United States Patent [19]

Mee

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[45] **July 15, 1975**

[54] **NOZZLE FOR PRODUCING SMALL DROPLETS OF CONTROLLED SIZE**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 103,170, Dec. 31, 1970, Pat. No. 3,788,542.

[52] **U.S. Cl.** ..... **239/524;** 239/512; 47/2; 252/359 A; 239/2 R

[51] **Int. Cl.** **B05b 1/26;** E01h 13/00

[58] **Field of Search** ..... 239/2 S, 2 R, 3, 8, 11, 239/14, 102, 185, 200, 225, 461, 519, 521, 508–512, 522, 524, 518, 542, 587, 590.3, 601, 124, 421; 47/2; 252/359 R, 359 A

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[57] **ABSTRACT**

Control of temperature and humidity of an environment is obtained by injecting a large volume of water droplets into the air with a major portion of the water droplets being in the range of from about 5 to 50 microns in diameter and with an average diameter in the range of from about 10 to 30 microns. Fog having droplets in the above-mentioned size range is produced by impacting a stream of water at a velocity in excess of about 135 feet per second against a smooth, solid surface. Such impact causes the stream of water to separate into droplets in the selected size range. In one embodiment a nozzle having an orifice in the range of from about 125 to 400 micron diameter and operated at a pressure in excess of about 350 psi is used to create a water jet. A flat surface having substantially the same diameter as the orifice, normal to the orifice, closely aligned with the orifice, and spaced only a short distance from the orifice is employed for impacting the stream coming out of the orifice. In other embodiments a surface having compound convexity is arranged in front of the orifice at a distance of up to about 4 millimeters. The surface can be spherical, conical, or other convex shape. The nozzle body withstands pressures in excess of about 350 psi.

