

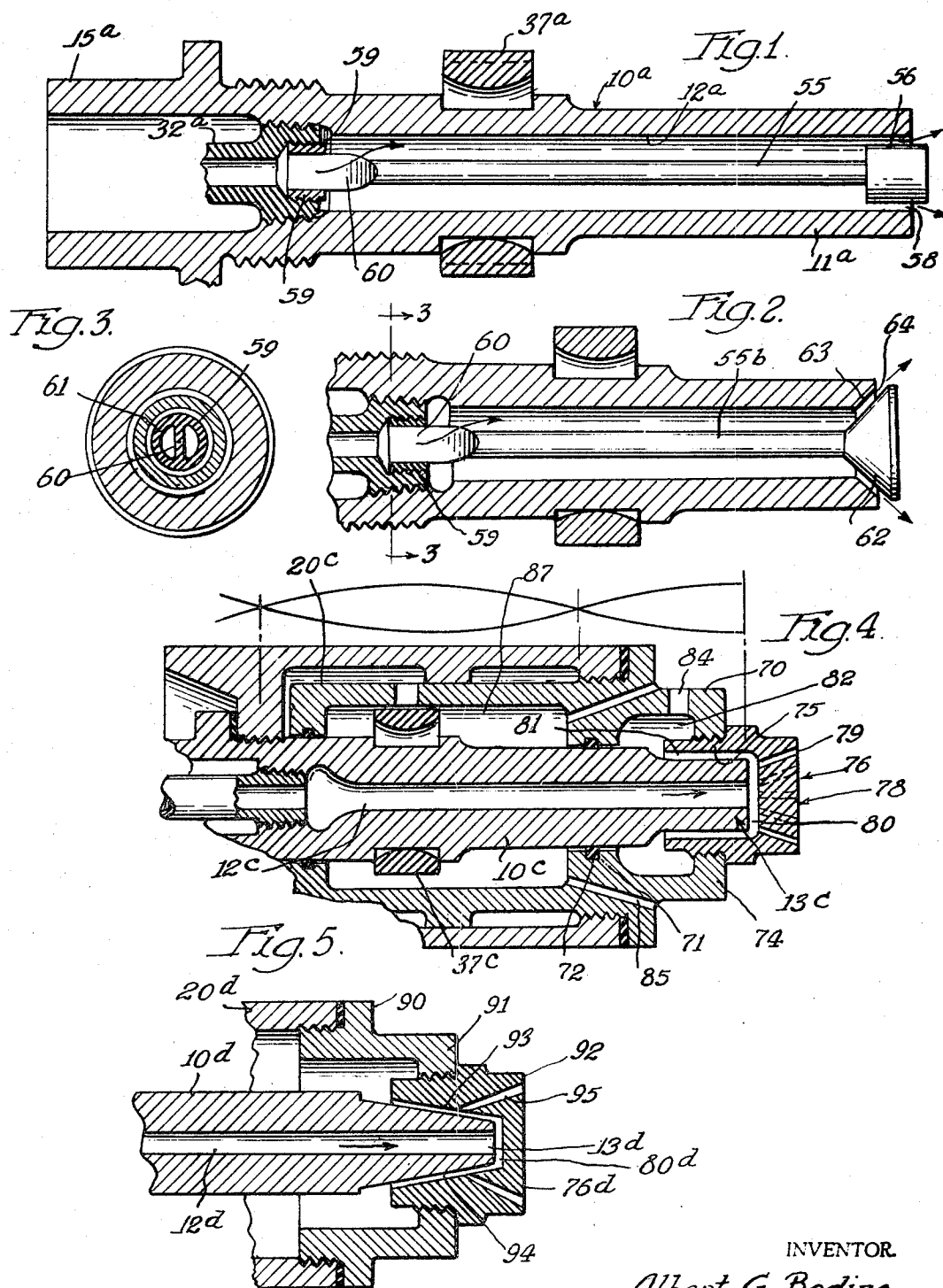
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SPRAYER

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3,474,967
SPRAYER

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U.S. Cl. 239—102

10 Claims

ABSTRACT OF THE DISCLOSURE

A sonically vibratory liquid sprayer having an elongated resonator rod in which a resonant standing wave vibration is generated by means of an orbiting-mass-type oscillator. A housing surrounds the rod, which is a hollow tube through which the liquid to be sprayed is directed. In one embodiment there is disposed concentrically within the tube a solid non-vibratory rod, while in a second embodiment the liquid after passing through the vibratory rod is directed outwardly from the device through a fixed non-vibratory cap having a plurality of apertures therein.

