

[54] **INJECTION SPRAY SYSTEMS**  
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[58] Field of Search.....**239/13, 135, 136, 239/5, 533, 534, 506**

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[57] **ABSTRACT**

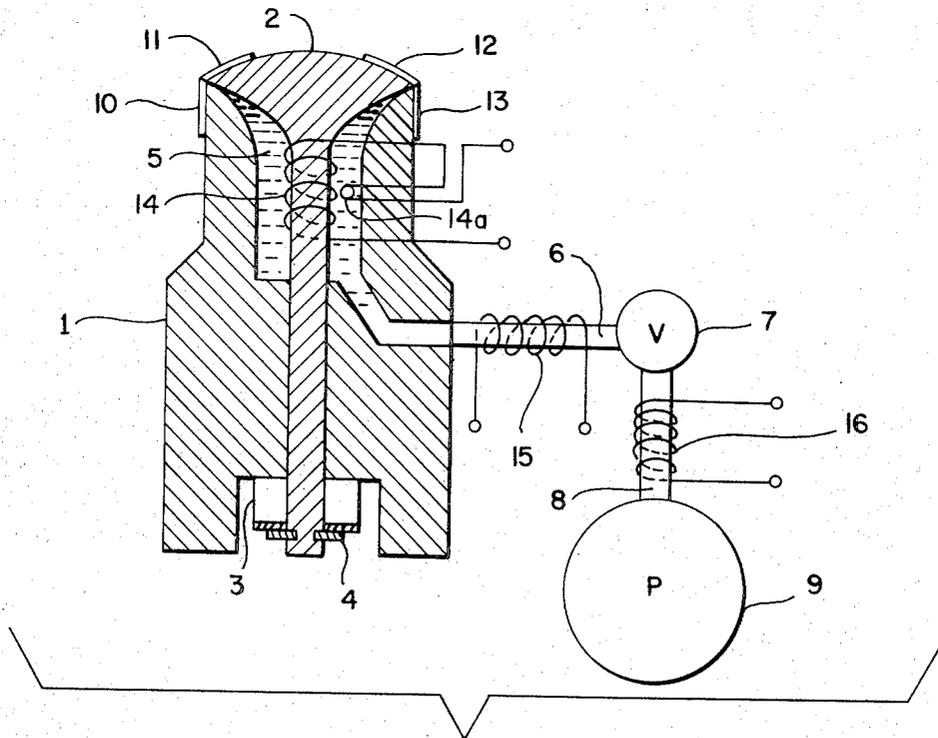
Injection spray systems and methods are disclosed for spraying heated and pressurized liquid through a nozzle orifice to produce very fine spray droplets. The pressurized liquid is heated to a temperature above ambient temperature whereby the vapor pressure of the liquid exceeds the pressure outside of the nozzle orifice so that discharge of the heated and pressurized liquid through the orifice produces very fine droplets.

