Do	15	.4490	.0335	.087	.385
Do	23	.5700	.0425	.090	.472
Do	30	.6719	.0516	.087	.593

It is to be noted that increases in airflow do not appreciably affect the liquid atomization rate; however the fineness of atomization is noticeably affected.

This method of liquid atomization, involving the use of one or more forces to lift a liquid from a lower level and to feed the liquid externally to an air stream passing through an orifice, offers atomization improvements and control advantages. Consider the case where a continuous flow of liquid is directed over a surface and an aperture located in the surface, and then forcing a gas through the aperture to effect atomization, as for example in the U. S. Pat. No. 3,421,692 by Babington, et al. Since the liquid is directed toward the aperture nonsymmetrically and from the upper side only, the rate of liquid entrainment varies around the periphery of the aperture. Furthermore, metering control is necessary on both liquid and air supplies. In contrast, the method of this invention in which the liquid is lifted from a lower level symmetrically from both sides of an aperture, gives superior results in regards to atomization uniformity. In addition, off-on control is simplified. With air off, the liquid is quiescent; and with air on, the liquid is almost instantaneously atomized. By varying the airflow rate, the degree of atomization is simply accomplished. The upper limit to airflow rate depends upon the maximum pressure which the air-dispensing container can withstand. In practical situations, however, fine atomization is accomplished at low pressures of 1 p.s.i. and above; 30—40 p.s.i. may represent practical upper limits of operation for most applications.

It should be pointed out that efficiency of atomization, in terms of pounds of liquid per pound of gas, is a variable depending upon the degree of atomization. This is clear from the previous discussion; in which the atomization rate remained fairly constant while the airflow rate increased considerably. This method of atomization is considered comparable, if not superior, to my previous method in atomization efficiency. Since orifice size and dispersion angle can be controlled in the nozzle of FIG. **1** to optimize dispersion, efficiency of atomization will likewise be optimal.

In addition to atomization improvements and control, the invention offers control over the liquid feed rate. In the foregoing discussion specific mention was made of the gaseous pressure above the liquid surface being the same as the ambient pressure surrounding the nozzle apertures. But, in practice the gaseous pressure above the liquid surface is preferably controlled with respect to the ambient pressure surrounding the nozzle apertures. By controlling the amount of this differential pressure the amount of liquid fed into the airstream is controlled accordingly.