This is a continuation in part of application Ser. No. 482,361, filed Aug. 25, 1965 now Patent 3,374,953.

In parent application Ser. No. 482,361, there is disclosed and claimed a tubular resonator rod through which liquid to be atomized is directed. A vibration generator of an orbiting-mass type applies a rotating radially oriented force on the resonator rod by means of a gyratory inertia ring encircling a portion of the rod, the ring moving in a raceway provided. The parent application is particularly directed to a configuration of a fluid chest which surrounds the resonator rod and serves to supply the fluid for driving the inertia ring to effect the resonant vibration in the rod. The herein invention relates to the parent case in that the fluid chest means utilized and claimed therein is adaptable for driving an inertia ring in the same manner on vibratory liquid sprayers. However, the invention disclosed herein particularly relates to novel design configurations for the vibratory rod and associated elements so as to achieve improved atomization of the material to be sprayed.

Prior to the invention described herein, it has been contemplated by others to utilize resonant vibration in a liquid atomizer spray. However, in such prior applications of the concept of utilizing this type of vibration, the entire element in which the fluid was carried and the associated nozzle through which it was ultimately directed were caused to vibrate. For example, in the parent copending application referred to above, the fluid is ejected through a vibrating tube. Another device in the prior art, the fluid is passed through a vibratory tube in a manner similar to that disclosed in the previously filed copending application and then passes to a nozzle at the end of the tube. The nozzle comprises a plastic roller which is mounted on a pin which sits within a plug that communicates with the main vibratory tube. A passageway carries the liquid passing through the vibratory tube to the area occupied by the roller. The plug and the whole vibratory tube vibrate as a unit whereby the roller is caused to vibrate relative to the pin in which it is seated. The liquid passes around the roller element as it vibrates. As can be seen, such a device does not provide a fixed control in the passageways around the vibratory plastic roller which will vibrate in a random fashion. Additionally, such a vibratory plastic roller is subjected to variance in fluid pressures coming through the tube and is further subject to clogging wherein the device is completely inoperative when the plastic roller

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becomes stuck and no longer vibrates in a random fashion. In other words, in this prior art device, the nozzle at the end of the vibratory tube always vibrates in a fashion dictated by the vibrations of the tube.

The invention described herein is an improvement over the prior art devices. It has been found that more reliable and significantly improved atomization occurs. The herein invention differs from that contemplated in the prior art in that the liquid material which is conducted through a vibratory tube element passes through a relatively narrow concentric passageway in which the walls of the tube vibrate relative to fixed walls of an additional fixed element. Thus in the concentric passageway through which the material passes prior to being emitted from the device, the liquid is subjected to extreme vibratory energy of the hollow tube element, acting upon the material which is in the form of a relatively thin film when filling the concentric area described.

In one embodiment of the invention, there is disposed through the center of the tubular element a fixed rod which is connected at its base to a nodal point in the standing wave vibration pattern wherein no vibration is occurring, yet at the opposite end of the rod adjacent the exit of the tube there is provided a solid body which is seated concentrically in the tube and is of larger diameter than the rod. The area between the solid body and the inner wall of the tube forms a concentric narrow chamber through which the liquid is forced to pass. The inner walls of the tube vibrate relative to the fixed solid body at this region inducing high vibratory energy on the thin wall of fluid. From this point the fluid exits from the device as an atomized spray.

