# United States Patent [19]

**Runstadler, Jr. et al.**

[11] **3,764,069**

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[54] **METHOD AND APPARATUS FOR SPRAYING**


[75] Inventors: **Peter W. Runstadler, Jr.**, Hanover, N.H.; **Eric T. Nord**, Oberlin; **Donald R. Hastings; Don R. Scarbrough**, both of Elyria; **Frederick R. Wilhelm**, Avon Lake, all of Ohio

[73] Assignee: **Nordson Corporation**, Amherst, Ohio



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[52] **U.S. Cl.** .................... **239/8**, 239/414, 239/419, 239/424.5, 239/426, 239/431, 239/434, 239/596

[51] **Int. Cl.** .................... **B05b 7/04**, B05b 1/06

[58] **Field of Search** .................... 239/419, 431, 432, 239/434, 337, 366, 368, 590, 414, 422, 423, 424.5, 426, 428, 429, 430, 552, 553, 590.3, 596, 599, 600, 8



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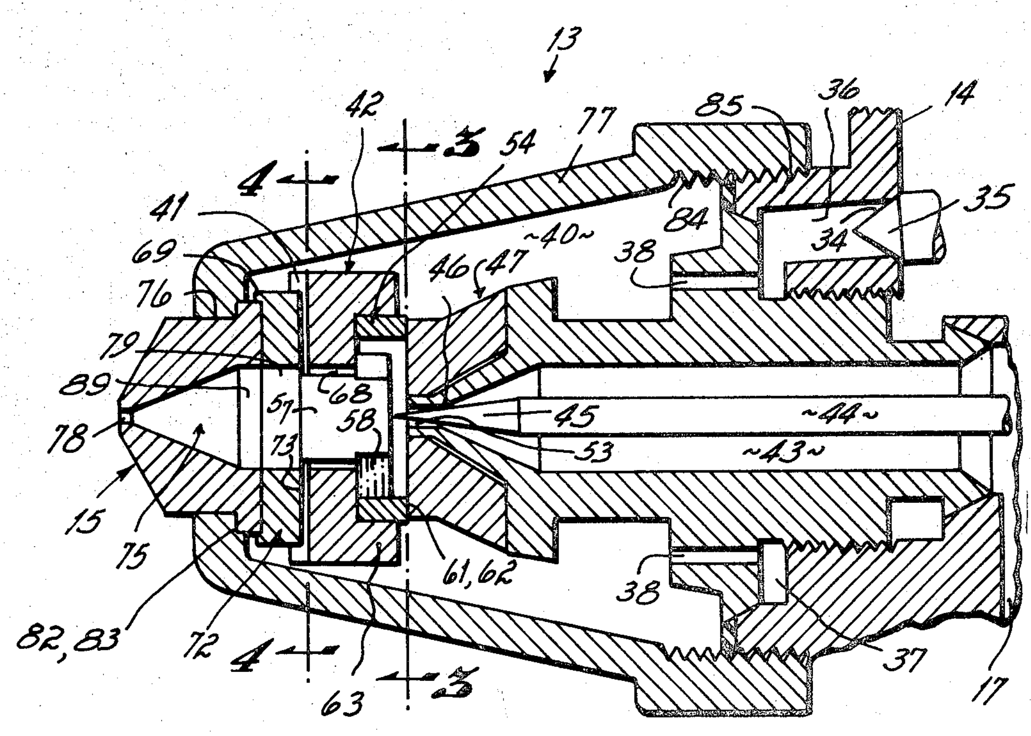
*Primary Examiner*—M. Henson Wood, Jr.
*Assistant Examiner*—Reinhold W. Thieme
*Attorney*—James S. Hight et al.


[57] **ABSTRACT**


A method and apparatus for atomizing and spraying liquids such as fuel, paint or water in the form of minute droplets utilizing a small amount of air to provide the atomizing force. The liquid under a pressure of from 30–100 psi is caused to flow in a thin film. Streams of gas at a slightly higher pressure are impinged against the liquid film so that the gas is sheared into microbubbles which are entrained in the liquid to form a froth in which the liquid is the continuous phase, and in which the air to liquid mass ratio is from 0.1 to 1.6. The froth flows through a space in which the pressure decreases as the froth moves toward a nozzle. During this flow the froth becomes homogeneous. The froth is discharged through a nozzle whereupon the air bubbles explode rupturing the liquid film and causing the liquid to disintegrate into finely atomized drops.

The apparatus for carrying out this method comprises a liquid film-forming channel connected to a liquid inlet line supplied with liquid under pressure, an air injection channel terminating adjacent to the liquid flow channel, a flow space interconnecting the liquid film channel and a nozzle orifice. In the preferred embodiment the film-forming channel is annular with air being injected from the outside of the channel. In a modification the liquid film-forming channel is planar with air being injected into the film from one or both sides of the channel.