9 Claims, 8 Drawing Figures

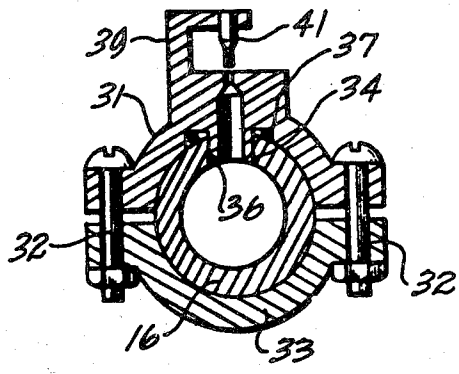


Fig. 1

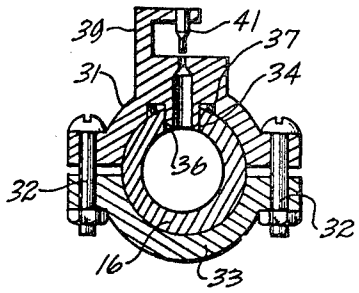


Fig. 5

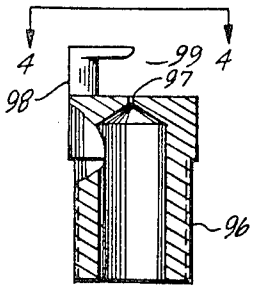


Fig. 6

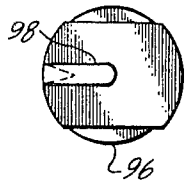


Fig. 2

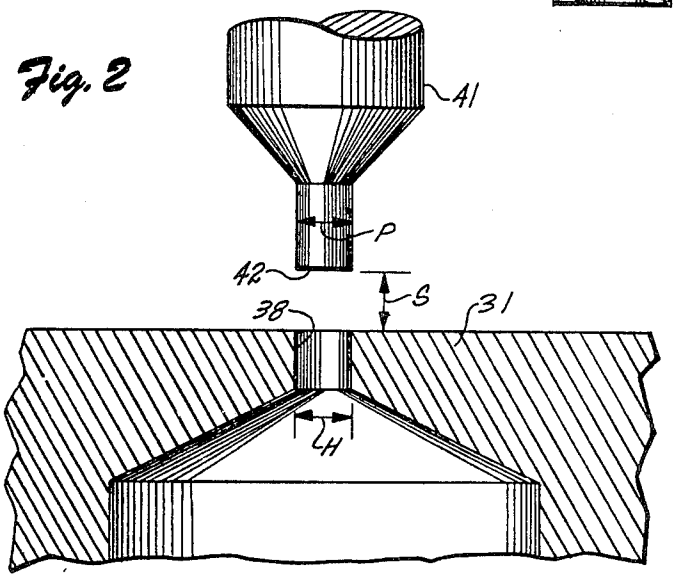


Fig. 3

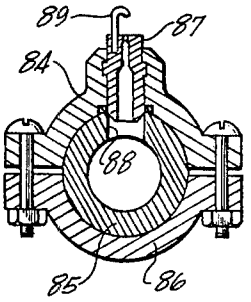


Fig. 4

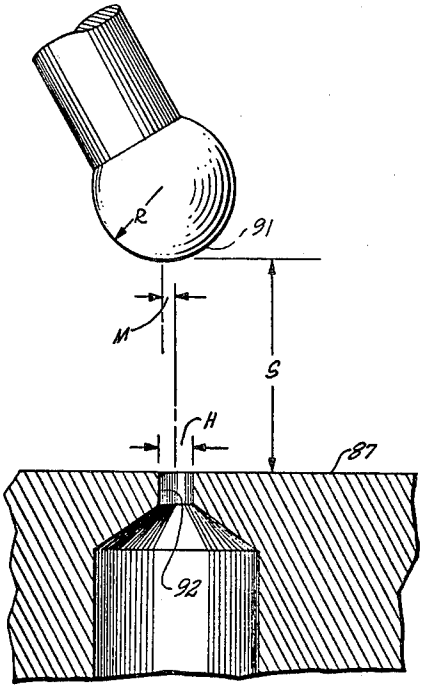


Fig. 7

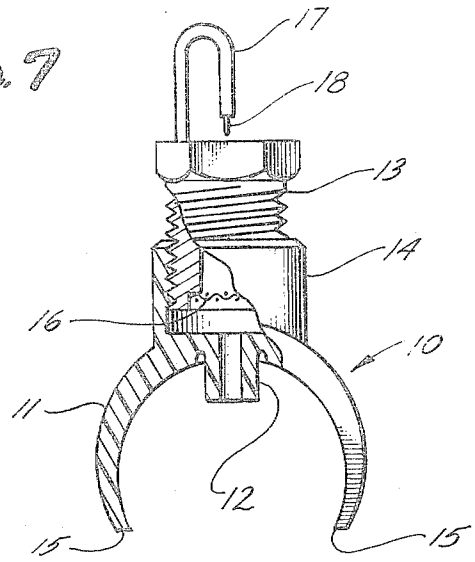
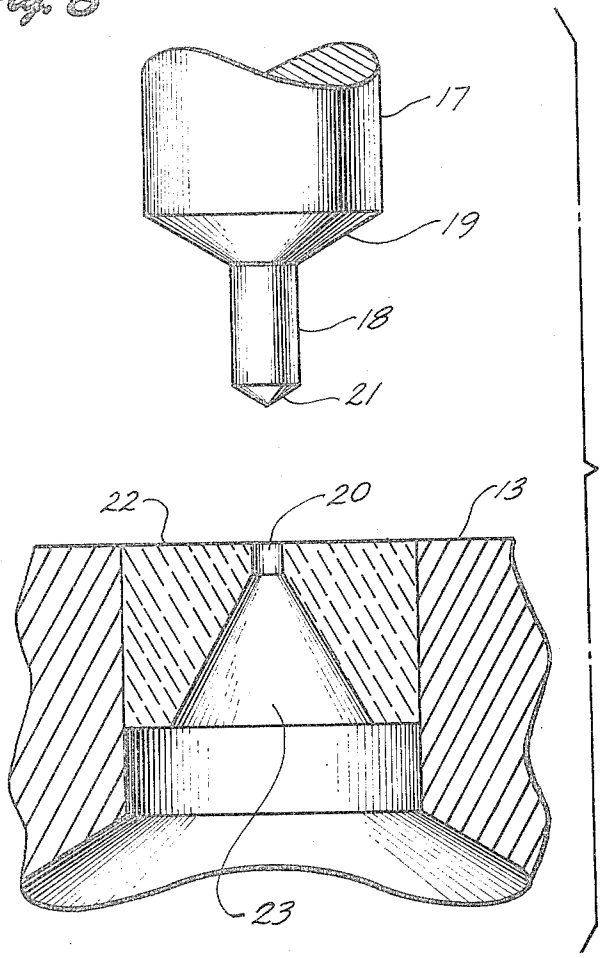


Fig. 8



NOZZLE FOR PRODUCING SMALL DROPLETS OF CONTROLLED SIZE

BACKGROUND

This application is a continuation-in-part of U.S. patent application Ser. No. 103,170 filed Dec. 31, 1970, now U.S. Pat. No. 3,788,542.

Evaporative cooling for reducing elevated temperatures in the environment has been attempted employing so-called pin nozzles for creating a fine spray of water distributed in the region to be cooled. Such an arrangement has been provided, for example, at market vegetable counters; however, such arrangements are not suitable for general environmental control. The difficulty with conventional pin nozzles has been that the spray produced is in the form of relatively large droplets that have a substantial fall velocity so that they settle out on the surrounding surfaces and are not readily available for direct evaporation from the droplets into the environment. In the prior art, all such arrangements have had sufficiently large droplets that a major portion of the water falls to the surrounding surfaces rather than appreciably cooling any mass of air.