In a second embodiment of the invention, a fixed housing concentrically surrounds the end of the vibratory tube, forming a chamber in that area between the outer wall of the tube and the inner wall of the housing. The housing additionally is provided with a plurality of orifices therein for emitting the liquid spray. Thus after the liquid passes down the length of the hollow vibratory tube, it is emitted into a concentric chamber formed at its end wherein it is subjected to high vibratory forces acting against the thin film formed in this area. The material is then forced from this closed area through orifices at the end of the device.

Thus, as can be seen, the main differences between the two embodiments is that in the first embodiment the fixed body is inside the tube forming a concentric narrow chamber within such tube, while in the second embodiment the fixed body is outside the tube, forming an externally concentric chamber for the liquid about the vibratory tube. In both instances, of course, the liquid is subjected to a vibratory force wherein the tube is moving relative to the fixed body. In all the embodiments, the vibratory tube element is adapted to be utilized with the novel housing configuration described in the copending parent application. Additionally, the oscillator drive to vibrate the tube can be that disclosed in the prior application. Thus, the herein invention is directed solely to the novel arrangement of the tube and fixed bodies to apply the vibratory energy in a concentric narrow chamber formed adjacent to the portion of the device from which the material exits.

It is believed the invention will be better understood from the following detailed description and drawings, in which:

FIG. 1 is a cross-sectional view of the first embodiment of the invention.

FIG. 2 is a cross-sectional view of a second embodiment of this invention.

FIG. 3 is a sectional view taken along lines 3—3 of FIG. 2.

FIG. 4 is a cross-sectional view of a third embodiment of the invention.

FIG. 5 is a cross-sectional view of a fourth embodiment of the invention, showing the head nozzle end of the device.

It has been found most helpful in analyzing the operation of the device of this invention to analogize the acoustically vibrating circuit involved to an equivalent electrical circuit. This sort of approach to analysis is well known to those skilled in the art and is described, for example, in Chapter 2 of "Sonics," by Hueter and Bolt, published in 1955 by John Wiley and Sons. In making such an analogy, force F is equated with electrical voltage E , velocity of vibration u is equated with electrical current i , mechanical compliance C_m is equated with electrical capacitance C_e , mass M is equated with electrical inductance L , mechanical resistance (friction) R_m is equated with electrical resistance R , and mechanical impedance Z_m is equated with electrical impedance Z_e .

Thus, it can be shown that if a member is elastically vibrated by means of an acoustical sinusoidal force $F_o \sin \omega t$ (ω being equal to 2π times the frequency of vibration),

$$Z_m = R_m + j \left(\omega M - \frac{1}{\omega C_m} \right) = \frac{F_o \sin \omega t}{u} \quad (1)$$

where ωM is equal to $1/\omega C_m$, a resonant condition exists, and the effective mechanical impedance Z_m is equal to the mechanical resistance R_m , the reactive impedance components ωM and $1/\omega C_m$ cancelling each other out. Under such a resonant condition, velocity of vibration u is at a maximum, power factor is unity, and energy is most efficiently delivered to a load to which the resonant system may be coupled.

It is important to note the significance of the attainment of high acoustical "Q" in the resonant system being driven, to increase the efficiency of the vibration thereof and to provide a maximum amount of energy for the vaporizing operation. As for an equivalent electrical circuit, the "Q" of an acoustical vibration circuit is defined as the sharpness of resonance thereof and is indicative of the ratio of the energy stored in each vibration cycle to the energy used in each such cycle. "Q" is mathematically equated to the ratio between ωM and ωR_m . Thus, the effective "Q" of the vibrating circuit can be maximized to make for highly efficient high-amplitude vibration by minimizing the effect of friction in the circuit and/or maximizing the effect of mass in such circuit.

Of significance in the implementation of the method and devices of this invention, is the high acceleration of the components of the elastic resonant system that can be achieved at sonic frequencies. The acceleration of a vibrating mass is a function of the square of the frequency of the drive signal times the amplitude of vibration. This can be shown as follows:

$$y = Y \cos \omega t \quad (2)$$

where Y is the maximum displacement in the vibration cycle and ω is equal to $2\pi f$, f being the frequency of vibration.