**43 Claims, 10 Drawing Figures**



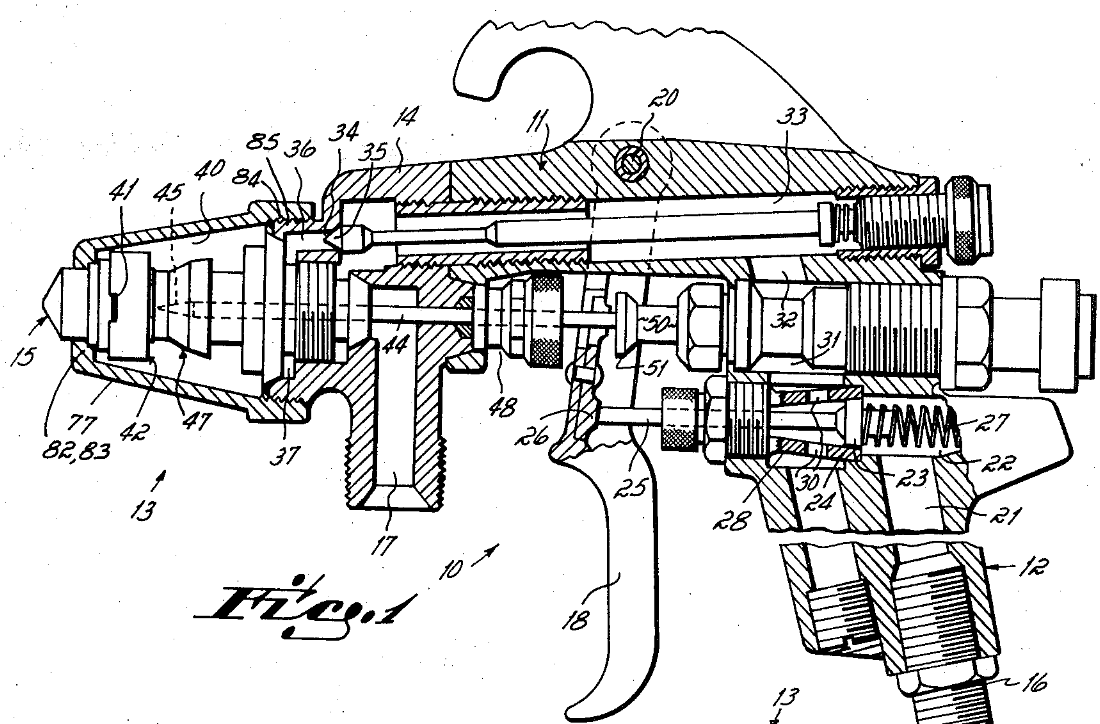


Fig. 1

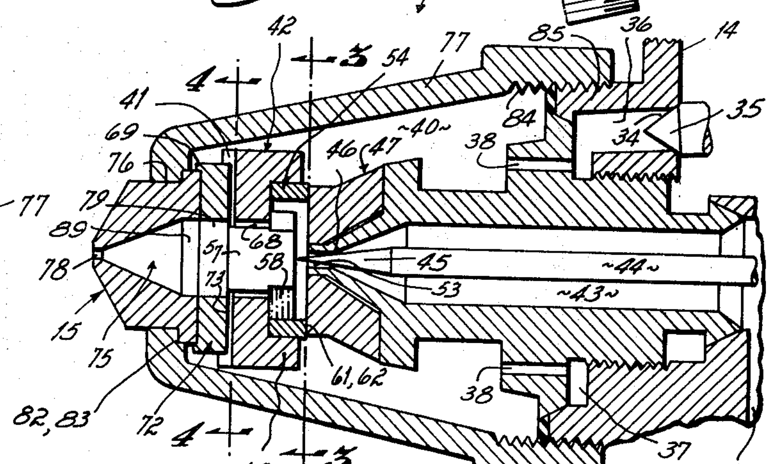


Fig. 2

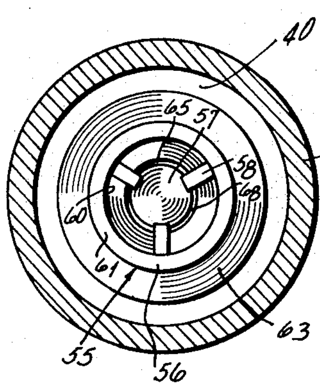


Fig. 3

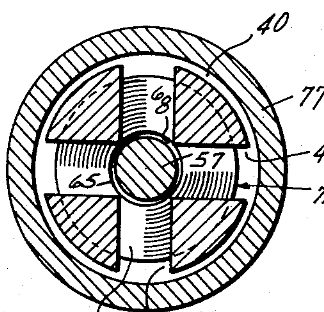


Fig. 4

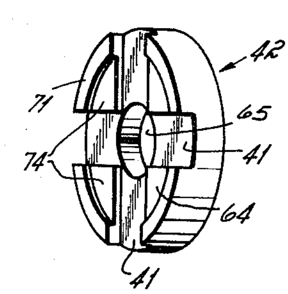


Fig. 5

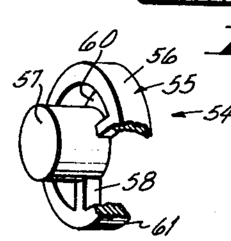


Fig. 6

INVENTORS
Peter W. Runstadler, Jr.
Eric T. Nord
Donald R. Hastings
Don R. Scarbrough
Frederick R. Wilhelm
BY Wood, Herron & Evans ATTYS

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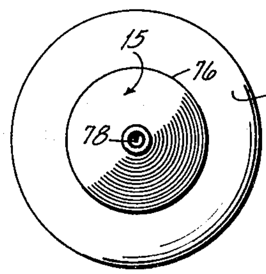


Fig. 7

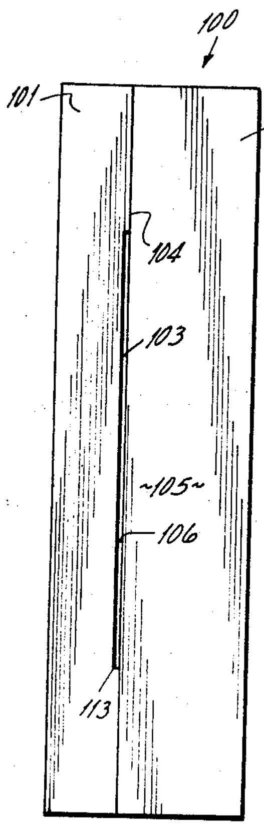


Fig. 9

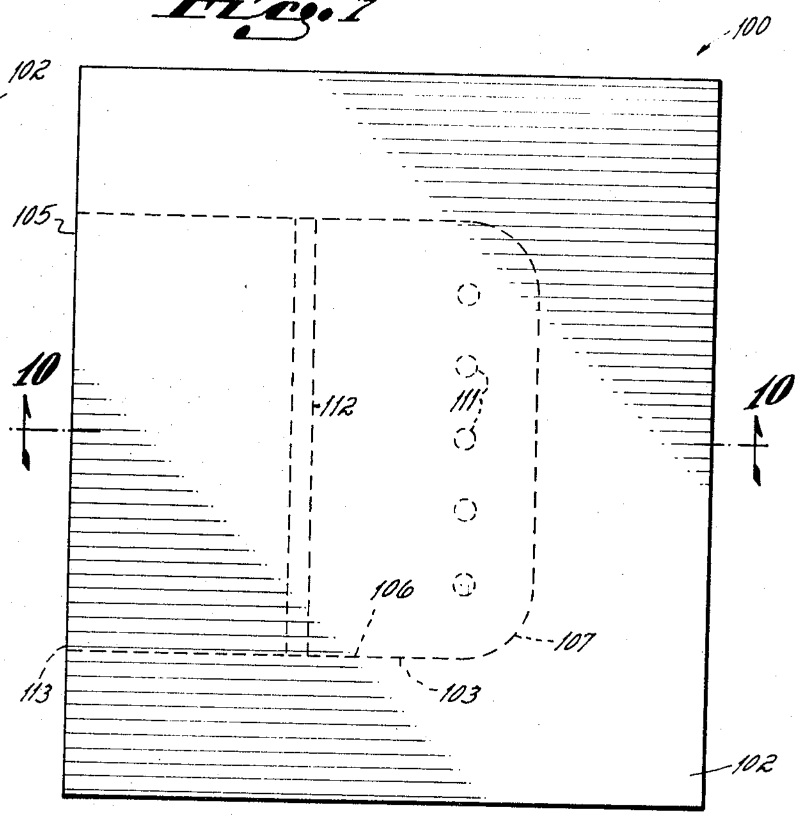


Fig. 8

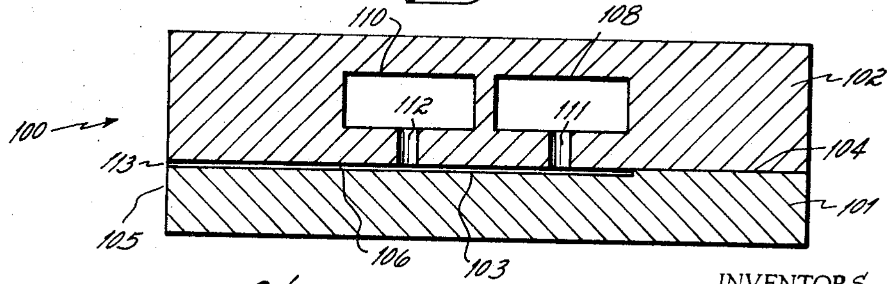


Fig. 10

INVENTORS
Peter W. Runstadler, Jr.
Eric T. Nord
Donald R. Hastings
Don R. Scarbrough
Frederick R. Wilhelm
BY Wood, Herron & Evans ATTYS

# METHOD AND APPARATUS FOR SPRAYING

## BACKGROUND OF THE INVENTION

This invention relates to a method and apparatus for atomizing and spraying various liquids such as paint, fuel oil, water, various molten adhesives and other materials, and the like, and is particularly directed to a novel method and apparatus for obtaining a fine and uniform spray of liquid by interaction of the liquid with air or another gas, both the liquid and air being at relatively low pressures, e.g., pressures of from 30 to 100 psi.