It has been recognized that in order to provide protection to crops against frost damage that a blanket of dispersed material opaque to infrared radiation is effective. Cooling of crops in low temperatures occurs most rapidly when the air is clear and the heat stored in the crops and soil is radiated into space at a high rate. It has long been recognized that fog, or clouds or the like inhibit free radiation of infrared from the soil and crops and thereby inhibit frost damage.

In order to produce such clouds, burning of sooty materials such as oil or old tires has been employed, however, the contamination of the environment due to the sooty material is highly objectionable and the particle size in the smokes produced is generally too small to be of maximum effectiveness for inhibiting radiation in the infrared spectrum.

Cloud generators employing a mixture of combustible material and water have also been employed and produce large amounts of fog that is objectionable because of the pollution due to the burning oils employed, and further the energy requirements for the system is excessively high.

In another system, water and hexadecanol or cetyl alcohol has essentially been boiled to produce a fog. Such a fog has water droplets in the size range from about 1 to 10 microns which has high opacity for visible radiation but is relatively transparent to infrared. Further, such a fog is relatively warm due to the required heating and tends to rise away from crops so that the protection is minimized, and fog must be continually produced to replenish that lost. The energy requirements for such fog making are also excessively high since they approach that required to vaporize water, which has an extremely high heat of vaporization.

It is, therefore, desirable to provide a means for producing a large amount of water droplets having a size appropriate for rapid direct evaporation to provide environmental cooling. In other situations droplets in the same size range are suitable for scattering infrared radiation for protecting crops against frost damage. In either case, for environmental cooling or freeze protection, the system should provide droplets small enough that the fall velocity is low and the droplets do not, in general, fall to the surfaces in the region where the environment is being controlled. Preferably, the means is operated with low energy requirements for minimized operating cost.

BRIEF SUMMARY OF THE INVENTION

Therefore, in practice of this invention according to a presently preferred embodiment there are provided nozzles impacting a stream of water having a velocity in excess of about 135 feet per second against a smooth, solid surface. Such impacting can, for example, be obtained by squirting water through an orifice diameter at a pressure in excess of 350 psi and impacting the stream on a flat surface substantially the same diameter as the orifice, and normal thereto and closely aligned therewith. Similarly, the stream from such an orifice can be impacted against a smooth, solid surface having complex convexity and spaced several millimeters from the orifice. Directional control of the fog produced is obtained by offsetting the center of curvature of the convex surface from the axis of the jet of water.

DRAWINGS

These and other features and advantages of the present invention will be appreciated as the same becomes better understood by reference to the following detailed description of a presently preferred embodiment when considered in connection with the accompanying drawings wherein:

FIG. 1 illustrates one embodiment of nozzle constructed according to principles of this invention;

FIG. 2 is an enlarged detail of the nozzle of FIG. 1;

FIG. 3 illustrates in transverse cross section another embodiment of nozzle constructed according to principles of this invention;

FIG. 4 is an enlarged detail of a portion of the nozzle of FIG. 3;

FIG. 5 illustrates in transverse cross section another embodiment of nozzle;

FIG. 6 is a top view of the nozzle of FIG. 5;

FIG. 7 is an end view, partly in cross section, of another embodiment of saddle tee and nozzle: and

FIG. 8 is an enlarged detail of the nozzle of FIG. 7.

DESCRIPTION

In order to obtain optimum cooling or frost protection, the droplet size of water sprayed into the environment should be small so that evaporation can proceed rapidly and completely before the droplets have a chance to fall to ground level or contact other surfaces to which the water adheres and is thereby made relatively unavailable for evaporative cooling or frost protection. If droplets are larger than about 50 microns in diameter their fall velocity is sufficiently high that a substantial proportion of the droplets reach the ground.

In order to assure evaporation in relatively higher humidity environments or at lower temperatures, it is preferred that the droplet size be as small as possible to present the greatest surface to volume ratio of the droplets. It is found, however, that in order to decrease the droplet size much below about 5 microns the energy requirements become excessive since the curvature of the droplet surfaces is high and high surface energies are involved. It is, therefore, preferred in practice of this invention to inject water droplets into the environment wherein a major portion of the droplets have diameters in the range of from about 5 to 50 microns. If the diameter of a large portion of droplets is

appreciably less than about 5 microns the energy required to produce the droplets is uneconomically high, and if the droplets are larger than about 50 microns the fall velocity is too high for effective environmental control.

In producing a fog of droplets not all of the droplets have the same diameter, and a range of diameters is actually obtained. It is found to be important that the average diameter of the droplets in the fog be in the range of from about 10 to 30 microns, that is, for example, when the fog has an average droplet diameter of 15 microns, approximately half of the droplets have diameters smaller than 15 microns and approximately half have diameters larger than 15 microns. In a fog having such a size distribution of droplets as provided in practice of this invention, it is found that the mass median diameter is about 30 microns, that is, half of the mass of water in the fog is in droplets having diameters larger than about 30 microns and half of the mass is in droplets having diameters less than about 30 microns.