Proceeding now to specific illustrations of apparatus which embody the method of liquid atomization. In FIG. **6** and FIG. **7**, air is illustrated as the dispersing medium and the nozzle means of fluid-dispensing container **45** with connecting fluid supply lines are referred to as constructed of stainless steel; however, it is to be understood that a variety of materials and different liquids and gases could be used. A containing vessel **38** holds the liquid **56** which is to be atomized. The vessel **38** also contains the means for liquid atomization, fluid supply lines, etc. The size of this containing vessel may be quite variable, as small as a match box, or several inches in each dimension, depending on application. In this illustration, consider the vessel to be say 2 inches deep, 3 inches wide and 3 inches long. This is of ample size for providing humidification for a home or small industrial plant. The liquid (water) **56** is supplied by a pump **52** or suitable water supply means having sufficient head pressure to cause water to move into the vessel **38** when the valve **51** is open. As shown, liquid level probes **48** and **49** sense the liquid level **47** and serve to maintain the water level constant. Whenever the water level falls and breaks contact with probe **48**, the liquid control unit **50** energizes the solenoid valve **51** to admit water to the vessel. When the liquid touches probe **48**, the solenoid valve **51** is deenergized and closes, stopping waterflow. Liquid level may be maintained by other suitable means, such as the common float valve which is used in automobile carburetors. Located within vessel **38** is a fluid-dispensing container **45** which may be similar to the nozzle means of FIGS. **1** to **5**, having a corona discharge wing **39** in its top portion with an aperture **46** cut therein to provide a discharge orifice. It is shown supported from beneath by the block **40** which locates the nozzle means **45** partially immersed within the liquid **56** with the discharge orifices **46** located above the liquid level **47**. The height of the orifices above the liquid level **47** may vary up to several inches. Also located within the vessel are two wettable feeding surfaces **41** for aiding in lifting the liquid prior to and during operation as previously discussed. These are shown attached to the lower portion of vessel **38** and symmetrically and evenly spaced with respect to the corona discharge wing **39**. The gap **57** may be adjusted to provide proper capillary effect for the liquid to be atomized; for this illustration 0.050 inch provides ample clearance and effective operation. A gas, air in this case, is supplied by the pump **42** or other suitable air supply means to provide air under pressure greater than the ambient pressure to the nozzle means fluid-dispensing container **45**. The valve **43** can be an electrical solenoid valve, for example normally closed, which is actuated by a humidistat **54** as required to maintain the desired humidity. When the humidity falls below the set point, the valve **43** opens to admit air through the supply line **44** to the fluid-dispensing container **45**. The action and mode of operation at the discharge orifice or aperture **46** to effect atomization of the water is exactly as previously discussed for FIG. **5**. The water is lifted from the lower level, moving through the openings **53** in the liquid-feeding surfaces **41** and passing up through the clearance gap **57** to the apertures where dispersion and atomization occur in the fan patterns **55**. It is to be emphasized that better results are achieved by utilizing an air supply device with a nozzle having the configuration as shown in FIGS. **5** and **6** and as discussed previously. This fluid dispersion nozzle gives the capability for maximizing the dispersion angle, up to at least 180°, while minimizing the aperture size. These two features provide the capability for finer atomization and more uniform dispersion than any other nozzle configuration. In this illustration, for example, the apertures can be made simply and easily down to 0.001 inch effective diameter with wide dispersion angle. Acceptable results have been achieved using an orifice of about 0.008 inch diameter with air pressure of only 2 p.s.i. One to four orifices **46** of 0.010 inch diameter and operating at 2—5 p.s.i. will provide ample humidification capacity for an average-sized home. The number and size of orifices can easily be modified to provide a wide range of a capacity for varied applications.

Although results indicate a number of advantages to the apparatus as illustrated in FIGS. **6** and **7**, the applicability of the method is not restricted to this specific example. For instance, the gaseous supply and dispersion means may be of several configurations which will achieve very satisfactory results for many applications, while perhaps not achieving maximum dispersion, degree and efficiency of atomization, or as simply. Furthermore the containing vessel **38** may be of numerous sizes and configurations, while continuing to serve the purpose as defined. Also the lqiuid-feeding surface **41** may likewise be varied in size and configuration while continuing to provide the defined supply channel through which the forces of capillarity, cohesion and adhesion, and suction pressure remain in effect. Alternate embodiments are therefore depicted in the following discussion.

FIG. **8** and FIG. **9** illustrate an alternate nozzle means with a different orifice configuration and different liquid-feeding surfaces. All of the auxiliary apparatus is the same as in FIGS. **6** and **7**. In this illustration there is provided a fluid-dispensing container **58** tubelike and horizontally disposed and directly connected to the gaseous supply line **44** and which is closed at the end **59**. This container, partially immersed in the liquid **56**, has one or more orifices **60** located at the top above the liquid surface **47**. The orifices are shown as circular; however, they may be of any shape such as oval, oblong or as a long slit. For efficient atomization there is an advantage to having a large periphery of the orifice in comparison to area. A number of small orifices is then preferable to one large orifice. The liquid-feeding surfaces previously shown in FIGS. **6** and **7** are shown in FIGS. **8** and **9** as a concentric tube **61** which tends to encase symmetrically the tubelike fluid-dispensing container or nozzle means **58**. The gap **62** between the fluid-dispensing container **58** and the liquid-feeding surface **61** may be varied in size as needed for the particular application. Openings **63** in the liquid-feeding surface **61** are provided beneath the surface **47** for liquid movement **64** into the gap **62**. Discharge openings **65** are also provided in the top portion **61** and are located in exact alignment with the orifices **60**. The openings **65** are provided somewhat larger in size than the orifices **60** to assure ample clearance for the discharging fluids **66**. In operation the apparatus works exactly as previously described with the gaseous discharge entraining and atomizing the liquid which is lifted from a lower level by various forces associated with suction pressure, capillarity adhesion, cohesion, and surface tension. The design of the atomizing device in FIGS. **8** and **9** is particularly simple in construction and will give very satisfactory atomization. The dispersion pattern **67** is circular and not as well dispersed as in the design of FIGS. **6** and **7**. Application simplicity is the major advantage of this design.