**5 Claims, 3 Drawing Figures**

[56] **References Cited**

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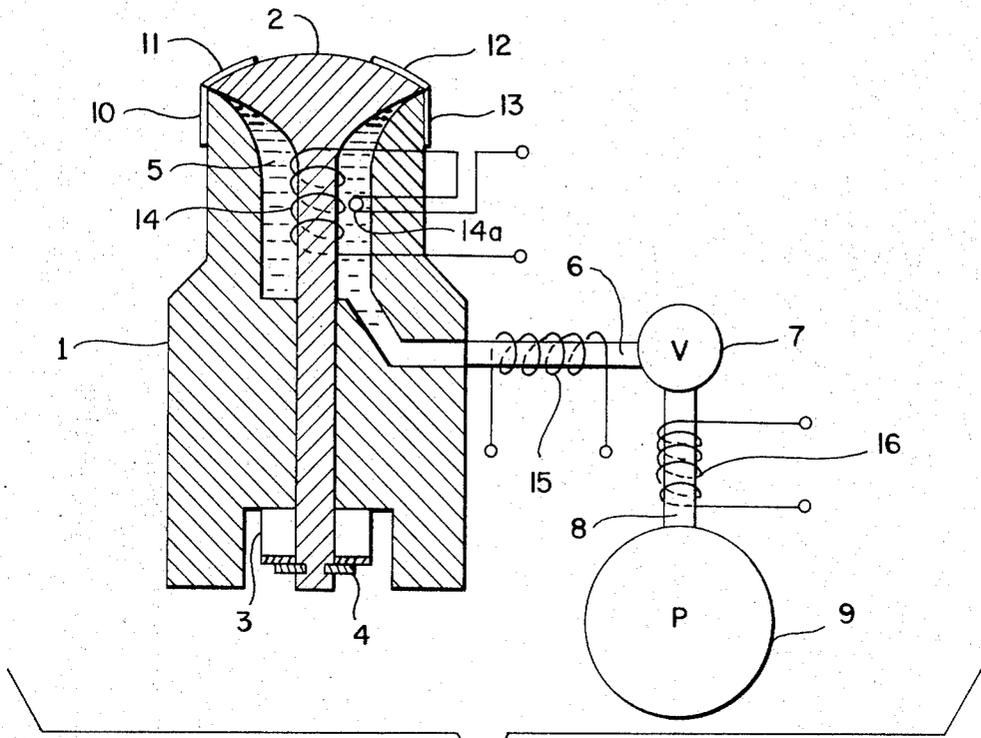


FIG. 1

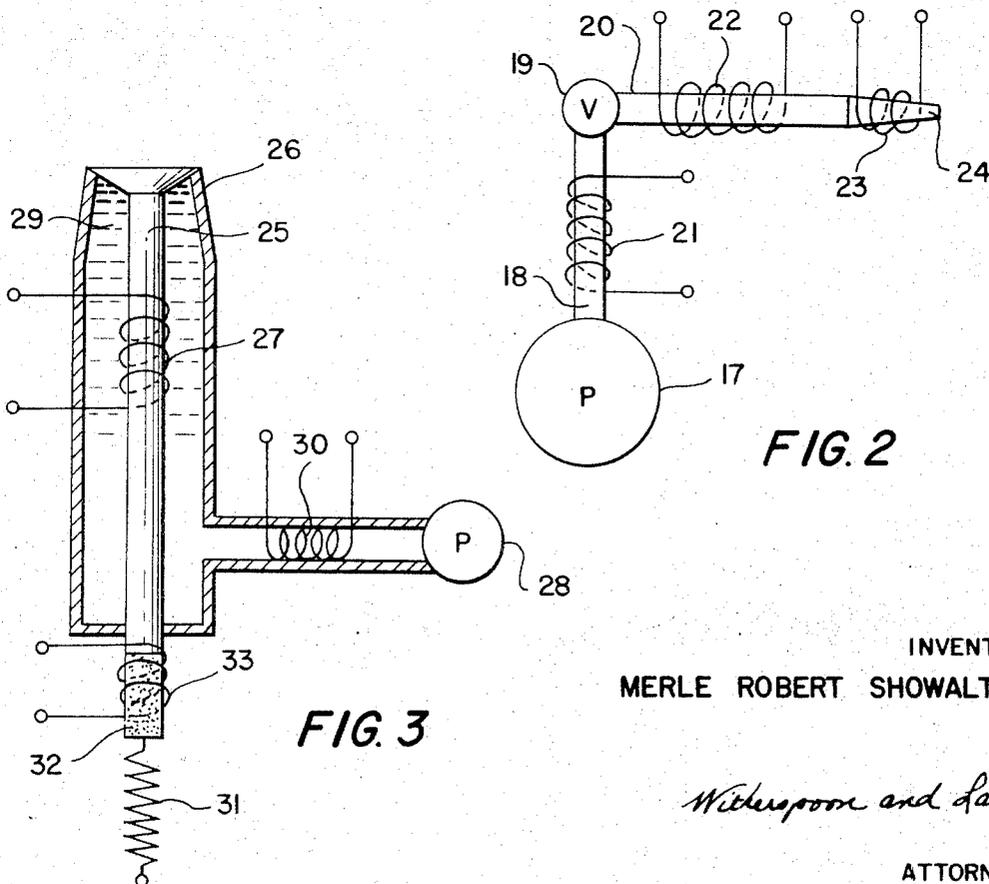


FIG. 2

FIG. 3

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## INJECTION SPRAY SYSTEMS

## SUMMARY OF THE INVENTION

The present invention relates to injection spray systems which produce fine sprays simply and with low energy requirements. The inexpensive production of very fine sprays is quite important to air pollution control. In most types of burners fine sprays will make possible complete combustion, since small fuel droplets vaporize and mix with air more quickly and completely than large droplets. Fine sprays also increase the efficiency of stack gas scrubbers. Spray systems which produce fine droplets are also important in any application where production of aerosols is useful, or where intimate mixing of two fluids is required.