There are at the present time many different applications in which it is desired to obtain a fine liquid spray having drop sizes of from 2 to 100 microns, for example, while utilizing only small amounts of air to achieve atomization of the liquid. For example, in the spraying of finish coating for such items as appliances, furniture and the like, it is desirable to apply paint, lacquer or other liquid coatings in the form of a fine uniform atomized spray. At the same time, it is desired to minimize the amount of air involved so as to minimize wastage of paint in the form of "overspray" or "bounce-back." Objectionable amounts of overspray and bounce-back are inherent in conventional air spray methods which use large amounts of high velocity air. These are not only deleterious from the point of view of material wastage, but also impose substantial problems of pollution control. Thus, in the typical paint spray installation involving several paint spray guns, it is conventional practice to provide a large capacity ventilation system capable of capturing paint particles entrained in a large mass of high speed air at capture velocities, for example, 150 feet per minute. Moreover, since the air carries a substantial amount of entrained paint which has been oversprayed or has rebounded, various types of filters or water curtains are required to minimize atmospheric pollution. Moreover the compressors, to provide the large quantities of compressed air, add materially to the cost of the installation and to its operating cost.

In the past, the principal alternative to this conventional air spray method has been the so-called "airless" paint spray, in which no air is utilized and the paint is extruded through a nozzle under a very high pressure from 300 to 3,000 psi. While airless paint spraying does provide the advantage of eliminating the high volumes of air associated with air type paint spraying, it does have the inherent disadvantage of requiring fairly costly high pressure paint pumps, paint lines and associated equipment. Also, in order to obtain fine quality finishes, it has often been found necessary to utilize a paint heater to heat the paint. These components make the cost of an airless paint spraying system relatively high. They also, of course, add to the cost of operating the system.

In many other areas and for quite different reasons, it is desirable to obtain a fine liquid spray coupled with minimum air flow. For example, in oil burners utilizing commercial fuel oil, it is desirable to provide small, uniform drop size of much less than 100 microns in order to obtain rapid and complete combustion, thereby preventing the formation of chemical oxidation products of a pullutant nature. In such systems it is also desirable to minimize the amount of air required to atomize the fuel and to utilize both oil and air pressures as low as possible to minimize both the cost of the installation and the cost of its operation.

Similarly, in systems for feeding automobile fuel to closed rankine cycle or steam engines, it is desirable to provide a fine, uniform fuel spray (from 5 to 30 micron drop size for automobiles) while utilizing a small amount of air coupled with a minimum air and fuel pressure. Again, the fineness of spray contributes to rapid and complete burning of the fuel, minimizing the formation of harmful pollutants. The use of only minimal amounts of air and relatively low air and fuel pressures minimizes the size and power requirements of the auxiliary engine equipment, i.e., air and fuel pumps.

Another type of device in which it is desired to provide a spray of fine drop size, for example, 100 micron drop size, is in the field of gas scrubbers. In these devices a fine water spray is contacted with a gas stream, for example, flue gas, in order that the particulates entrained in the gas can be removed before the gas is released to the atmosphere. In such devices it is desirable that the water drop size be small and uniform to provide a good intermixture of the air and gas providing optimum probability that a particulate will strike a droplet of water and adhere thereto. Again, in such installations it is desirable that a minimum amount of air be utilized to achieve the required atomization in order to achieve maximum economy of operation of the scrubber.

Another form of apparatus having the same desiderata and utilizing water as a spray liquid is climate control apparatus. For example, in many areas, it is desirable to form a fine mist or "fog" of water particles of from 2 to 15 micron drop size to protect crops from freezing during nighttime periods. Such a spray is also useful in providing a humid environmental cover in arid climates. Again, in this type of installation it is desirable to minimize the pressure of the liquid and air and to minimize the volume of air so as to minimize the initial cost and the cost of operation of the equipment. The same general considerations apply to evaporative coolers in which water is sprayed to dissipate heat therefrom as an alternative to passing water through a cooling tower.

Another example of an installation in which it is desirable to provide a small fine liquid spray formed with a minimal amount of air is in a spray dryer in which a food substance in liquid form is sprayed into a tower and is spray or freeze-dried to convert the liquid to a particulate or powder material. This type of equipment is utilized in the preparation of many types of food products such as gelatin desserts, powdered coffee and the like. In such installations it is desirable to obtain a uniform fine droplet size of the liquid in order to obtain an optimum quality final product. At the same time, it is desirable to utilize a small amount of air in order to minimize both the initial cost of the installation and the operating cost.

## SUMMARY OF THE INVENTION

The principal object of the present invention is to provide a novel method of forming a fine spray of liquid droplets utilizing small quantities of low pressure air as the atomizing agent.

the e present invention is predicated upon the concept of atomizing and spraying a liquid by utilizing forces stored within a myriad of microbubbles previously injected into the liquid to convert it into a froth.

This froth is passed through a passage and is then forced outwardly through an orifice. As the froth flows through this orifice the compressed gas bubbles expand rapidly in an explosive manner and thereby fragmentize the liquid film surrounding the bubbles causing the liquid to break up into small, minute droplets preferably in the order of from 2–100 microns in diameter. The action of the exploding bubbles constitutes essentially the sole atomizing mechanism, i.e., there is no internal atomization within the nozzle nor any external shearing atomization except possibly for a very minor amount resulting from the outward flow of the spray relative to the quiescent air. Moreover, under the pressure conditions employed, the orifice itself, for example, a round orifice or plane elongated slit, is ineffective to atomize a non-froth liquid stream.

One important aspect of the present invention is the provision of an atomizing method in which the froth is produced within a nozzle and subsequently expelled from a nozzle in such a manner as to make maximum use of the exploding bubbles to atomize the liquid.

We have determined that optimum effectiveness of the air as an atomizing agent in this spraying method is obtained by making the froth as homogeneous as possible prior to its discharge from the nozzle. In accordance with the present invention, optimum initial injection of air bubbles into the liquid is obtained by forming the liquid into a film in the area of air injection.