When the average droplet diameter is less than about 10 microns, the energy requirements for forming the droplets are excessively high because of the high surface energy of the highly curved small droplets. It is, therefore, important that the major portion of droplets have diameters in excess of about 5 microns, and that the average droplet diameter be greater than about 10 microns. The average droplet diameter should also be less than about 30 microns, and the major portion or droplets have diameters less than about 50 microns. When the average diameter exceeds about 30 microns, the mass of water contained in relatively larger diameter droplets becomes high and the rate of evaporation is thereby lowered. The larger diameter droplets also have a higher fall velocity and these two factors can in many circumstances result in undue settling of fogs produced, thereby wetting surrounding surfaces without achieving desired environmental control.

Since it has been found that fog having the above identified size characteristics is important for environmental control, means are provided in practice of this invention for producing such a fog of fine droplets.

FIG. **1** illustrates in transverse cross section an embodiment of fog producing nozzle constructed according to principles of this invention and capable of producing a major portion of droplets in the size range of from about 5 to 50 microns and having an average droplet diameter in the range of from 10 to 30 microns. As illustrated in this embodiment, the fog nozzle **17** is in the general form of a saddle tee having a plastic body **31** capable of withstanding an internal pressure of at least 350 psi and preferably in excess of about 500 psi since it is found that pressures in this range are important in practice of the invention. The plastic body **31** is secured to a pipe **16** by a pair of bolts **32** and a U-shaped bracket **33** on the opposite side of the pipe from the body. A small internal tubular extension **34** on the body is inserted in a hole **36** drilled through the side of the plastic pipe. The body is sealed to the pipe by an O-ring **37** around the extension **34.**

A small orifice **38,** better seen in the enlarged view of FIG. **2,** is provided between the interior of the body **31** and the exterior. The length of the small orifice **38** is not extremely critical but it should be short enough that fluid friction is not excessive and should be longer than mere knife edge, which as a practical matter would not be obtained without special processing. The orifice geometry should be such that there is laminar flow of water through it at the high velocities and pressures involved in such nozzles. Control of droplet size is difficult and an excess of large droplets are obtained if flow through the orifice is turbulent.

The diameter H of the orifice is of importance, and should be in the range of from about 125 to 400 microns so that a stream of water passing through the orifice has a diameter in this range. If the orifice has a diameter less than about 125 microns, several disadvantages accrue. Such a small orifice is particularly susceptible to plugging due to small particles, corrosion products or the like, and orifices larger than this are less susceptible to plugging. A smaller orifice is also much more difficult and expensive to form. Most particularly, however, the quantity of water that can be forced through the orifice at reasonable pressures when it is less than about 125 microns is quite small and an excessive number of nozzles would be required in order to obtain a practical total volume of water from a system. Thus, if the orifices are less than about 125 microns in diameter, the nozzles are more expensive to make and a considerably increased number of them are required. Additionally, when the orifice size is reduced below about 125 microns, the droplets formed by the nozzle are somewhat smaller and hence have a greater surface energy, thereby increasing the energy requirements to properly operate the nozzle. Thus, for numerous reasons, it is found that a minimum orifice diameter of about 125 microns is critical.

The maximum practical diameter of the orifice is about 400 microns, although this limit has not been determined with precision. It is known that an orifice having a diameter of about 250 microns is eminently satisfactory at water pressures in excess of 350 psi, and that an orifice having a diameter of 500 microns is not satisfactory at pressure as high as 1,000 psi. The larger diameter orifice results in a substantial number of droplets in the resultant fog having diameters greater than about 50 microns and these are beyond the preferred range described hereinabove.

The purpose of the orifice **38** is to obtain a high velocity stream of water having a diameter in the range of from about 125 to 400 microns. It is important that this stream of water have a velocity in excess of about 135 feet per second in order to produce fog droplets, a major portion of which are in the size range of from about 5 to 50 microns and which have an average diameter in the range of from about 10 to 30 microns. In order to achieve this high velocity in the small diameter stream, a pressure in excess of about 350 psi is required in the system, and preferably the pressures are in the range of about 350 to 500 psi. Higher pressures can be employed; however, the energy requirements for obtaining the high pressures are high and the slightly increased flow rate of water through the orifice does not justify the additional expense in the installation and operating costs.