Fine spray producing systems have commonly had relatively narrow spray flow ranges because spray nozzles capable of producing fine sprays have had single sized orifices. Flow through an orifice of constant area is proportional to the square root of the pressure drop across the orifice, so that an X-fold increase in flow rate requires an X<sup>2</sup>-fold pressure increase. The present invention discloses injection spray nozzles which have a characteristic opening pressure  $P_0$  where the spray orifice is elastically forced closed below  $P_0$  and opened proportional to pressure  $P$  minus  $P_0$ , where  $P$  is the pressure of the liquid in the nozzle, so that flow  $f$  equals  $f = K(P - P_0)^{3/2}$  where  $P > P_0$

$f = 0$  where  $P \leq P_0$  Thus variable orifice spray nozzles make possible injection spray systems with wide flow ranges for relatively small pressure variations. For instance, with  $P_0 = 20$  psia, a pressure change from 21 psi to 40 psi produces a 90 fold flow variation. The exponent 3/2 in the flow equation can be increased or decreased by using a nonlinear force curve spring.

In the preferred form of the invention, the fluid to be sprayed is heated to a temperature where the vapor pressure of the fluid exceeds the pressure in the space into which it is to be sprayed but is less than the opening pressure  $P_0$  of the nozzle. When the liquid leaves the nozzle orifice it boils instantly, making the effective viscosity and surface tension of the fluid in and past the spray orifice very small whereby the liquid breaks up into extremely small drops. Liquids can be broken up into tobacco smoke sized droplets for high flow rates and low pressures in this way. The size of the spray droplet distribution depends on the difference between the pressure in the space into which the nozzle sprays and the vapor pressure of the liquid at the spray orifice; the greater the excess of liquid vapor pressure over ambient pressure, the smaller the droplets. To produce smoke sized sprays (mass mean droplet diameters of a micron and less) generally requires that the liquid be heated to its boiling point and then enough extra heat added to equal 5-10 percent of the heat of vaporization of the liquid. The amount of heat required to produce ultrafine sprays varies from liquid to liquid. For years it has been known that a spray system spraying a liquid with a vapor pressure insufficient alone to open the spray system but in excess of the pressure of the space into which the system sprays will produce fine sprays efficiently. Aerosol cans which spray deodorant, paint, etc., work on this principle, by boiling freon or a hydrocarbon which boils below atmospheric temperature and pressure as it sprays into the atmosphere. However, the use of this principle for liquids which do

not boil at normal atmospheric temperatures and pressures in new. The use of a controlled heat input to a pressurized spray system permits the flashing principle to be used for spraying any liquid. This is a substantial advance in the art of spray devices, especially for spraying liquids with low boiling points, or for spraying liquid fuels into combustion systems.

In all spray nozzles, fluid buildup just outside the spray orifice will impede spray performance causing nozzle drip and/or large drops rather than the desired small drops. Heating the sprayed liquid and the nozzle so that fluid buildup does not occur or evaporates quickly is one way of eliminating the problem. Making the nozzle area subject to deposits of a substance with surface properties which resist wetting by the liquid being sprayed also reduces the problem. The fluid buildup problem can also be attacked by producing gas bubbles in the fluid before ejection; these bubbles pop on fluid ejection, and the gas blows away the fluid buildup. Bubbles can also greatly reduce mean droplet size under certain temperature, pressure, and flow conditions. Fluid buildup can also be reduced by vibrating the nozzle with a mechanical oscillator arrangement.

