

[54] **PRESSURE WAVE ATOMIZING METHOD**

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[22] Filed: **Jan. 17, 1972**

[21] Appl. No.: **218,118**

Related U.S. Application Data

[60] Division of Ser. No. 889,596, Dec. 31, 1969, Pat. No. 3,677,525, which is a continuation-in-part of Ser. No. 669,109, Jan. 19, 1968, abandoned.

[52] U.S. Cl. **239/4, 239/102, 239/DIG. 20**

[51] Int. Cl. **B05b 17/04**

[58] Field of Search **239/4, 102, DIG. 20**

[56] **References Cited**

UNITED STATES PATENTS

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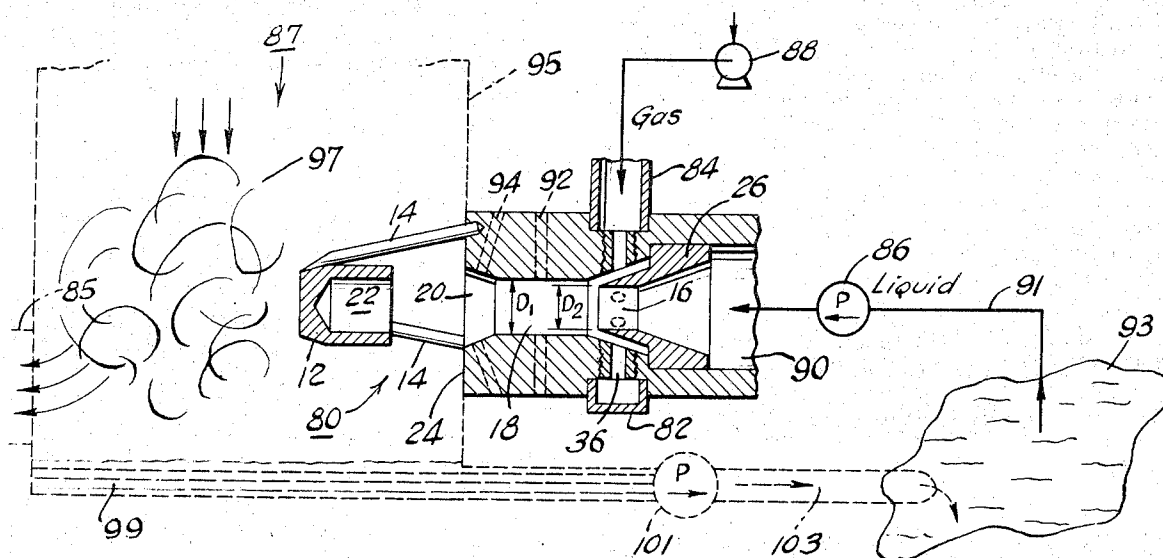
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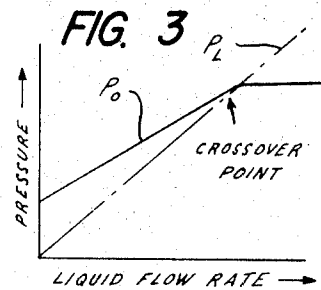