The homogeneity of the froth is further increased by causing the froth to flow through a space in which there is a slight degree of internal turbulence such as that incident to flow through a smooth wall passage, and in which the pressure decreases causing the bubbles to expand. As a result of this dual action the bubbles tend to move closer together with only thin walls of liquid between them. These thin walls are more readily ruptured when the bubbles expand and explode after discharge through the nozzle and no sizeable volume of liquid without air bubbles is expelled through the nozzle to cause oversize drops.

We have further determined that the atomizing effectiveness of the exploding bubbles is optimized by causing the bubbles at the discharge orifice to be under as high a pressure relative to the inlet pressures of the liquid and air as possible. More particularly, as is explained in detail below, the pressure of the froth at the discharge orifice bears a critical ratio to the inlet or stagnation pressure. We have determined that for the range of inlet pressures utilized and for the types of materials sprayed, as discussed above this critical ratio approaches a maximum value (giving a maximum orifice pressure of the gas bubbles) when the mass ratio of air to liquid is entrained in the range of from 0.1 to 1.6. We have further determined that the froth in the passage behind the nozzle should not be subjected to substantial turbulence or the outlet pressure will drop and the effectiveness of the exploding bubbles will be decreased.

One of the principal advantages of the present method is that it requires only relatively low air and liquid pressures; the liquid pressure being from 30 to 100 psig, and the air pressure only slightly higher, e.g., 0.5 to 2 psi higher than the liquid pressure adjacent to the injection area. Moreover, the method requires only relatively small quantities of air, for example, one-tenth the amount of air previously required in conventional air spray nozzles. As a result, the present method can be used advantageously in any of the environments described above.

By way of example, a paint spray system employing the present method can be used in installations in which air is supplied from a shop air line carrying a conventional pressure of perhaps 50 psi. The paint or other coating materials can be supplied from a low pressure pump or from a pressurized tank. Thus, the cost of the initial installation as well as the cost of operating the system is relatively low. Moreover, the coating material being sprayed is not enclosed in a large quantity of high velocity moving air. Thus, undesirable overspray and bounce-back are either minimized or substantially eliminated. This not only results in an appreciable material saving, but also facilitates the use of a substantially smaller ventilating and filtration system to prevent air pollution.

Another advantage of the present spraying method is that it not only results in small drop size, but also results in a relatively uniform drop size. This again is advantageous in the operation of many of the types of systems described above.

A still further advantage of the present invention is that it facilitates the provision of fine spray characteristics utilizing less critical spray nozzles than have been required heretofore. Specifically, since the nozzle orifice itself does not perform an atomizing function, as for example does a conventional airless paint spray nozzle, the nozzle geometry can be larger and is less critical and thereby less difficult to machine.

These and other objects and advantages of the present invention will be more readily apparent from the following detailed description of the drawings illustrating a preferred embodiment of the invention.

In the drawings:

FIG. 1 is a partial vertical sectional view through one form of a spray gun constructed in accordance with the principles of the present invention.

FIG. 2 is an enlarged vertical cross-sectional view through the nozzle end of the gun.

FIG. 3 is a cross-sectional view taken along line 3—3 of FIG. 2.

FIG. 4 is a cross-sectional view taken along line 4—4 of FIG. 2.

FIG. 5 is a perspective view of the collar member.

FIG. 6 is a perspective view of the orifice plate member.

FIG. 7 is an end view of the nozzle.

FIG. 8 is a top plan view of a modified form of spray nozzle embodying the principles of the present invention.

FIG. 9 is an end view of the modified form of nozzle shown in FIG. 8.

FIG. 10 is a cross-sectional view taken along line 10—10 of FIG. 8.

## DESCRIPTION OF METHOD INVENTION

The present method can be employed to atomize and spray various liquids in many different applications in which it is desired to have a fine spray formed utilizing only a small quantity of air or other gas with relatively low pressures on both the liquid and air. By way of example, the present method can be utilized to spray commercial fuel in oil burners, molten liquids such as adhesives, water in gas scrubbers, evaporative coolers, and climate control equipment, for example, equipment for creating a fog to prevent nighttime freezing of citrus or similar crops, automotive fuel in automotive combustion systems, liquid foods such as gelatin in freeze driers, and the like. In each of these cases the liquid being sprayed is substantially incompressible and is atomized by means of a compressible gas such as air.

In accordance with the present method, the liquid being sprayed is first caused to flow in the form of a thin film of from 0.005 to 0.050 inches in thickness. The liquid is under a pressure of the order of 30 to 100 psi. A compressible gas is then injected through a small orifice into this film. The gas pressure at the orifice is preferably slightly above, e.g., 0.5 to 2 psi greater than, the liquid film pressure so that the film shears off the gas into a myriad of microbubbles which are entrapped in the film to convert it to a froth.

The froth is then advanced in a confined area toward a nozzle orifice. During the path of movement of the froth toward the nozzle, the pressure in the froth drops somewhat so that the entrained bubbles in the froth expand slightly creating a more homogeneous mixture in the froth. However, as is explained in greater detail below, the pressure of the froth before it emerges from the nozzle cannot drop below a certain critical pressure, for example 60% of the pressure of the liquid at the inlet.

When the froth is forced to exit through the nozzle into an environment at a lower pressure, e.g., atmospheric pressure, the pressurized bubbles entrained in the froth suddenly expand and in fact seem to explode. In so doing, they break up the liquid matrix into a large number of very small droplets, for example, droplets of the order of 2 to 100 microns in size. These droplets are propelled forwardly from the nozzle at a relatively small velocity, for example, a velocity of the order of 200 feet per minute at a distance of 10 inches from the nozzle. In this method of atomizing liquid, the exploding froth constitutes the sole atomizing mechanism. For reasons described below, it is desirable that there be no turbulent type of atomization occurring within the nozzle. Indeed, the present method can be carried out utilizing nozzles having small circular orifices, or elongated slit orifices which, by themselves, are ineffective to cause any atomization whatsoever of a plain liquid stream at their pressures.

In the present method of atomizing liquid, air or other gas is intermixed with the liquid in a quantity such that the mass ratio, i.e., the ratio of air to fluid in the froth, is in the range of from 0.1 to 1.6. The use of air and liquid in these ratios results in obtaining optimum spraying effectiveness utilizing the minimal quantity of air. The reasons for this can best be understood from a somewhat more detailed consideration of the process in terms of the hydrodynamic properties of the materials involved.

More particularly, when an incompressible fluid and a gas are mixed to provide a homogeneous mixture of two phases in which the liquid is the continuous phase, the properties of this homogeneous mixture or froth are similar to those of a compressible fluid. Thus, if such a mixture is formed under a pressure appreciably above atmospheric, e.g., a pressure from 30 to 100 psi, and is forced to exit through an orifice to atmosphere, the flow will exhibit compressible, choked-flow characteristics if the orifice pressure ratio is sufficiently large. The exit flow velocity is sonic. However, the "sonic" velocity of the mixture will be quite low (relative to that of air at standard temperature and pressure) so that the exit velocity from the choked nozzle will be of the order of 100 feet per second. When the process is carried out so that the orifice pressure of the mixture is raised appreciably above the critical choke value, then the entrained bubbles expand suddenly and "explode" when they enter the ambient pressure field. This violent expansion fragments the film of liquid surrounding the bubbles to form a uniform fine spray.