In view of the above it is an object of this invention to provide an injection system and method for spraying liquids from a nozzle to form small droplets wherein pressurized liquid heated to a temperature sufficiently high so that the vapor pressure of the liquid exceeds the pressure outside of the nozzle is forced through the nozzle to produce small droplets.

It is another object to provide an injection system for spraying liquids from a nozzle having a variable orifice to form small droplets wherein pressurized liquid is heated to a temperature sufficiently above ambient temperatures so that vapor pressure of the liquid exceeds the ambient pressure so that the heated and pressurized liquid may be discharged through the variable orifice which is responsive to the pressure of the liquid in the nozzle to form small droplets and vapor.

It is yet another object to provide an injection system as in the foregoing objects and wherein means are provided for controlling the pressure of the liquid and thus control the opening of the variable orifice.

It is a still further object to provide an injection system for producing small droplets wherein a pressurized fluid made up of liquid with bubbles therein is discharged through a variable orifice which is responsive to pressure to produce small droplets.

The above and additional objects and advantages of this invention will become more apparent when considered in light of the foregoing detailed description and drawing showing by way of example several embodiments of this invention.

## IN THE DRAWINGS

FIG. 1 is an assembly view of one embodiment of this invention showing the nozzle assembly in cross section,

FIG. 2 is an assembly view of another embodiment of this invention wherein a different type of nozzle is employed, and

FIG. 3 is an assembly view of yet another embodiment wherein a solenoid is used to operate the pintle of the nozzle to control orifice size.

## DETAILED DESCRIPTION

Referring now to the drawings, FIG. 1 is a cross sectional view of a spray system with a conical spray injection nozzle having a spray orifice varying with nozzle input pressure, and with means for heating the liquid in the spray system to a temperature where its vapor pressure exceeds the pressure of the space into which the system sprays. Nozzle body 1 contains and seats valve shaped nozzle pintle 2 which is elastically forced against the open body portion to close same by means of compression spring 3 which is compressed between body 1 and pintle 2 by means of clamp washer 4. The internal clearance between nozzle body 1 and pintle 2 forms fluid chamber 5 which is fluidly connected to pressurized fluid source 9 through line 8, control valve 7, and line 6. The operation of the system is as follows: fluid pressure in chamber 5 controlled by means of valve 7 tends to raise pintle 2 off body 1. Any clearance between the upper part of body 1 and pintle 2 forms a spray orifice producing a disc shaped or conical spray pattern. Below a certain critical pressure  $P_0$  the compression of spring 3 keeps the nozzle spray orifice closed and the nozzle produces no spray. As pressure in chamber 5 rises above pressure  $P_0$  pintle 2 rises off body 1 and liquid is discharged therefrom. For linear constant springs a linear pressure increase of pressure  $P$  above  $P_0$  produces a linear increase in nozzle spray orifice size, so that liquid flow through the nozzle obeys the relation  $f(P - P_0)^{3/2}$ . The nozzle is therefore able to spray over a large flow range for a small pressure range.

The operation of the nozzle in FIG. 1 is sometimes impeded by fluid buildup on the outside of the nozzle around the spray orifice, which causes large droplets and nozzle drip. Machining so that pintle 2 and body 1 fit smoothly around the orifice and are closely aligned reduces this problem. In FIG. 1, outside nozzle surfaces around the spray orifice are treated with coating 10, 11, 12 and 13. This coating is of a substance which resists wetting by the fluid being sprayed (this substance would be hydrophobic for a nozzle spraying water and hydrophilic for a nozzle spraying oil). This coating resists the formation of fluid buildup.

The spray system in FIG. 1 has means for heating the liquid to be sprayed to a temperature where the vapor pressure of the liquid exceeds the pressure in the space into which the nozzle sprays, so the liquid boils on ejection from the nozzle, producing extremely small droplets. Heat is added by heating coils 14, 15 and 16. Temperature of the liquid is controlled so that the liquid temperature produces a vapor pressure which exceeds the pressure into which the system sprays but is less than the nozzle opening pressure  $P_0$ . Increasing the tension of spring 3 to increase  $P_0$  increases maximum permissible temperatures and vapor pressures. Heat can be added before the choking valve 7, as by coil 16; after the valve but before the nozzle, as by coil 15; in the nozzle itself, as by coil 14, or by some combination of these. A variable thermo control element 14a may be provided in the heating coil 14 circuit and placed in the chamber 5 to control the temperature of the liquid therein. Similar control arrangements may be used in conjunction with heating coils 15 and 16 as required. The heat addition and control systems can be designed in many ways, but in any case the temperature of liquid