Another alternate design, given in FIGS. **10** and **11**, shows respectively vertical sectional and top views of an atomization apparatus which utilizes a rectangular tubelike fluid-dispensing container. Again all of the auxiliary apparatus is the same as in FIGS. **6** and **7**. The rectangular fluid-dispensing container **68** is directly connected to the gaseous supply line **44** and is closed at the other end **69** to retain an internal pressure greater than the outside pressure say above the liquid surface **47**. This container **68** is partially immersed in the liquid **56** and is provided with one or more orifices **70** located at the top and centered with respect to the sides. The apertures, as noted, are above the liquid level surface **47**. They may be of any shape such as circular, oval, oblong, or slitlike. Provided also is a liquid-feeding surface **71**, designed and arranged symmetric to the container **68** to provide a gap **72** which may be varied in dimension according to the specific application. The gap **72** allows liquid to enter from beneath the surface **47** and to move upward through the gap. Discharge openings **73** are provided in the top portion of the liquid-feeding surface **71** and are located in exact alignment with the orifices **70**. The openings **73** are provided somewhat larger in size than the orifices **70** to provide clearance for the discharging fluids **74**. Operation, again, is exactly as previously described for this method of atomization. The gaseous fluid discharging through the aperture **70** entrains and atomizes liquid which is lifted within the gap **72** from a lower level.

The previous illustrative examples of apparatus for liquid atomization have involved partial immersion of the fluid-dispensing container within a liquid medium wherein the free surface is no lower than the bottom of said container. In FIGS. **12** and **13** the free surface is below the bottom of the fluid-dispensing container. Initial lifting of the liquid **56** is by capillarity or by suction pressure caused by the discharging gaseous fluid. Once feeding has commenced, the liquid is continuously and uniformly lifted by forces of suction, cohesion, capillarity, and surface tension. This illustration shows the fluid dispensing container as a cylindrical tube **75** into which a gas **76** is introduced; however any design as discussed heretofore for this invention will work equally satisfactorily. Two orifices **77** are provided for illustrative purposes. In operation the liquid **56** enters the bottom opening **78** located below the free surface **47** and rises by capillarity or suction pressure within the gap **80** provided between the liquid direction surfaces **81**. The height h of lifting to the bottom of the gaseous containing tube **75** is adjustable depending upon application requirements. The determining factors which limit h are (1) the height of capillarity as determined by the liquid-surface adhesion forces and width of gap **80** and (2) the amount of suction pressure developed at the orifice **77**. This may be up to several inches if proper conditions are provided. The liquid moves freely around both sides 82 of the cylindrical container 75 where it is drawn to the aperture 77 and atomized at 83 through openings 84 as previously discussed.

In all illustrations it may be pointed out that the free liquid surface can easily be covered to prevent evaporation, contamination, or for other reasons. For example if a combustible liquid is being atomized and burned directly above the atomizer, enclosure of the liquid may be necessary. Alternatively, a simple modification in liquid feeding to the atomization device may be made as illustrated in FIGS. 14 and 15. Again the cylindrical tube for a fluid-dispensing container is illustrated. A gas 85 is supplied from a source at a pressure above ambient 86 to the inside 87 of the container 88. The tube 88 is closed at the end 89 and is shown containing three orifices 90 at the top. A cylindrical liquid-feeding surface 91 is provided which symmetrically surrounds the container 88 to provide a gap 92 for liquid feed. Liquid can move freely beneath and around the container 88. At the top portion of the liquid-feeding surface 91 are located openings 93, symmetrical with respect to the orifices 90. In this design liquid 94 communicates or moves freely from a separate liquid supply reservoir 95 having a free liquid surface at the same ambient pressure 86 as surrounding the atomizer. This liquid surface must be at a level below the orifices 90 to obtain proper operation. Operation of the atomizer and forces involved are exactly as previously discussed; the only difference is that the liquid is remotely located. This principle is applicable to any of the atomizer designs illustrated herein.