A theoretical analysis of a two phase mixture such as a liquid-air mixture is based upon certain simplifying assumptions which include the following: (1) the liquid is incompressible, (2) effects due to viscosity and vapor pressure of the liquid are not important, (3) the gas is an ideal gas with constant specific heat, (4) the mixture is truly homogeneous in that the gas bubbles are assumed to be so small that an arbitrarily small sample contains the same mass ratio of gas to liquid, (5) the flow is adiabatic and the gas and liquid are always at equal temperature, (6) the flow is assumed one dimensional and inertial transients are neglected, (7) it is assumed that a pressure signal is transmitted through the mixture with a definite speed of sound.

Given these assumptions, it can be shown that when the supply or stagnation pressure is sufficiently high relative to the ambient pressure the flow velocity at the exit orifice equals the "sonic" velocity and the flow through the orifice is choked. Under these conditions, with sonic velocity flow through the orifice, there is a critical pressure ratio R within the nozzle. The critical ratio R is a ratio of the pressure at the exit orifice $P^*$ divided by the pressure at the inlet, or stagnation pressure, $P_o$. In short, $R = P^*/P_o$. Viewed differently, the pressure within the nozzle and at the orifice will never drop below the critical pressure $P^*$ which is equal to the critical ratio times the stagnation pressure $P_o$. Thus, $P^* = R\ P_o$. The higher the pressure at the orifice the more violent will be the expansion and bursting of the entrapped air bubbles upon flow through the orifice and exposure to atmospheric pressure; and, hence, the more effective will be the atomization of the liquid being sprayed. In the pressure range utilized in the present method, i.e., 30 to 100 psi, and with the types of liquids being sprayed, we have determined that the critical pressure ratio is optimized at approximately 0.6 when the mass ratio of air to liquid is maintained within the range of from 0.1 to 1.6. Within this range the air exits at the highest pressure possible for a given inlet pressure so that maximum fragmentation of the liquid is obtained from each individual air bubble. Moreover, there is sufficient air entrained to effectively atomize all of the liquid matrix. At the same time, there is not a substantial excess of air involved which might cause deleterious results such as, for example, overspray in a paint system or conversion of a froth with liquid as the continuous phase to air as the continuous phase.

In the present method the substantial uniformity of drop size results from achievement of a homogeneous froth at the discharge orifice. This homogeneity is achieved by providing a short flow space between the region in which air bubbles are injected into the froth and the orifice. There is a slight amount of turbulence as the froth flows through this region which aids in homogenizing the froth, and there is a continuous pressure drop which results in an expansion of the individual bubble size. During this expansion the skins of the bubbles tend to get thinner, reducing the amount of liquid between individual bubbles and thereby preventing the flow through the orifice of any appreciable body of liquid not containing air bubbles effective to fragment the liquid when the bubbles explode.

At the same time, however, the amount of internal turbulence is kept at a very low level, for any substantial turbulence in the interior of the nozzle functions to lower the stagnation pressure level $P_o$. Since the orifice pressure $P^* = R\ P_o$, any lowering of the stagnation pressure $P_o$ causes a lowering of the orifice pressure $P^*$. The lowering of this orifice pressure reduces the pressure differential on the bubbles after they leave the orifice and, hence, decreases their explosive, atomizing effect.

In the present method, the principle atomizing mechanism is the explosive action of the entrained bubbles in the froth. There is a slight secondary atomizing effect obtained from the shearing effect of the environmental air on the liquid particles as they move forwardly from the nozzle. There is no internal, mechanical atomizing action within the nozzle, nor is there any external, mechanical atomizing action through the use of externally directed air jets or the like. Moreover, under the relatively low pressure through which material is extruded through a nozzle, the nozzle orifice itself does not create any significant mechanical atomization.

## DESCRIPTION OF THE APPARATUS

The present method can be carried out with many different forms of apparatus. These different forms of apparatus, however, have several basic elements in common, i.e., a fluid inlet line, means for forming a thin fluid film, means for injecting a stream of air into the film to form a froth in which a myriad of microbubbles of air are entrained within the liquid, a confined space through which the froth passes prior to its exit from the nozzle, and an orifice through which the froth is emitted.

In order to provide a full understanding of the relationship of these components, the invention will be first described in detail with relation to a preferred form of spray nozzle embodied in a gun for spraying paint. However, this same atomizing structure divorced from the gun can be utilized for spraying the other materials referred to above such as fuel oil. The invention will also be discussed with relation to a modified form of discharge orifice. Other suitable forms of apparatus for carrying out the present method are shown in the copending application of Peter W. Runstadler, Jr., Eric T. Nord, Donald R. Hastings, Samuel R. Rosen, Don R. Scarbrough and Frederick R. Wilhelm for "Method and Apparatus for Producing a Flat Fan Paint Spray Pattern" filed on even date therewith.

A typical spray gun **10** adapted to utilize the present atomizing means of the present invention for spraying paint is shown in FIG. **1**. In a typical application, spray gun **10** could be used to apply a decorative or protective coating to a product, such as refrigerator, automobile part, furniture, containers, or the like. The coating materials to be sprayed include not only paints, but also enamels, lacquers, stains, varnishes, emulsions, waxes, adhesives and the like. For the purposes of simplifying the description of the present application, the word "paint" is used in a very generic sense to encompass all of these various types of coating materials. It is to be understood, however, that spray gun **10** is merely exemplary and the atomizing means of this invention can be incorporated in many different devices. For example, while spray gun **10** is a hand-held, non-electrostatic gun, the present atomizing means can be incorporated advantageously in non-hand-held automatic paint spray guns of the general type shown in Juvinall U.S. Pat. No. 3,169,883.

Also, while spray gun **10** is not shown as being provided with any paint charging means, the present atomizing means can be used advantageously in connection with electrostatic spray guns having any suitable means for applying a charge to the paint spray. One generally suitable form of paint charging device is shown in Juvinall et al. U.S. Pat. No. 3,169,882. Thus, it is to be expressly understood that the details of the gun shown in FIG. **1** are shown by way of illustration and not by limitation.

More particularly, spray gun **10** includes a body portion **11**, a handle portion **12**, and a spray head portion **13** mounted on the forward end of a barrel portion **14** and having a nozzle **15** mounted at its forward end. The handle portion **12** of the gun is provided with a suitable fitting **16** for coupling the gun to an air line, for example, a shop air line under a pressure of 50 psig. The barrel portion **14** is provided with a paint inlet conduit **17**. This conduit is adapted to be connected to a paint spray line by means of any suitable coupling. It is to be understood that the paint spray line is normally fed with paint which is pumped under pressure from a paint supply tank, or alternatively, is fed from a pressurized tank. The paint pressure at the gun is relatively low and is preferably in the range of from 30 to 100 psi immediately upstream from the air injection area.

In the gun shown, flow of paint through the gun to the spray head and flow of air through the gun is controlled by means of a trigger **18**. The trigger is pivotally mounted to the body by means of pivot pin **20**.