and nozzle must be maintained so that liquid vapor pressure at the orifice itself exceeds the pressure into which the system sprays, or the spray will not flash, boil and break into extremely small droplets. This in practice often means that the nozzle should be separately heated. Vapor pressure must be below  $P_0$  or it will be impossible to turn the system's flow off quickly. When the vapor pressure of the fluid is within this proper range small droplets are produced, with mean droplet size decreasing as the difference between vapor pressure and space pressure increases, and fluid buildup outside of the nozzle is minimized or eliminated.

By controlling the temperature and pressure ranges in the system in FIG. 1 the fluid sprayed through the nozzle can be made to be a mixture of liquid and gas in the form of tend These bubbles tend to make the nozzle self cleaning and to produce small droplets. Heating the fluid in line 16 to a temperature which corresponds to a vapor pressure somewhat higher than the pressure in line 6 and chamber 5 will cause many bubbles to be produced as the hot liquid passes from valve 7, and bubbles will form until equilibrium between pressure and vapor pressure is again established in line 6 and chamber 5. Various other means of generating bubbles are well known to the fluidic arts and can be added to the structure of FIG. 1.

Various modifications of the structure in FIG. 1 suggest themselves. Other structures for controlling input pressure to the nozzle can obviously be substituted for system 6, 7, 8, and 9. Compression spring 3 can easily be changed for a coil spring, the shape of nozzle body 1 and pintle 2 can be modified, and various methods of alignment of 1 and 2 can be substituted for the alignment arrangement of FIG. 1. Effective spray nozzles need not be radially symmetric and may spring from various shaped holes. The heating systems of FIG. 1 can also be changed: the lines, valve, or nozzle could be insulated to reduce heat losses to the outside, and the electrical heating means of FIG. 1 could be replaced or supplemented by other heating means (for instance heat pipes). Various methods of thermostatic control for the system are well known to the art of temperature control systems.

FIG. 2 shows a spray system with means for heating the liquid in the spray system to a temperature above atmospheric temperature where its vapor pressure exceeds the pressure of the space into which bubbles. system sprays which does not necessarily include a variable orifice nozzle. Liquid pressure source 17 is connected by line 18 through valve 19 to line 20 and nozzle 24. The liquid in the spray system is heated by means of heating coil 21 around or in line 18 and/or by heating coil 22 around line 20, and/or by heating coil 23 around nozzle 24. Nozzle 24 may be a fixed orifice or may utilize the same principles as the nozzle in FIG. 1 if the nozzle is made of an elastic material so that the spray orifice is closed below a certain pressure and opens with increasing pressure. Obviously, different nozzle types and methods of introducing heat can be substituted for nozzle 24 and heat coils 21, 22, and 23, as is the case in FIG. 1.

FIG. 3 shows a spray system where liquid vapor pressure is greater than the pressure of the space into which the system sprays and where flow may be controlled directly at the nozzle spray orifice. Pintle 25 rests in

nozzle body 26, the clearance between pintle and body forms a liquid chamber 29 which is heated by heating coil 27 and/or by heating coil 30 whereby the liquid temperature is high enough so that vapor pressure of the liquid is greater than the pressure of the space into which the nozzle sprays. Pintle 25 is held closed by the elastic tension of spring 31 and is mechanically connected to magnet 32 which is surrounded by magnetic coil 33 to form a solenoid assembly. Energization of coil 33 causes pintle 25 to rise and open the nozzle, this control of the current in coil 33 will control movement of the pintle and the spray volume controlled thereby, or if fluid pressure itself opens the nozzle, current oscillations in coil 33 can oscillate pintle 25 and disturb the spray flow streamlines, producing smaller droplets. The spray flow can be pulsed at various frequencies depending upon the pulsed energy supplied to coil 33 or can be made continuous as desired. Such pulsing can be employed to rapidly reciprocate the pintle 25 to vibrate the nozzle. If flow is pulsed, flow volume can be controlled by varying pulse duration, frequency, or amplitude. The opening and closing of the nozzle spray orifice can be controlled mechanically as well as electrically. Various means of accomplishing this are familiar to the fluidic arts, for instance in the art of fuel injection systems for engines.