In order to break the high velocity stream of water into droplets in the range of 5 to 50 microns, the stream is impacted against a smooth, solid surface that serves to spread the stream. In the embodiment illustrated in FIGS. **1** and **2,** an L-shaped arm **39** extending upwardly from the body **31** hooks over and supports a cylindrical pin **41** directly over the orifice **38.** The pin **41** has a smooth, flat end surface **42** substantially normal to the axis of the orifice **38.** The end surface **42** has a diame-

ter P substantially identical with the diameter H of the orifice **38**, that is, in the range of from about 125 to 400 microns. It is quite important that the flat surface **42** be carefully aligned with the orifice **38** so that the offset between the center of the surface and the axis of the orifice is less than about 15 microns. This close alignment is required so that the high velocity water stream is certain to impact the flat surface squarely so that very little, if any, of the stream can pass the surface without hitting or being deflected by it. If any significant quantity of the stream does pass the surface without impact, relatively large droplets are obtained outside the preferred range.

It might be supposed that criticality of alignment of the pin with the orifice could be minimized by employing a pin significantly larger in diameter than the orifice. A small enlargement can in fact be tolerated; however, as the diameter of the flat end of the pin is increased, the direction of spreading of water from the nozzle becomes flatter rather than a cone shape, thereby increasing the probability of the resultant fog droplets striking surrounding surfaces or interacting with droplets produced by adjacent nozzles. Larger diameters also tend to make the shape of the edge of the pin more critical since an irregularity in this edge may disrupt the uniform flow of water and cause a portion of the fog to have relatively large droplets outside the preferred range.

Concomitant with the requirement of close axial alignment of the end surface of the pin with the orifice is the requirement that the spacing S between the flat surface **42** and the orifice **38** be about the same as the diameters of the orifice and pin. This requirement arises from the fact that a high velocity stream of water such as emerges from the orifice tends to oscillate laterally at a frequency and amplitude depending on the size and velocity of the stream and the physical properties of the water. By maintaining the spacing S approximately the same as the diameter of the stream of water, the inherent oscillations do not cause the stream to deviate sufficiently that any significant fraction of the stream fails to impact or be deflected by the flat surface **42**.

When the high velocity water stream squarely impacts the surface **42** it is spread radially and travels outwardly a short distance as a continually thinning cone-shaped sheet. This radiating cone-shaped sheet of water also becomes thinner and oscillates as it travels radially, and in a short distance the oscillation builds to a point that the sheet breaks into a plurality of radiating filaments or tiny cylinders of water traveling at high velocity. These high velocity filaments in turn oscillate and in a short distance break up into a large number of individual droplets.

The diameter of the filaments formed as the sheet of water oscillates is dependent on the velocity of the water and also the thickness of the sheet. If the orifice diameter is too large, the thickness of the sheet is so great that the filaments formed upon breaking up of the sheet are too large to form droplets, the major portion of which are in the range of from about 5 to 50 microns and which have an average diameter in the range of from about 10 to 30 microns. Likewise, if the velocity of the stream of water is too low, the surface tension or surface energy properties of the water tend to pull the sheet together, i.e., make a steeper cone, or even cause the sheet of water to converge rather than diverge, and again the filaments formed are too large to break into droplets having a major portion in the range of from 5 to 50 microns. Thus, it is important that the water stream impacting on the solid surface be sufficiently small and sufficiently fast to obtain the preferred range of droplet sizes.

It will be apparent, of course, that this also explains the need for maintaining the position of the flat surface in line with the orifice, and maintaining the spacing S within the indicated limits. If the stream has a substantial portion that fails to be deflected by the solid surface, that portion of the sheet of water formed may be excessively thick to form small enough filaments. Likewise, by failing to impact the surface, the direction of the flow of the water is not changed sufficiently and that portion of the sheet may not radiate from the pin at a sufficient velocity to break into proper size filaments to obtain droplets smaller than 50 microns.

A particularly preferred embodiment of nozzle constructed in the manner illustrated in FIG. 2 has an orifice diameter H, a pin diameter P, and a spacing S therebetween, all of about 200 to 250 microns. This embodiment is particularly preferred since it provides reliable operation, droplets of nearly optimum size, and is economical to manufacture and operate. When such a nozzle is operated at a pressure in excess of 350 psi it produces water droplets having an average diameter of about 15 microns, a major portion of which are in a size range of from about 10 to 50 microns. Droplets so produced evaporate rapidly and completely under conditions where the air is less than saturated with water vapor, and produce a fog of particular utility when the relative humidity approaches 100 percent. This size range is near optimum for maximum of backscattering of infrared radiation. Such a fog also has a relatively high degree of opacity in the visible region for providing a suitable medium on which to project an image. A nozzle constructed with these dimensions can be made without exorbitant manufacturing costs, and the volume of water that can be passed through the orifice is sufficiently large that only a moderate number of such nozzles are required in most systems.

If the aforementioned nozzle dimensions are increased substantially above about 250 microns, the water droplet diameters are increased, thereby reducing the rate of evaporation and the backscattering efficiency for infrared. If the orifice diameter and other related dimensions are decreased substantially below about 200 microns, the manufacturing costs increase at a substantial rate, and so do the number of nozzles required in a system in order to achieve a selected total quantity of water injected into the environment. Thus, it is found that a nozzle having an orifice diameter, pin diameter, and spacing each of about 200 to 250 microns is highly advantageous for environmental control purposes.