In the gun shown, air flows through air inlet conduit **21** to a chamber **22** which is normally closed by a valve **23** adapted to seat against a tapered annular seat **24**. Valve member **23** is carried by a stem **25** which extends forwardly from the handle into engagement with a pad **26** formed on the rear surface of trigger **18**. Valve **23** is spring-urged to its closed position by means of a compression spring **27** disposed within chamber **22**. This spring, acting through stem **25**, is likewise effective to urge the trigger to its forwardmost position.

Tapered sleeve member **28**, which forms a seat for valve **23**, is provided with a plurality of radial passageways **30** effective, when valve **23** is unseated, to interconnect chamber **22** and, hence, air inlet conduit **21** with a passageway **31**. This passageway in turn communicates through a bore **32** to elongated passageway **33**. Air moves forwardly along this passageway through an orifice **34** controlled by a needle valve **35**. The needle valve threadably engages body **11** and is adapted to be held in its adjusted position by a conventional lock nut arrangement.

Orifice **34** communicates with a bore **36** and annular groove **37**. aAnnular groove **37** in turn communicates with a plurality of longitudinal passageways **38** terminating in an enlarged chamber **40**. As is explained in detail below, air is supplied from this chamber to the atomizing section of the gun through air injection slots **41** formed in collar member **42**.

Trigger member **18** also is effective to control the flow of paint to the atomizing means. More particularly, as is best shown in FIGS. **1** and **2**, paint enters the gun through paint conduit **17**. Paint flows from this conduit forwardly through a passageway **43** surrounding valve stem **44.** The valve stem is provided with a tapered end **45** adapted to seal against seat **46** formed in fluid tip member **47.** Valve stem **44** extends rearwardly through a suitable packing member **48** carried by the barrel and through an enlarged opening formed in trigger member **18.** The valve stem carries a sleeve member **50** which is slidably mounted in the gun body **11.** Sleeve **50** has a head member **51** formed adjacent to its forward end and disposed for abutment with a pad **52** formed on the rear surface of the trigger.

When trigger **18** is depressed, air valve **23** is shifted rearwardly out of engagement with tapered seat **24** so that air is free to flow from inlet conduit **21** through chamber **22,** radial ports **30,** passageway **31,** bore **32,** passageway **33** through port **34.** As the trigger is further depressed, paint needle valve **44** is shifted rearwardly so that its tapered end **45** is withdrawn from the valve seat **46** formed on tip member **47.** Thus, paint flows through paint conduit **17** and passageway **43** through the port **53** formed at the forward end of tip member **47.** In this manner, both a separate air and paint spray are admitted to the atomizing section of the gun. When trigger **18** is released, paint valve stem **44,** moves forwardly to stop paint flow, and then valve **23** closes to cut off the air flow.

The atomizing section of the gun comprises an orifice member **54** best shown in FIGS. **5** and **6.** As there shown, the orifice member **54** includes a base portion **55** including an annular peripheral rim **56** and three inwardly extending radial spiders **58** interconnecting the rim and a cylindrical projection **57** which extends forwardly of the base. The orifice plate is mounted in the gun with the rear face **61** of base portion **55** in abutment with the forward face **62** of the tip member **47.** Rim **56** of orifice member **54** is partially telescopically received within a rearwardly extending flange **63** of collar member **42.**

Collar member **42** includes a transverse wall **64** having a central bore **65** of slightly larger diameter than the diameter of cylindrical projection **57.** This bore is at least partially in registry with flow passageways **60** defined by the inner face of rim **56,** spiders **58** and projection **57,** the wall of bore **65** together with the outer periphery of projection **57** defines an annular film-forming flow channel **68.** Preferably this channel is between 0.005 inch and 0.050 inch in thickness.

Two diametral cross slots **41** are milled in the forward face of the collar member. These slots extend across the complete diameter of the collar member and are cut completely through a forwardly extending rim or flange **71.** In one preferred embodiment each of the slots is 0.13 inch wide and 0.015 inch deep as measured from the forward face of transverse wall **64.** In this same embodiment the diameter of projection **57** is equal to 0.120 inch while the diameter of collar opening **65** is 0.160 inch so that the annular film-forming channel **68** is 0.20 inches in thickness. It is obvious that inwardly connected air passageways of these configurations than slots **41** can be utilized if desired.

In this same preferred embodiment, the length of projection **57** is such that it terminates just forwardly of transverse wall **64** when the collar and orifice plate are assembled. However, this projection can extend further forwardly of the transverse wall, can terminate flush with the forward face of wall **64** of even slightly behind it if desired.

The forward face of the coller member **42** abuts an annular ring **72** which in turn abuts nozzle member **15.** This ring **72** is centered with respect to collar member **42** by engagement of the periphery of the ring with the inner wall of forwardly extending flange **71** of the collar member. The rear face **73** of the ring **72** engages the four quadrantal pad-like portions **74** formed on the forward face **64** of the collar member in the areas between the cross channels **41.** Thus, the ring cooperates with the collar to form four radial air injection channels interconnecting chamber **40** with annular paint flow passage **68.** It is to be understood that this ring can be formed integral with nozzle member **15** as desired. Nozzle member **15** is telescopically engaged by a rim **69** formed on ring **72.**

Nozzle member **15** further includes a forwardly extending cylindrical bore, or passage, **75** which adheres from a maximum diameter section **89** to the size of orifice **78.** The diameter of section **89** is equal to that of central bore **65** in the collar member and opening **79** in ring **72.** In a preferred embodiment orifice **78** is 0.035 inch in diameter and passes through a wall section 0.035 inch thick. The nozzle member protrudes through a central opening **76** in retaining nut **77** with the outer end of the nozzle having orifice **78** being disposed forwardly of the end of nut **77.**

The nozzle member **15,** ring **72,** collar **42** and orifice plate **54** are held in stacked relationship against one another and against tip member **47** by the retaining nut **77.** The forward end of this nut is provided with a recessed shoulder **82** which abuts an annular shoulder **83** formed on the forward portion of nozzle base member **87.** The opposite end of the retaining nut is provided with internal threads as at **84** for engagement with a threaded cylindrical extension **85** on barrel member **14.**

In operation, trigger **18** is pressed to open air valve **23** and paint valve **44.** Paint under a pressure of from 30–80 psig flows past open needle valve **44** and through the discharge opening in the tip member **47.** Paint passes through flow openings **60** in the orifice plate **55** and enters annular film-forming channel **68** formed between projection **57** and the surrounding spaced wall of the collar member **42.** Air under pressure flows past needle valve **35** through passageways **36** and **38** into chamber **40** and, hence, radially inwardly along four channels formed by cross slots **41.** The pressure of the air line is regulated by needle valve **35** so that the pressure of the air at the ends of the air injection slots **41** where the air intersects the paint film in flow channel **68** is slightly greater, e.g., 2 psi greater, than the paint pressure in the flow channel.