In the detailed description of the invention and the claims the term "liquid" covers any combination of solids, liquids and gases which will act as a liquid such as stable slurries, gels, and colloids. The term "liquid" does not apply to the state of a substance above the critical point on a pressure-temperature three phase diagram.

The terms "atmospheric temperature" and "atmospheric pressure" refer to standard temperature and pressure (0° Centigrade and 760 mm. Hg.).

The term "entrainment" with respect to the spray orifice nozzle refers to the formation of liquid deposits adjacent or on the nozzle, which is the amount of washing.

The term "mass mean diameter" refers to the diameter of droplets in a spray distribution where the mass of liquid in droplets smaller than this diameter equals the mass of liquid in droplets larger than this diameter.

The term "stable aerosol droplets" refers to droplets so small that the aerodynamic drag of the droplets is so small that gravitational or ballistic settling is practically insignificant.

What is claimed is:

1. A method of forming liquid droplets and vapor by spraying a pressurized liquid where substantially all of the mass of the sprayed liquid is in droplets with a mass mean diameter less than 25 microns comprising the steps of:

pressurizing the liquid,  
 delivering the pressurized liquid to a nozzle assembly having a spraying orifice,  
 heating the liquid without involving chemical changes in said liquid and prior to discharge through the spray orifice to a temperature sufficiently above atmospheric temperature so that the vapor pressure of said liquid exceeds the pressure of the space into which the orifice sprays, controlling the heating of the liquid so that said liquid

is maintained in liquid state until discharge through the spray orifice, and discharging the heated and pressurized liquid through said spray orifice shaped to produce flow streamlines without substantial liquid entrainment on the outside surface of the spray orifice to form spray droplets having a mass mean diameter less than 25 microns.

2. The method as set forth in claim 1 and wherein the vapor pressure is increased to produce spray droplets having a mass mean diameter of less than 10 microns.

3. The method as set forth in claim 1 and wherein the vapor pressure is increased and the entrainment properties of said orifice surface are reduced to produce spray droplets having a mass mean diameter of less than 1 micron.

4. A method of forming droplets from a pressurized liquid said method comprising the steps of:

pressurizing a liquid,  
 delivering the pressurized liquid to a nozzle assembly having a variable orifice closed by elastic means and responsive to pressure,  
 controlling the pressure of the liquid delivered to the nozzle to determine orifice size,  
 heating the liquid prior to introduction into the orifice to a temperature above the temperature outside the orifice whereby the vapor pressure of the liquid exceeds the pressure outside the orifice,  
 controlling the heating of the liquid so that the vapor pressure of the liquid is less than the pressure required to overcome the closing force of the elastic means, thereby insuring that the liquid is maintained in liquid state until discharge through the variable orifice, and  
 discharging the heated and pressurized liquid through the orifice, said orifice being shaped to produce flow streamlines without substantial liquid entrainment on the outside surface of the spray orifice to form spray droplets having a mass mean diameter of less than 25 microns.

5. A method of forming liquid droplets and vapor by spraying a pressurized liquid where substantially all of the mass of the sprayed liquid is in droplets with a mass mean diameter less than 25 microns comprising the steps of:

pressurizing the liquid,  
 delivering the pressurized liquid to a nozzle assembly having a variable area spraying orifice,  
 heating the liquid without involving chemical changes in said liquid and prior to discharge through the spray orifice to a temperature sufficiently above the temperature immediately adjacent the orifice so that the vapor pressure of said liquid exceeds the pressure of the space into which the orifice sprays, controlling the heating of the liquid so that said liquid is maintained in liquid state until discharge through the spray orifice, and discharging the heated and pressurized liquid through said spray orifice shaped to produce flow streamlines without substantial liquid entrainment on the outside surface of the spray orifice to form spray droplets having a mass mean diameter less than 25 microns.

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