The acceleration a of the mass can be obtained by differentiating Equation 2 twice, as follows:

$$a = \frac{d^2 y}{dt^2} = Y \omega^2 \cos (\omega t) \quad (3)$$

The acceleration a thus is a function of Y times $(2\pi f)^2$. At resonance, Y is at a maximum and thus even at moderately high sonic frequencies, very high accelerations are achieved making for correspondingly high vibrational forces at the interface of the tube with the liquid.

In considering the significance of the parameters described in connection with Equation 1, it should be kept in mind that the total effective resistance, mass, and compliance in the acoustical vibration circuit are represented in the equation and that these parameters may be distributed

throughout the system rather than being lumped in any one component or portion thereof.

It is also to be noted that an orbiting-mass oscillator may be utilized in the device of the invention that automatically adjusts its output frequency to maintain resonance with changes in the characteristics of the load. Thus, in the face of changes in the effective mass and compliance presented by the load, the system automatically is maintained in optimum resonant operation by virtue of the "lock-in" characteristics of applicant's unique orbiting-mass oscillator. The orbiting-mass oscillator automatically changes not only its frequency but its phase angle and therefore its power factor with changes in the resistive impedance load to assure optimum efficiency of operation at all times.

As explained in the parent application, the end of the vibrating tube through which the fluid to be vaporized is emitted is always located at an antinode of the standing wave vibration pattern so that maximum vibrational energy is achieved at this point. Alternatively, the portions of the system which are desired to remain completely stationary are affixed to the portion of the tube where a node of the generated resonant wave pattern exists. By being so affixed at this point there is no transmission of the vibratory energy to the surrounding parts so that they will not at all be affected.

Reference is directed to FIG. 1 showing a first embodiment of the invention. In this embodiment, the tubular resonator member, designated generally by reference numeral 10a, has an enlarged axial bore or duct 12a. An axial stem 55 is disposed coaxially within bore 12a, and carries at its outer end, within the end portion of the barrel 11a, an enlarged cylindrically formed head 56, which defines with the interior surface of the cylindrical bore 12a a ring-shaped liquid atomizing chamber and nozzle orifice 58. The head 56 is stationary and annularly spaced by the narrow annular discharge gap from the walls of the bore 12a. A stationary mounting for the stem 55 is provided by mounting it at a nodal region of the vibration pattern of tubular resonator member 10a. In this instance, the stem 55 is shown to have at its rearward extremity an integral sleeve member 59 which is threaded into a socket formed in the externally threaded plug on the end of the liquid feeding stem 32a. The solid stem 55 is joined to the sleeve mounting member 59 by means of a thin-walled diametrical portion 60 which affords liquid passages on both sides thereof. Inertia ring 37a is rotatably driven in the manner described in the parent application to cause resonant elastic vibration of resonator member 10a. The remainder of the embodiment of FIG. 1 may be as in the device of the parent application, and is therefore, for simplicity, omitted from the drawings.

In the operation of the device of FIG. 1, the resonator member has a resonant, gyratory, standing wave action. In the device of FIG. 1, the liquid ejection extremity of the barrel 11a moves gyratorially relative to the stationary head 56, and thus the width of the annular or ring-shaped spray nozzle gap or orifice is alternately narrowed and then widened at any given point, in effect moving around the annular orifice at the frequency of vibration. This alternate narrowing and widening of the annular orifice gap causes an alternating rarefaction and compression of the liquid at successive points within and around the orifice, with the result of improved sonic activation and resultant atomization and ejection of the spray in a uniform mist.

In FIGS. 2 and 3 there is shown a modification of the embodiment of FIG. 1, consisting of the use of a modified conical spray directing head 62 on the forward extremity of the stationary mounting stem 55b. The conical surface of head 62 is spaced by a narrow annular gap 63 from a conical surface 64 formed at the end of bore 12a in tubular resonator 10b. The conical annular gap 63 thus, in this instance, constitutes the atomizing and discharge spray orifice of the nozzle. The embodiment of FIGS. 2 and 3 has properties similar to those of FIG. 1 but with

the additional feature that the spray emitted from the device is discharged in a more divergent cone.