It will be recognized that the size of droplets obtained is a function of stream diameter and velocity and also the surface properties of the water. Therefore, some reduction in the velocity or increase in size may be obtained by adding a small quantity of surfactant to the water in order to reduce the surface energy, and it should be understood that such modification is within the scope of practice of this invention. It is preferred, however, that "pure" water be employed without addition of surfactant for a variety of reasons, not the least of which is the difficulty of adding surfactant with pre-

cision in the small quantities required in a continuous flow system such as employed in practice of this invention.

FIG. 3 illustrates in transverse cross section another embodiment of fog producing nozzle constructed according to principles of this invention. As illustrated in this embodiment, the nozzle is also in the form of a saddle tee having a body **84** capable of withstanding internal pressure in the range of from at least 350 to 500 psi clamped to a pipe **85** by a U-shaped bracket **86.** A hollow metal plug **87** is molded in the plastic body **84** and aligned with a hole **88** through the side of the pipe **85.** Staked into the metal plug **87** is a hook-shaped pin **89** having a spherical end **91** (best seen in FIG. **4**) over an orifice **92** in the plug **87.**

As in the embodiment hereinabove described and illustrated in FIG. **2,** the orifice **92** has a diameter H in the range of from about 125 to 400 microns so that when water at a pressure in excess of 350 psi is provided within the plug **87** a water jet having the diameter of the orifice is ejected at a velocity in excess of 135 feet per second. The spherical end **91** of the pin **89** is positioned before the aperture and spaced apart therefrom by a distance S, and in this embodiment having a curved solid surface **91** against which the water stream can impact, it is found that the distance S is less critical and can be several millimeters, for example.

The radius of curvature R of the spherical end **91** of the pin is preferably in the order of about 500 microns and can be in the range of from about 250 to 1500 microns without significantly degrading performance of the fog producing nozzle. The center of curvature of the end **91** is also deliberately offset from the axis of the orifice **92** by an amount M rather than being directly in line therewith. The direction of offset of the end of the pin from the axis of the orifice is towards the portion of the hook-shaped pin **89** (FIG. **3**) interconnecting the tip and the plug **87.** The optimum amount of offset M is readily determined empirically for a selected pin and orifice size to obtain the desired fogging pattern.

When a pin, either rounded as illustrated in FIG. **4** or flat as illustrated in FIG. **2,** is exactly centered on the orifice the resultant conical sheet of water and hence array of fog droplets is substantially uniform in all directions radially from the pin. Because of the mechanical interconnection between the pin and the body in which the orifice is provided there is typically a small arc adjacent the orifice where a mechanical obstruction to radial flow of fog is present. Fog droplets striking the supporting post adhere to it and accumulate to form larger drops that fall from the fogging nozzle. In one embodiment of such nozzle having a flat pin, it is found that a little more than 10 percent of the water passing through the orifice strikes the supporting post and drips from the region of the nozzle. This amount of water represents an inefficiency in the fogging system and is preferably avoided.

By deliberately offsetting the center of curvature of the surface **91** from the axis of the orifice **92,** the distribution of water in the fog produced is skewed to one side, and when the spacing M is properly selected empirically an arc of about 30° centered in the direction of the offset is substantially free of any fog. Since the offset is in the direction of the supporting post, very little of the fog produced by the nozzle actually impacts against the post and is therefore free to be injected into the surrounding environment. This results in a very high efficiency in the fogging nozzle with substantially all water available for evaporation into the environment.

It is found that, although quite convenient for manufacturing purposes, it is not necessary that a spherical surface be employed in the offset arrangement such as provided in FIG. **4.** It is found that a smooth, solid surface having compound convexity in differing degrees can be employed. By compound convexity is meant that the surface is convex in and near the region of impact of the water stream in any plane containing the axis of the stream of water. Thus, the stream impacts on a smooth surface that curves away from the region of impact in all directions.

In the embodiment illustrated in FIG. **2,** the flat end surface of the pin is substantially normal to the axis of the orifice through which the water jet is ejected. This results in a substantially uniform radial distribution of fog droplets around the pin. It might be supposed that tilting of the plane surface of the end of a flat pin would direct the fog droplets produced to one side. This is, in fact, the case, and some nonuniformity of fog droplet distribution can be obtained in this manner; however, a significant side effect is obtained that degrades performance more than impact of a portion of the droplets on the supporting pin. As a flat surface is tilted relative to the axis of the water jet, a substantial portion of the water forms in a pair of streams ejected towards each side and of sufficiently large size that droplets much larger than the desired range are produced. Thus, for example, if a flat surface is tilted at the proper angle (depending on the jet velocity and diameter), a spray of droplets covering an angle of about 180° can be obtained, and about half of the water passing through the orifice appears as a fog in this region. At the same time, however, a pair of heavier streams flow laterally from the pin and break up into large droplets that fall inefficiently without forming fog or substantial evaporation.