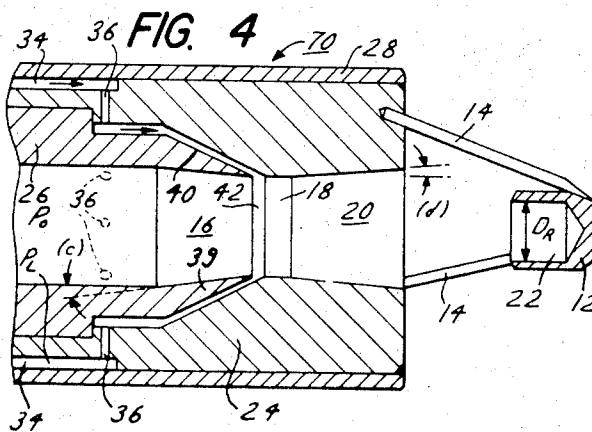
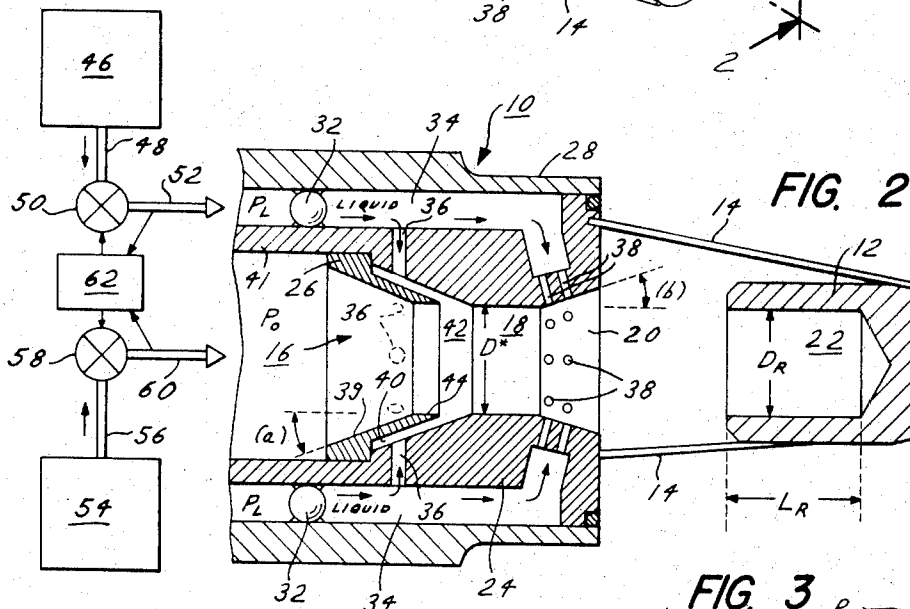
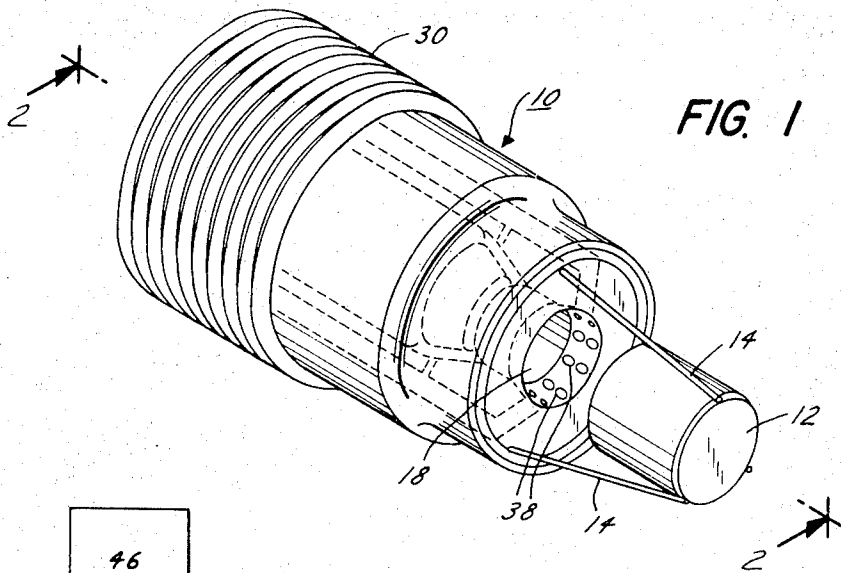
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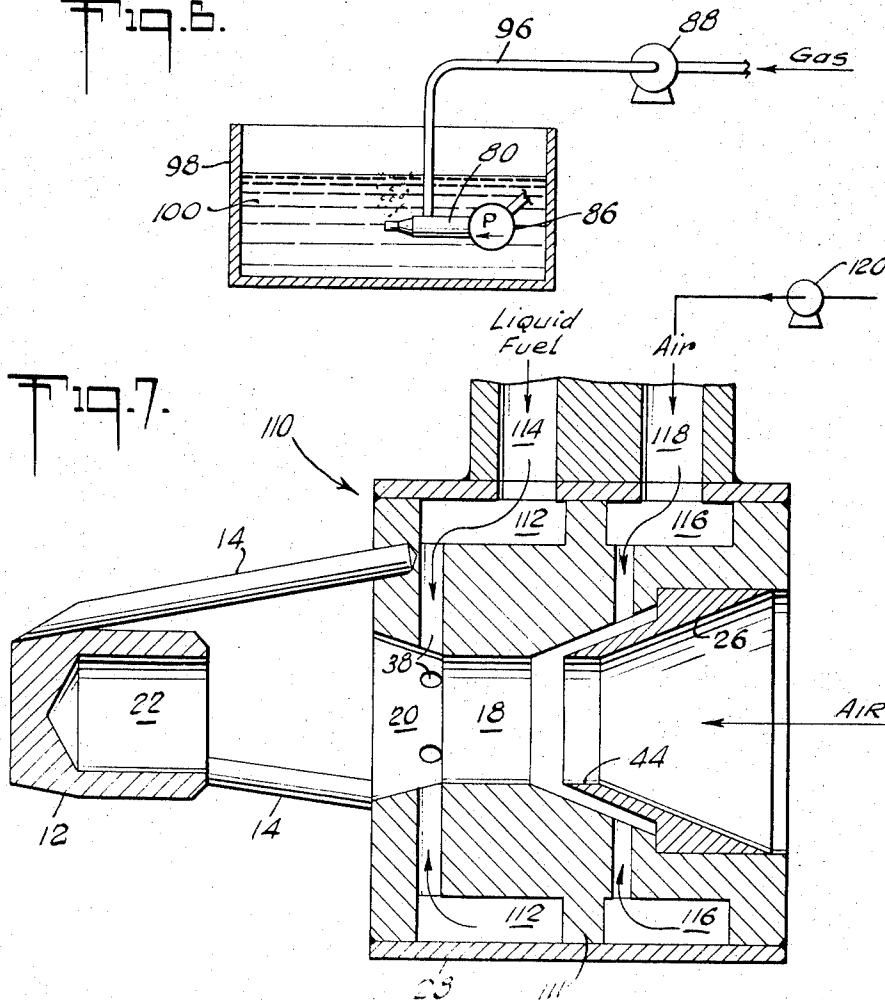
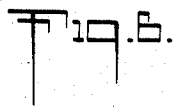
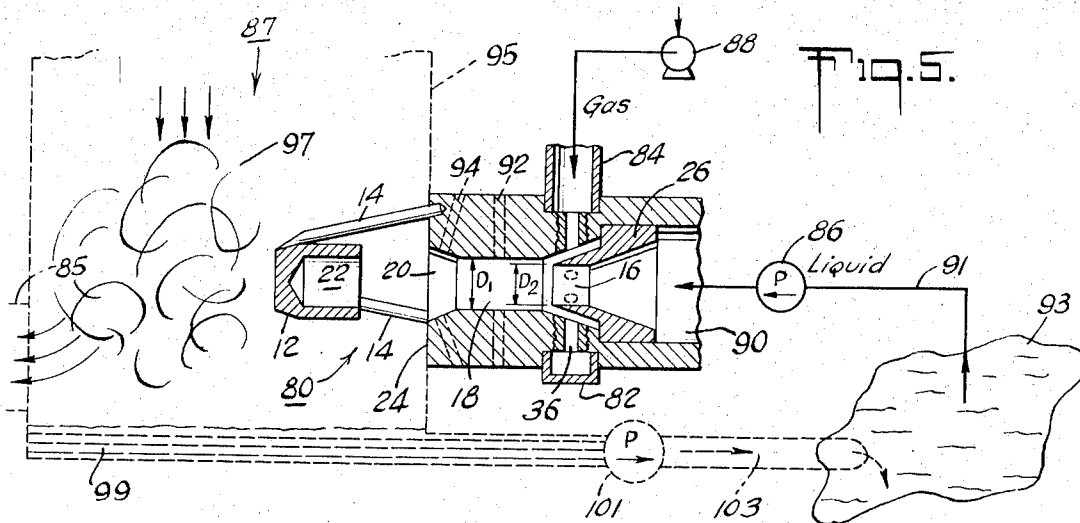
ABSTRACT