As can be seen, the embodiments in FIGS. 1-3 embrace the concept of a hollow cylindrical tube moving relative to a fixed center body. The vibration of the tube 10a is well and accurately controlled, due to the action of the oscillator 39. There are no random vibrations involved in the operation of the devices. In both instances, gaps 58 and 63, respectively, shown in FIGS. 1 and 2, provide a relatively thin film of liquid between the inner wall of the vibrating tube and the bodies constituting the spray heads. A maximum transfer of the vibratory energy can be made through the thin film of material causing high effectivity in the operation of these devices wherein the dissipation of energy through the liquid medium is minimized. The controlled squeezing of the thin film due to the gyratory motion of the tube 10a about the heads 56 and 62, respectively, produces a controlled spray head which is at all times predictable and accurate. This could not be readily achieved if the head and the body were both vibrating together.

Reference is next directed to FIG. 4, showing another embodiment. The tubular resonator member is in this instance designated generally by the reference numeral 10c, and it has a liquid duct 12a, as in the embodiment of FIG. 1. The departure here is that the liner 20c a tubular extension portion 70 at its forward end, with an integral annular wall portion 71 closely spaced to the tubular member 10c at a nodal point in the latter, and preferably sealed thereto as by O-ring 72. The extension portion 70 has at its forward extremity an inwardly extending flange 74, which is internally threaded to receive the cylindrical side wall portion 75 of a nozzle cap member 76. The cylindrical side wall portion 75 of this cap member 76 is of sufficient diameter to accommodate the gyratory action of the forward end nozzle portion of the tubular resonator member 10c, and it has, just forwardly of the nozzle portion, an end wall 78, the latter being separated by a narrow space 80 from the extremity of the tubular member 10c.

The cap 76, in the illustrative embodiment, has a plurality of diverging flow orifices or passageways 79, which communicate with the space 80 between the cap wall 78 and the end of the tubular resonator member 10c. The space 80 will be seen to be in communication via the relatively narrow annular space 81 between tubular resonator member 10c and the side wall 75 of the cap member with a space 82 inside the liner extension 70. An air inlet hole 84 in the extension portion 70 permits intake of air into the space 82. In this embodiment, the air which has been utilized in the driving of the inertia ring 37c is exhausted from chamber 87 via a plurality of discharge passageways 85 formed in the extension member 70.

In operation, the tubular member 10c is vibrated at resonance by the inertia ring 37c, as before. Liquid passing down the duct 12a in the resonator member 10c is atomized and ejected from the nozzle orifice 13c into the confined space 80. This atomized liquid is finally ejected and sprayed via nozzle passageways 79 in a highly sonically-agitated state. It will be noted that the gyratory forward end nozzle portion of the tubular resonator member 10c works in its gyratory fashion within the narrow annular space 81 between it and the side wall 75 of cap 76, thereby creating sonic wave pulses in the fluid in the spaces 81 and 80, and the sonic impulses of this action contribute a very high agitation effect to the atomized liquid being ejected via the ports or passageways 79. The vibratory energy acting on the thin film of liquid in regions 80 and 81 creates a highly vaporized condition. The passage of the atomized liquid outwardly through the passageway 79 tends to create a reduction in pressure in the region 81, and this reduction in pressure is compensated by air taken in through port 84 and the space 82 inside the liner extension 70.

The depression in pressure or suction spoken of in the preceding paragraph can also be compensated, in a modified version of the device, by removing the O-ring seal at 72 and permitting partially spent air leaving the vibration ring 37c to flow directly into the space 82 and thence into the space 81. This air may then mix with the atomized liquid in the air space 81, and be discharged via the passageways 79 with the atomized liquid. Such auxiliary air derived from the vibration generator will be understood to be under some pressure above atmospheric in the chamber space 87 and may thus, particularly if the apertures 84 and 85 are either plugged or omitted, add its pressure energy to the driving of the atomized liquid outwardly through the ejection passageways 79.