It is found that a flat surface skewed away from normal to the axis of the orifice by more than a small amount tends to produce droplets in which a significant portion are larger than about 50 microns and, therefore, for most applications such an arrangement is impractical. Similarly, if the flat surface is significantly larger than the stream of water impacting thereon, the tendency of the water to wet and adhere to the flat surface apparently slows the radial velocity enough that a significant portion of the droplets have diameters in excess of about 50 microns. The effect of the edge of the flat surface becomes important when it is enlarged and, further, the spray of fog is flattened. Apparently with a compound curved surface wherein the radius of curvature is in the order of about 500 microns, the radiating sheet of water separates from the surface quickly rather than traveling any substantial distance along the surface, and the velocity is not significantly reduced.

The use of a compound curved surface in front of the orifice substantially relaxes the requirement for close spacing between the surface and the orifice, and this is apparently due to the significantly larger acceptable size of the compound curved surface as compared with the flat surface so that the location of impact of the water stream on the surface is much less critical. The inherent oscillation of the water stream over the distance S between the orifice and the pin will not vary the location of impact sufficiently to degrade performance

so long as the distance is small enough that the oscillation has not caused the stream to break into separated droplets. A spacing of about four millimeters has been found to be satisfactory.

FIGS. **5** and **6** illustrate a simplified nozzle having a compound curved impact surface and constructed according to principles of this invention. As illustrated in this embodiment, there is provided a hollow body **96** capable of withstanding an internal pressure of at least 350 psi and exteriorly threaded for connection to a water supply. An orifice **97** is provided in the body in communication with the hollow interior. As in the previously described embodiments the orifice **97** has a diameter in the range of from about 125 to 400 microns.

Integral with, or connected to, the body **96** is a hook-shaped post **98** that extends upwardly and ends in a compound curved surface **99** immediately in front of the orifice **97.** The compound curved surface **99** can be as much as 3 or 4 millimeters away from the orifice, and the exact curvature thereof is not found to be critical so long as it is smooth and in the general order of about 500 microns, that is in the range of about 250 to 1500 microns. Preferably, the center of the principal curvature of the surface **99** is between the axis of the orifice and the post **98** so that the principal portion of the fog produced when the water stream impacts on the surface is ejected into the environment in a direction that does not cause impact against the post so as to promote optimum efficiency in the fogging nozzle.

FIG. **7** illustrates in partial cross section another embodiment of nozzle constructed according to principles of this invention. As illustrated in this embodiment there is provided a plastic saddle tee having a generally crescent shaped body **11.** This body has an inside diameter the same as the outside diameter of standard polyvinyl chloride pipe. For standard ½ inch pipe having an outside diameter of about 13/**16** inch the body extends along the length of the pipe about 1⅛ inch. Side wings **15** on the body also extend more than half way around the pipe for firm gripping during installation. A short stem **12** is provided on the inside of the body midway along its length for fitting into a lateral hole in the side of a standard PVC pipe.

To install the saddle tee on a pipe, both the interior of the tee and the exterior of the pipe are suitably primed and the interface is coated with conventional PVC cement. The saddle tee is simply pressed onto the pipe with the stem **12** fitting into the hole in the wall of the pipe. The wings **15** of the body temporarily bend aside as it is snapped on the pipe and thereafter they hold it in engagement with the pipe until the cement has had an opportunity to thoroughly cure. Water sealing and much of the strength is due to cement between the stem and the hole. It is found that such an arrangement makes a very tight joint on the pipe and is economical to make and install.

A stainless steel insert **13** is threaded into the side arm **14** of the saddle tee. A fine stainless steel screen **16** having openings smaller than the water orifice through the insert is pressed into the inner end of the insert. If such a screen is made slightly oversize it firmly lodges in place when pressed in and there is no problem of it working loose. The screen serves to catch any fine particles that evade the primary filtering system used in systems employing such nozzles or fine particles that may have remained in the pipes used to make this system. The simple expedient of placing a screen in each nozzle substantially completely avoids problems of plugging.

A U-shaped post **17** has one end inserted in the end of the insert **13.** Preferably this post is held firmly in position by deforming the insert around it after the pin has been put in a blind hole. At the other end of the post and over the center of the insert there is an axial pin **18.** The pin is typically about 750 microns long with a diameter of about 375 to 400 microns and integral with the post. The transition between the pin and post, as better seen in the enlarged view of FIG. **8,** is typically a conical surface **19** having an included angle of about 120°.