Air emerging from the inner ends of slots **41** intersects the annular film of paint and is sheared off in the form of a myriad of entrained microbubbles in the paint. The paint with the entrained air bubbles moves forwardly as a froth through the chamber provided by the opening **79** in ring **72** and the passageway **75** formed in the nozzle. As the froth moves toward the orifice **78** in the nozzle, the pressure in the froth gradually decreases so that the bubbles tend to expand slightly, thereby tending to make the froth more uniform or homogeneous. Also, while there is a slight turbulence within the nozzle which aids to some extent in rendering the froth homogeneous, the turbulence is not of a sufficient magnitude to appreciably lower the stagnation pressure.

As the froth exits from orifice **78**, the bubbles, which are still pressurized at the critical pressure which is approximately six-tenths of the paint pressure in the channel, are surrounded by atmospheric pressure, the bubbles rapidly expand fragmenting the surrounding paint into uniform small droplets believed to be of the order of from 10 to 100 microns. The spray of paint thus formed moves forwardly from the nozzle toward the target to be painted. The spray contains a relatively small quantity of air, for example, the mass ratio of air-to-paint is in the range of 0.5 to 1.6.

As was indicated above, this general atomizing structure, i.e., the annular film-forming flow chamber, the inwardly-directed air injection ports, and a nozzle having an orifice and a froth-homogenizing chamber intermediate the air injection area and the orifice can be utilized without the remaining elements of the spray gun to spray other types of material, such as fuel oil in a commercial burner, fuel oil for an automobile engine, water for environmental control apparatus, liquids for spray drying and the like.

Another form of spraying equipment embodying the present invention for spraying any of these latter materials is shown in FIG. **8, 9** and **10**. As there shown, the apparatus comprises a body **100** formed of two sections **101** and **102**. Section **101** is provided with a generally rectangular recess **103** along the inner face in abutment with the planar face **104** of body section **102**.

This recess together with face **104** constitutes a flow passage **106** including a film forming area, an air injection area, a homogenizing flow space, and a discharge orifice. Passage **106** extends from the interior of the spray unit body **100** to forward face **105** of the body and is preferably from 0.005" **to** 0.050 inch in thickness. In one preferred embodiment the width of the flow passage formed between the two members is approximately 1.5 inches, while the length of the passage from the air injection area to the discharge orifice is approximately 0.3 inch. The inner ends of the passage may be rounded as shown at **107** in FIG. **8**. A liquid inlet passage **108** and an air inlet passage **110** are formed in body member **102**. These passages are connected in any suitable manner to liquid and air supply lines respectively. These supply lines (not shown) are supplied respectively with liquid, such as fuel oil, water, or the like, under a pressure of from 30 to 100 psig and with air or other gas also under pressure.

In the embodiments shown, liquid flows through conduit **108** to liquid supply bores **111** which are 0.060 inch in diameter and which is open into passage **106** 0.010 inch in thickness. In this passage, the liquid spreads out to form a film and flows outwardly to the discharge orifice.

Air is introduced through conduit **110** which is connected to any suitable source of compressed air. Air flows from conduit **110** through an air injection slot **112** which is 0.030 inch in width and which interconnects the conduit with passage **106** intermediate fluid inlet port **108** and the exit orifice **113**.

The air pressure in conduit **110** is regulated so that the pressure of the air in port **112** is preferably slightly in excess, e.g., 2 psi, of the pressure in the paint adjacent the discharge end of injection port **112**. Air is thus forced from injection port **112** into the film of paint. The air is sheared off in the form of a myriad of microbubbles which become entrained in the paint film converting it to a froth. This froth flows outwardly toward exit orifice **113**. As it moves forwardly, the pressure of the forth decreases, but does not drop below the critical pressure which is approximately six-tenths the pressure of the liquid in bore **111**. During the travel of the froth toward the orifice slot, the froth homogenizes. When it leaves the exit orifice the entrained air bubbles which have been maintained under the critical pressure are suddenly subjected to atmospheric pressure. These bubbles expand rapidly and burst to break up the liquid into a fine spray which is projected forwardly from the slot.

From the above disclosure of the general principles of the present invention and the above detailed description of two embodiments, those skilled in the art will readily comprehend various modifications to which the invention is susceptible. Thus, for example, in apparatus of the type shown in FIGS. **8–10** it may be found desirable in some cases to provide a second air injection channel **112** opening into flow passage **106** from the opposite side of channel **112** (from the bottom in FIG. **10**). If such a second air injection slot is provided, it is formed in body section **101**. It is identical with air injection slot **112** and is fed through a second conduit **110**. The second injection slot extends transversely of passage **106** parallel to slot **112** and is positioned either slightly rearwardly or forwardly of the slot **112** with no overlap between the slots.

Having described our invention, we claim:

**1.** A method of atomizing a liquid, said method comprising the steps of

injecting a plurality of microbubbles of gas into a stream of liquid to form a froth,

said froth consisting of a mixture of gas and liquid in which the mass ratio of gas to liquid is in the range of 0.1 to 1.6,

causing said froth to flow through a confined space toward a discharge orifice therein,

causing said froth to flow outwardly through said orifice whereupon the entrained bubbles expand and burst to break up said liquid into a spray of fine particles.

**2.** The method of claim **1** in which said confined space is defined by smooth walls so that no substantial turbulence is introduced into the froth.

**3.** The method of claim **1** in which said liquid is subjected to a pressure of from **30–100** psi immediately prior to the froth formation.

**4.** The method of claim **3** in which the gas pressure, when injected into the liquid, is slightly higher than the liquid pressure.

**5.** The method of claim **1** in which the pressure on said froth as it flows through said confined space is gradually reduced.

**6.** The method of atomizing a liquid, said method comprising the steps of

forming a thin film of said liquid, causing said thin film to pass transversely of an air stream directed against said film to thereby inject a plurality of microbubbles of air into the thin film to form a froth,

causing said froth to flow through a confined space toward a discharge orifice therein,

causing said froth to flow outwardly through said orifice whereupon the entrained bubbles expand and burst to break up said liquid into a spray of fine particles.

7. The method of claim 6 in which said confined space is defined by smooth walls so that no substantial turbulence is introduced into the froth.

8. The method of claim 6 in which said liquid is subjected to a pressure of from 30–100 psi immediately prior to the froth formation.

9. The method of claim 8 in which the gas pressure, when injected into the liquid, is slightly higher than the liquid pressure.

10. The method of claim 6 in which the pressure on said froth as it flows through said confined space is gradually reduced.

11. The method of claim 6 in which said froth consists of a mixture of gas and liquid in which the mass ratio of gas to liquid is in the range of 0.1 to 1.6.

12. The method of claim 6 in which said liquid film is of an annular configuration.

13. The method of claim 12 in which the gas is injected from the outside of said annulus.

14. The method of claim 6 in which said film is a planar film and in which said gas is injected transversely of said plane.

15. The method of spraying paint, said method comprising the steps of

forming a thin film of paint, causing said thin film of paint to pass transversely of an air stream directed against said film to thereby inject a plurality of microbubbles of air into the thin film to form a froth,

causing said froth to flow through a confined space towards a discharge orifice therein,

causing said forth to flow outwardly through said orifice whereupon the entrained bubbles expand and burst to break up said paint into a spray of fine particles.

16. The method of claim 15 in which said confined space is defined by smooth walls so that no substantial turbulence is introduced into the froth.