FIG. 5 shows a further modification, which embodies, among other things, the feature discussed in the preceding paragraph by which partially spent air from the vibration generator is added to the atomized liquid in the process of the ejection of the latter. In this case, the liner 20d is extended, as at 90, and formed with an inwardly turned flange 91 in which cap member 92 is threadably attached. The cap member 76d is generally similar to that of FIG. 4, with the exception that it is formed with a tapered or frusto-conical interior air passage wall 93, the forward end portion of the resonant tubular member 10d being formed with the same taper, as illustrated, so as to form a narrow frusto-conical air passage 94 therebetween. The air used to drive the inertia ring (not shown) is in this case introduced at a sufficiently high pressure that, after driving the inertia ring, it is still at a substantial pressure above atmospheric. Accordingly, this still pressurized air is entirely discharged via the conical passage 94 through the final discharge passages 95, which in this instance lead directly from the passage 94 through the forward end face 92 of the cap 76d. As before, the liquid traveling down the duct 12d in the resonant member 10d is discharged from the orifice 13d in an atomized state. This atomized liquid travels via the space 80d and a portion of the space 94 to the discharge passages 95, which in this case lead directly from the space 94. Accordingly, in this embodiment of the invention, the atomized liquid ejected from the orifice 13d mixes with the still pressurized air coming off the gyrator ring 37d, and additionally pressurized atomized liquid is thus ejected forcibly from the passageways or nozzle openings 95. The sonic activity occurring in the space 94 between the stationary cap 76d and the gyratory nose or nozzle portion of the resonator 10d adds a further desirable sonic agitation effect to form a uniform mist, much as described in connection with the other embodiments.

I claim:

1. A sonically vibratory liquid sprayer comprising: an elongated tubular resonator having a lateral mode of resonant standing wave vibration, with a velocity antinode at an outlet end through which liquid is ejected from said resonator and at least one velocity node spaced therefrom; means for generating said resonant standing wave vibration in said resonator, said means coupled to said resonator in a region of a velocity antinode of said standing wave vibration; and a stationary body disposed adjacent the end of said resonator, a narrow passageway being formed between said resonator and said body, whereby said liquid being ejected from said resonator through said passageway is atomized by the force of the relative movement between said resonator and said body.
2. The device of claim 1 wherein said stationary body comprises: a stem disposed within said tubular resonator, said stem attached to said resonator adjacent a node of said standing wave vibration.
3. The device of claim 2 wherein said stem has an enlarged head section concentrically disposed in the end of

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said resonator through which said fluid is ejected, whereby an annular fluid passage is formed between said head portion and the inner wall of said resonator.

4. The device of claim 3 wherein said head portion is cylindrically shaped.

5. The device of claim 3 wherein the wall of said resonator is conically tapered outwardly at the end thereof in which said head portion is disposed; and

said head is correspondingly conically shaped to form an outwardly diverging conical annulus at the outlet end thereof.

6. The device of claim 1 wherein said stationary body comprises:

a cap supported in front of and surrounding the outlet end of said resonator tube, said cap having at least one outlet orifice therein.

7. The device of claim 6 wherein said cap is supported by a stationary housing surrounding said resonator, said housing attached to a portion of said resonator adjacent a node of said standing wave portion.

8. The device of claim 6 wherein said cap has side walls concentrically surrounding said resonator adjacent the outlet end thereof, forming an annular fluid passage clearance between said side walls of said cap and said outlet end of said resonator.

9. The device of claim 8 wherein the outer surface of said resonator adjacent the outlet end thereof is tapered toward said cap and the side walls of said cap are correspondingly tapered to form said concentric portions.

10. A sonically vibratory liquid sprayer comprising: an elongated tubular resonator having a lateral mode

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of resonant standing wave vibration, with a velocity antinode at an outlet end through which liquid is ejected from said resonator and at least one velocity node spaced therefrom;

means for generating said resonant standing wave vibration in said resonator, said means coupled to said resonator in a region of a velocity antinode of said standing wave vibration;

a stationary body disposed adjacent the end of said resonator, a narrow passageway being formed between said resonator and said body, whereby said liquid being ejected from said resonator through said passageway is atomized by the force of the relative movement of said resonator to said fixed body; and means for providing a flow of air to said narrow passageway.

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