The tip of the pin **18** is approximately aligned with a water orifice **20** through the end of the insert **13.** The tip of the pin **18** has compound curvature as hereinabove described and is in the form of a cone **21** coaxial with the pin **18.** At the peripheral edges where the water leaves the conical surface **21,** the effective radius of curvature is about 190 to 200 microns. Both the tip of the cone **21** and the peripheral edge have transition curvatures of no more than about 5 micron radius. Even if the tip is made with a sharper point it erodes to a radius in this order after a moderate period of use. Since the end of the pin has compound curvature it is found that precise alignment with the orifice **20** is not required nor is close spacing to the orifice of great criticality.

The cone **21** has an included angle of about 120°, but the cone of fog generated thereby depends to a substantial extent on the velocity of water from the orifice **19.** The cone angle of 120° seems to be nearly optimum for producing fine water droplets and is a surface of compound curvature that is very easily manufactured. Its absence of criticality of alignment is comparable to the spherical surface hereinabove described and the conical surface is more easily manufactured.

The water orifice **20** is in a small synthetic sapphire insert **22** tightly pressed into the threaded metal insert **13** which is screwed into the saddle tee. Typically, the orifice has a diameter of about 200 microns and preferably the length of the orifice is about the same as its diameter. A conical passage **23** leads from the body of the insert **13** to the orifice **20** so that viscous drag through the orifice is minimized and there is laminar flow in the jet of water coming out of the orifice. Turbulent flow causes formation of more large droplets of water and can significantly reduce nozzle efficiency. The sapphire insert avoids orifice erosion problems and minimizes variations between nozzles which may occur when metal orifices are used.

The pin **18** has a diameter of about 380 microns and it is found that any alignment of the pin with the orifice that permits the entire stream to hit the conical end **21** is sufficient. Since alignment of the pin with the orifice is not critical, manufacturing tolerances can be reduced. Further, the spacing between the end of the pin and the orifice has relaxed criticality because of the conical tip having compound convexity. As a result, such nozzles are quite economically manufactured.

It is particularly preferred in embodiments of nozzle having compound convexity at the point of impact with the water stream, that the orifice have a diameter of about 200 to 250 microns. This particular size is preferred since operation of such a nozzle at a pressure in excess of about 350 psi results in injection of water droplets having an average diameter of about 15 mi-

crons. As pointed out hereinabove, this particular droplet size distribution is of particular advantage in obtaining high evaporation rate without undue energy expenditure, and a fog produced of such droplets is near optimum for infrared backscattering. Such an orifice size minimizes manufacturing costs of individual nozzles and minimizes the number of nozzles required in a system while still maintaining a preferred droplet size distribution.

Several embodiments of nozzle incorporating principles of this invention have been described and illustrated herein. Several embodiments of fog producing nozzle for injecting water droplets in the range of from about 5 to 50 microns into the environment have been described and illustrated herein. Many other arrangements for obtaining impact of a high velocity stream on a smooth, solid surface for efficient droplet production will be apparent to one skilled in the art. Because of the many possible modifications and variations, it is to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A nozzle for producing fog wherein a major portion of the water droplets are in the range of from about 5 to 50 microns in diameter and the average diameter is in the range of from about 10 to 30 microns comprising:

a body capable of withstanding an internal water pressure of at least 350 psi;

a substantially cylindrical water orifice in the body having a diameter in the range of about 125 to 250 microns;

a member external to the body and having an end portion opposite the orifice, the end portion of the member being in the form of a smooth cone having an included angle of about 120° and a diameter of about 400 microns, the axis of the cone being substantially parallel to the axis of the orifice.

2. A fog producing nozzle as defined in claim 1 wherein the end portion of the member is spaced apart from the orifice a distance less than about 4 millimeters.

3. A fog producing nozzle as defined in claim 2 wherein the cone has its axis offset from the axis of the orifice.

4. A fog producing nozzle comprising:

a body capable of withstanding an internal water pressure of at least 350 psi;

a substantially cylindrical water orifice in the body having a diameter in the range of about 125 to 250 microns;

a member external to the body and having an end portion opposite the orifice, the end portion of the member being in the form of a smooth compound curved convex surface.

5. A fog producing nozzle as defined in claim 4 wherein the curved surface has a radius of curvature in the order of from about 125 to 1500 microns.

6. A fog producing nozzle as defined in claim 5 wherein the end portion of the member is spaced apart from the orifice a distance less than about four millimeters.

7. A fog nozzle as defined in claim 5 wherein a principal center of curvature of the compound curved convex surface is offset from the axis of the orifice.

8. A fog producing nozzle as defined in claim 4 wherein the member comprises a support arm interconnecting the body and the convex surface and positioned to one side of the orifice; and wherein a principal center of curvature of the convex surface is between the axis of the orifice and the support arm.

9. A fog producing nozzle as defined in claim 4 wherein the curved surface is a cone having its axis substantially parallel to the axis of the orifice.

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