Fluids to be mixed and atomized are fed into a converging-diverging nozzle which directs them towards a cavity member. In one embodiment of the invention, liquid is forced through the central opening of the nozzle, and gas is injected into the liquid at a plurality of points around the liquid stream through an inclined baffle structure near the converging portion of the nozzle. In another embodiment, air is fed into the central opening of the nozzle, and liquid through the baffle structure, as well as downstream from the baffle structure. The liquid supply flow rate and the gas supply pressure are regulated so that the input gas pressure is greater than the minimum liquid pressure but less than the maximum liquid pressure. The upstream liquid feed passageway is effectively closed at low flow rates, while being open at high flow rates, thus enabling the maintenance of relatively high liquid back-pressures for accurate flow rate control over a wide range of flow values.

12 Claims, 7 Drawing Figures







PRESSURE WAVE ATOMIZING METHOD

This is a division of application Ser. No. 889,596, filed Dec. 31, 1969, now U.S. Pat. No. 3,677,525, which is a continuation-in-part of U.S. Pat. application Ser. No. 669,109, filed Jan. 19, 1968, now abandoned.

This invention relates to apparatus and methods for atomizing and mixing fluent materials and burning combustible fluids.

U.S. Pat. No. 3,240,254, which is assigned to the same assignee as this application, describes atomizing and fuel burning structures and methods which utilize a converging-diverging gas accelerating and expansion nozzle together with a cavity resonator to produce high-intensity sonic pressure waves. Fluent materials such as liquids are introduced into the high-speed gas stream moving through and issuing from the nozzle, at various positions within or out-side of the nozzle. The resonant sonic pressure wave energy atomizes the liquids into minute droplets of a highly uniform size. When used in burners, such atomizers produce flames of excellent quality over a relatively wide range of fuel flow rates.

Although atomizers and burners constructed in accordance with the above-identified patent are superior to other prior devices and are highly satisfactory for most purposes, it is an object of the present invention to improve upon them by increasing their "turn-down ratios;" that is, by increasing the ratio of the maximum flow rate to the minimum flow rate at which fluids can be atomized satisfactorily.

In accordance with the foregoing, it is a major object of the present invention to provide atomizing, mixing and fuel burning apparatus and methods which give relatively very high turn-down ratios while maintaining highly satisfactory atomization. A further object of the present invention is to provide such apparatus which is simple in construction and operation, has relative large fluid feed holes which do not become clogged easily, which is economical to use and requires relatively low gas flow rates, which will operate effectively in a liquid ambient medium, and which is relatively inexpensive to manufacture. A further object is to provide an improved liquid feed means for such apparatus.

Further objects, aspects and advantages of the present invention will be set forth in and will be apparent from the following description and drawings.

In the drawings:

FIG. 1 is a perspective view of an atomizing and fuel burning device constructed in accordance with the present invention;

FIG. 2 is a cross-sectional, partially schematic view taken along line 2—2 of FIG. 1;

FIG. 3 is a graph illustrating qualitatively variation of some of the operating parameters of the device shown in FIGS. 1 and 2; and

Each of FIGS. 4, 5, 6 and 7 is a cross-sectional view of another embodiment of the invention.

The atomizer and burner device shown in FIGS. 1 and 2 includes a nozzle assembly 10, and a cavity resonator member 12 which is secured to one end of the nozzle assembly 10 by means of three support struts 14.

Referring specifically to FIG. 2, the nozzle assembly 10 includes a gas accelerating and expanding nozzle comprising a converging inlet section generally indicated at 16, a diverging outlet section 20, with a straight-wall cylindrical "stabilizing" section 18 interconnecting the converging and diverging sections. As

is disclosed in greater detail in the above-mentioned U.S. Pat. No. 3,240,254, pressurized gas, preferably air, is introduced into the converging section 16 of the nozzle, and the nozzle is believed to accelerate the gas to supersonic velocities and expand it to sub-ambient pressures at the exit opening of the diverging section 20. The resonator member 12 has a resonator cavity 22 which resonates the pressure waves created by the nozzle, and the device thus produces high-intensity sonic or ultra-sonic pressure waves.

The nozzle assembly 10 is composed of three main components; an internal nozzle member 24, a "baffle" member 26 within the member 24, and an outer sleeve 28. As is shown in FIG. 1, the sleeve 28 has a threaded portion 30 (not shown in FIG. 2) at one end which is used for coupling the nozzle to gas and liquid supply conduits. Several metal balls 32 are welded in position to permanently space the inner nozzle member 24 from the outer sleeve 28 as is shown in FIG. 2 and thus form an annularly shaped liquid flow conduit 34.

The baffle member 26 is generally frusto-conically shaped, and has an angle of inclination (α) equal to the angle of inclination of the frusto-conically shaped walls of the converging nozzle section of the nozzle member 24. The left end of the baffle member 26 is force-fitted into the cylindrical inner wall 41 of the nozzle member 24, and forms a liquid flow passageway 40 between the wall 39 of the baffle and the nozzle wall.

Several symmetrically-positioned liquid feed holes 36 pass through the wall of the nozzle member 24 and exit into the passageway 40 formed between the baffle wall 39 and the nozzle wall. The downstream end of the baffle member 26 forms a liquid flow opening 42 through which liquid passes into the stabilizing section of the nozzle. The baffle 26 has a cylindrical end portion 44 which has the same diameter D as the stabilizing section 18 and thus effectively forms a portion of the stabilizing section. The exit opening 42 is substantially cylindrically shaped and is continuous around the entire periphery of the nozzle.