In all previous illustrations of this disclosure, the nozzle means has been depicted as tubelike, with at least one orifice located along the upper portion of the surface. Multiple orifices are easily provided with these designs and would be located preferably in a straight line along the upper surface and symmetric with respect to a vertical line passing through the center of the container. Symmetrical location of the orifices provides more uniform lifting and feeding of the liquid from both sides of the orifices through the gap than, for example asymmetric lifting of the liquid from one side only. A nonsymmetrical arrangement of the orifices with respect to the vertical line will work satisfactorily if the liquid on either side can move freely to the aperture without passing over a surface having a higher elevation than the apertures. For example the nozzle means 45 in FIG. 6 can be rotated right or left nearly 90° with continued uniform feeding to both sides of the apertures.

Consider now FIGS. 16 to 19 which illustrate alternate designs for single orifices that are quite different from the previous designs. In these designs, the liquid is lifted through a gap that surrounds a vertically tapered gaseous dispensing container. The shapes could be referred to as hollow conelike whose outer surface is also a liquid-feeding surface. FIGS. 16 and 17 give a vertical sectional and top view respectively of a liquid atomization device having a single circular orifice. A gas 96 is supplied under pressure greater than the ambient pressure 99 to the fluid-dispensing container 98 which is tapered vertically. Located at the top of 98 is circular aperture 100 which provides an exit for the gaseous fluid. A liquid 101 is shown provided from a separate liquid supply reservoir 102 having a free liquid surface at the same ambient pressure 99 as surrounding the atomizer. The liquid surface, as discussed previously, must be lower than the aperture 100. The liquid communicates freely within the supply tube 103 and up the gap 105 between the liquid-feeding surface 104 and the outer surface of the fluid-dispensing container 98. In operation the discharging gaseous fluid atomizes the liquid 106 exactly as previously discussed. One slight difference is that the liquid feeds completely uniformly in the gap 105 around the circular orifice; whereas, in previous designs illustrated the liquid feeds approximately uniformly to the exit periphery of the discharging gas.

FIGS. 18 and 19 similarly illustrate a single orifice design but for flat-fan dispersion. A gas 107 is supplied under pressure greater than ambient 110 to the gaseous dispensing container 108 which is tapered vertically and which has a single orifice 109 for fan dispersion. A liquid 111 is provided from a separate liquid supply reservoir 112 as in FIGS. 16 and 17. The liquid 111 moves freely within the liquid supply tube 113 and up into the gap 114 between the liquid-feeding surface 115 and the gaseous container 108 outer surface. Operation again is exactly as previously described to obtain fine atomization of the liquid 116.

In the previous designs, utilizing capillary forces to help lift and hold the liquid near the gas emitting orifice, the exterior surface of the nozzle means was described and illustrated as one of the wettable feeding surfaces. An alternative is to utilize completely separate, distinct, and removable if desired, wettable surfaces such as is illustrated in FIGS. 20 and 21. Two concentric surfaces, 115 being the inner one and 116 the outer one, are closely spaced to provide gap 117 thru which the liquid 118 will move by capillary forces, and otherwise, to the vicinity of the nozzle. The circular orifice 119 emits fluid 120, such as a gas, while the concentric orifice, 121 feeds the liquid into the gas stream. Since the wettable feeding surfaces 115 and 116 are not a physical part of the nozzle means 122, they can be removed easily for cleaning, replacement such as for changing the material to achieve different liquid angle contacts, or for secondary blending control. Being separate, the gap 117 can be made and maintained more precisely to specified dimensions. It is understood that the physically separate removable wettable surfaces as described above can be utilized with any design, including multiple orifices.

The foregoing designs showed the gaseous pressure above the free liquid surface to be the same as the ambient pressure around the nozzle apertures. It is to be emphasized that this is not a requirement. By regulating the gaseous pressure above the free liquid surface with respect to the pressure on the liquid at the apertures the liquid flow rate is controlled. The latter design is preferred in many instances. It should also be pointed out that separate regulation of the liquid flow rate can be achieved by means of an adjustable metering valve, in contrast to the previously described solenoid "on-off" valve, located between the liquid supply having a free surface and the nozzle means.