17. The method of claim 15 in which said paint is subjected to a pressure of from 30–100 psi immediately prior to the froth formation.

18. The method of claim 15 in which the gas pressure, when injected into the paint, is slightly higher than the paint pressure.

19. The method of claim 15 in which the pressure on said froth as it flows through said confined space is gradually reduced.

20. The method of claim 15 in which said froth consists of a mixture of gas and paint in which the mass ratio of air to paint is in the range of 0.1 to 1.6.

21. The method of claim 15 in which the paint film is of an annular configuration.

22. The method of claim 15 in which air is injected from the outside of said annulus.

23. Apparatus for atomizing a liquid,

said apparatus having a gas conduit and a liquid conduit,

means communicating with said liquid conduit and de-fining a film-forming channel for said liquid, said channel having opposed walls,

means including an opening in one of said walls and in communication with said gas conduit for injecting bubbles of gas from said gas conduit into the liquid film formed in said film-forming channel to form a froth,

a member having an orifice,

a confined space intermediate said froth-forming means and said orifice through which froth flows with the entrained gas bubbles remaining under pressure, whereby when froth is dis-charged through the nozzle orifice the gas bubbles expand to break up the liquid into a spray of fine particles.

24. The apparatus of claim 23 in which said confined space is configured so that the pressure on said froth decreases as the froth flows toward the orifice.

25. The apparatus of claim 23 in which said film-forming channel is annular.

26. The apparatus of claim 25 in which the means for injecting bubbles of gas comprises radial channels directed inwardly toward the liquid film.

27. The apparatus of claim 23 in which said confined space is defined by smooth walls so that no substantial amount of turbulence is introduced into said froth.

28. The apparatus of claim 23 in which said film-forming channel is a straight channel having a closed end remote from said orifice and in which said liquid is introduced into said channel adjacent to the closed end thereof,

said gas being injected into said channel in a transverse direction intermediate said orifice and the region where said liquid is introduced into said channel.

29. the apparatus of claim 28 in which said orifice comprises an opening extending the full width of said channel.

30. Apparatus for atomizing a liquid comprising a body portion,

an air conduit through said body portion,

a liquid conduit through said body portion,

an orifice plate including a cylindrical projection,

a collar member, including a transverse wall having a central opening receiving said projection to define an annular film-forming channel,

the orifice plate having an opening extending therethrough to place said film-forming channel in fluid communication with said liquid conduit,

means defining an air injection channel opening adjacent to said film-forming channel,

said air injection channel being in fluid communication with said air conduit,

a nozzle member having a nozzle orifice formed therein,

means defining a confined passage between said film-forming channel and nozzle orifice.

31. The apparatus of claim 30 in which said air injection channel is formed as inwardly extending slot in said collar member.

32. The apparatus of claim 30 in which the walls of said confined passage are smooth so that no substantial turbulence is introduced into said froth.

33. A paint spray gun for spraying paint, comprising a body portion,

an air conduit through said body portion,

a paint conduit through said body portion,

an orifice plate including a cylindrical extension,

a collar member, including a transverse wall having a central opening receiving said extension to define an annular paint film-forming channel,

the orifice plate having an opening extending therethrough to place said paint film-forming channel in fluid communication with said paint conduit,

means defining an air injection channel opening adjacent to said paint film-forming channel,

said air injection channel being a fluid communication with said air conduit, a nozzle member having a nozzle orifice formed therein,

means defining a confined passage between said paint film-forming channel and nozzle orifice.

**34.** The paint spray gun of claim **33** in which said air injection channel is formed as inwardly extending slot in said collar member.

**35.** The paint spray gun of claim **33** in which the walls of said confined passage are smooth so that no substantial turbulence is introduced into said froth.

**36.** Apparatus for atomizing a liquid, comprising

a body portion,

an air conduit through said portion,

a liquid conduit through said portion, said liquid conduit terminating in a tip member having a liquid discharge opening formed therein,

an orifice member, said orifice member including a base portion having a rear face in engagement with said tip portion, a cylindrical projection extending forwardly of said base portion,

a collar member including a rearwardly extending flange embracing the periphery of said orifice base, and a transverse wall having a central opening receiving said projection to define an annular film-forming channel,

the orifice plate having a passageway extending therethrough to place said film-forming channel in fluid communication with the liquid discharge opening of said tip,

said collar member including a forwardly projecting peripheral flange, the forward face of the transverse wall or the collar member having an inwardly projecting slot formed therein and communicating with said central opening, said slot also extending outwardly through said forwardly projecting flange,

the forward face of said collar member being in abutment with a member overlying said slot to define an air injection channel,

means interconnecting the outer end of said slot with said air conduit,

nozzle means providing an internal passage and including a nozzle orifice, whereby when air is injected into said film of paint a froth is formed which flows outwardly through the space in said nozzle and when the froth is discharged from the nozzle orifice the air bubbles expand to break up the paint in a spray of fine particles.

**37.** The apparatus of claim **36** in which said collar member is provided with two diametral air injection slots in its forward face.

**38.** The apparatus of claim **36** further comprising a retaining nut surrounding said tip, orifice member, collar, and base of said nozzle member, said retaining nut defining an air chamber interconnecting the air conduit and said air injection channel.

**39.** The apparatus of claim **36** in which said retaining nut includes a shoulder engaging said nozzle member base for holding said nozzle member, collar and orifice member in stacked relationship against said tip member.

**40.** A paint spray gun for spraying a flat fan spray, said gun comprising

a body portion,

an air conduit through said portion,

a paint conduit through said portion, said paint conduit terminating in a tip member having a paint discharge opening formed therein,

an orifice member, said orifice member including a transverse base portion having a rear face in engagement with said tip portion, a cylindrical projection extending forwardly of said base portion,

a collar member including a rearwardly extending flange embracing the periphery of said orifice base, and a transverse wall having a central opening receiving said projection to define an annular film-forming channel,

the orifice plate having a passageway extending therethrough to place said film-forming channel in fluid communication with the paint discharge opening of said tip,

said collar member including a forwardly projecting peripheral flange, the forward face of the transverse wall or the collar member having an inwardly projecting slot formed therein and communicating with said central opening, said slot also extending outwardly through said forwardly projecting flange,

the forward face of said collar member being in abutment with a member overlying said slot to define an air injection channel,

means interconnecting the outer end of said slot with said air conduit,

nozzle means providing an internal passage and including a nozzle orifice, whereby when air is injected into said film of paint a froth is formed which flows outwardly through the space in said nozzle and when the froth is discharged from the nozzle orifice the air bubbles expand to break up the paint in a spray of fine particles.

**41.** The paint spray gun of claim **40** in which said collar member is provided with two diametral air injection slots in its forward face.

**42.** The paint spray gun of claim **40** further comprising a retaining nut surrounding said tip, orifice member, collar, and base of said nozzle member, said retaining nut defining an air chamber interconnecting the air conduit and said air injection channel.

**43.** The paint spray gun of claim **40** in which said retaining nut includes a shoulder engaging said nozzle member base for holding said nozzle member, collar and orifice member in stacked relationship against said tip member.

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