Without further discussion and illustration, the foregoing illustrates the essential characteristics of the present invention to the extent that ready adaptation can be made in various applications. Such adaptations are considered to be within the spirit and scope of the present invention.

I claim:

1. A device for liquid atomization and fluid blending comprising a liquid reservoir with means for supplying liquid as required to maintain a near constant free surface level, a fluid dispersion nozzle means comprising a relatively large elongated fluid feed conduit and a smaller elongated discharge orifice portion fluidly communicating with the interior of said conduit including an elongated wall portion having a semicylindrical internal curvature substantially semicircular in cross section forming a corona orifice cavity slitted transversely to provide at least one discharge orifice or aperture for fan-shaped fluid dispersion, said orifice cavity being unslitted on either side of said orifice for a distance greater than its diameter, said dispersion nozzle being disposed generally horizontally, with said orifice disposed above said free surface such that adhesion forces between the liquid and external surfaces of said nozzle means causes the liquid to rise along said nozzle surfaces to the vicinity of said orifice slit, means for supplying a fluid, at a pressure greater than the ambient pressure above the said liquid free surface, into said fluid dispersion nozzle means whereby said fluid discharges from said orifice in a fan-shaped pattern, said dispersing fluid peripherally entraining and divergently dispersing said liquid at orifice into finely atomized particles blended uniformly with said fluid, said liquid continuously rising up the external surface of said nozzle means by forces of adhesion, cohesion, surface tension and pressure differential, whereby said liquid is stressed into a thin

film along the upper portion of said discharge orifice portion which with further stressing during entrainment provides fine atomization and blending.

2. A device for liquid atomization and fluid blending comprising a liquid reservoir with means for supplying liquid as required to maintain a near constant free surface level, a fluid dispersion nozzle means comprising a relatively large elongated fluid feed conduit and a smaller elongated discharge orifice portion fluidly communicating with the interior of said conduit including an elongated wall portion having a semicylindrical internal curvature substantially semicircular in cross section forming a corona orifice cavity slitted transversely to provide at least one discharge orifice or aperture for fan-shaped fluid dispersion, said orifice cavity being unslitted on either side of said orifice for a distance greater than its diameter, said dispersion nozzle being disposed generally horizontally, with said orifice disposed above said free surface, means for supplying a fluid, at a pressure greater than the ambient pressure above the said orifice, into said fluid dispersion nozzle whereby said fluid discharges from said orifice in a fan-shaped pattern, at least two distinct wettable surface means extending from below the free surface means and the exterior side surfaces of said nozzle means for initial capillary rise of liquid through said gaps which further rises by adhesion forces to the vicinity of said aperture whereby, when said fluid is discharged from said aperture, the liquid, at least partially due to pressure differential, adhesion, cohesion, surface tension and capillarity, rises continuously in said gap to surround said aperture and is dispersed divergently by said fan-shaped fluid discharge into finely atomized particles blended uniformly with said fluid.

3. The device of claim 2 wherein means is provided for controlling the flow of fluid from said aperture.

4. The device of claim 2 wherein means is provided for controlling the flow of liquid rising to surround said aperture by regulating the pressure differential between the fluid emitting from said aperture and the ambient pressure above said free liquid surface.

5. The device of claim 2 wherein the angle of contact between the liquid and each of the wettable surface means is up to 90°.

6. The device of claim 2 wherein the wettable surface means are removable.

7. The device of claim 2 wherein a multiplicity of apertures are provided which give a parallel array of fluid discharge and atomized liquid, at least one of which apertures is insulated from the liquid to provide controlled blending of atomized liquid with fluid discharged from nozzle means.

8. The device of claim 7 wherein the insulating means is an integral part of a removable wettable surface means.

9. The device of claim 2 wherein the aperture is so formed to give a flat-fantype dispersion of an angle up to approximately 190°.

10. The device of claim 2 wherein the free surface of the liquid is maintained preferably between 1 mm. and 100 mm. from the nozzle aperture

11. The device of claim 2 wherein the pressure differential between the free surface of the liquid and the ambient atmosphere adjacent the aperture is between 0.5 p.s.i. and 50 p.s.i.