Additional liquid feed holes 38 are positioned symmetrically in the nozzle member so as to exit into the diverging section 20 of the nozzle. The total cross-sectional area of the holes 36 preferably is approximately equal to the total cross-sectional area of the holes 38. In one specific embodiment of the invention which has been built and tested, there are eight of the upstream holes 36 and sixteen of the holes 38.

In prior art fuel burning methods using atomizers such as those shown in the above-identified patent, the liquid to be atomized, such as fuel oil, is fed from a reservoir 46 (see FIG. 2) through a pipe 48, a pump 50 and another conduit 52 into the liquid flow conduit of the atomizer. Compressed air, steam, or the like is supplied to the converging nozzle inlet by means of any convenient, well-known pressure source 54 through a pipe 56, a valve 58 and another pipe 60. In the usual prior fuel burning installation of relatively high heat-producing capacity, a known linkage control device 62 is provided which senses the pressure P_L at which the liquid fuel is supplied, and simultaneously measures the pressure P_o at which gas is supplied to the atomizer. The control device 62 automatically varies the liquid pressure P_L and the gas pressure P_o to change the heat output in response to changing heat demands on the system, and maintains a differential between the liquid and gas pressures throughout the entire range of varia-

tion of the burner output. One pressure always is greater than the other pressure.

In the above-described prior art atomizers, ordinarily only one set of liquid feed holes is used. The inventors have discovered that the turn-down ratios of such atomizers is limited by the liquid feed characteristics of the atomizer at very low liquid flow rates. The total cross-sectional area of the feed holes must be large enough to pass up to several hundred gallons per hour. When a single set of feed holes large enough to pass such quantities of liquids is used to feed liquids at very low flow rates, the liquid flows through only some of the holes and not others, with the result that the flame pattern sometimes is asymmetrical. Furthermore, the liquid pressure P_L drops virtually to zero. The result of this is that the pressure sensed by the control system 62 is zero, and the system cannot control the flow rate at lower liquid pressures. Thus, the minimum flow rate and, hence, the turn-down ratio, is limited by the inability of the control system to function at lower flow rates.

The present invention solves the foregoing problems by providing, in addition to the usual holes 38, another set of holes 36 at a position in the nozzle where the gas stream pressure working against the flow of liquid through the holes 36 varies from a positive value which exceeds the liquid pressure, to a value which is lower than the liquid pressure. When the gas pressure is lower than the liquid pressure, as it is at very high liquid flow rates, liquid flows not only through the passages 38 but also through the holes 36 so that, in effect, the total feed passage cross-sectional area is the sum of the areas of the holes 36 and 38. However, when the gas pressure is greater than the liquid pressure, as it is at low flow rates, the higher gas pressure substantially prevents liquid from flowing through the holes 36 and forces substantially the entire quantity of liquid to flow only through the holes 38. The holes 38 are positioned so that the gas pressures at their exit openings always are considerably lower than the fluid feed pressure so that there is always a flow of liquid through the holes 38 as long as any liquid is being supplied. At such low flow rates, the effective cross-sectional area of the liquid flow passages is reduced to half of the value at high flow rates, with the result that a liquid pressure P_L greater than zero is developed and liquid flows through all of the holes 38 around the periphery of the nozzle. Thus, the atomizer produces a symmetrical spray of flame pattern. Since a pressure P_L is developed which is large enough to be sensed by the control system 62, it is possible for the control system to vary the flow rate to far lower levels than in previous devices. Thus, the effective turn-down ratio of the device is greatly increased. For example, in devices of the present invention which have been tested using water as the liquid and air as the input gas, turn-down ratios of 30 to 1 have been achieved.

It is believed that in a nozzle with the relative dimensions shown in the drawings, substantially no liquid flows through the holes 36 until the inlet pressure P_0 approximately equals the liquid supply pressure P_L , and then liquid flows at all pressures at which P_L is greater than P_0 . The point at which liquid first starts feeding in substantial quantities through the holes 36 is termed herein as the "cross-over point." In accordance with one aspect of the present invention, the control system 62 is made to vary the gas pressure, P_0 so that the liquid pressure P_L exceeds the input gas pressure P_0 by a cer-

tain amount at the high flow rates and is less than the gas pressure at the low flow rates. This has been found to insure that the "cross-over" point will occur at some point in the range of maximum to minimum flow rates, and that the turn-down ratio will be maximized.

FIG. 3 is a graph showing the qualitative relationship between the pressures P_L and P_0 as the liquid flow rate through the device is varied in the manner described above. The curves describing the variations in P_0 and P_L need not be linear as shown in FIG. 3, but can be of different shapes determined in accordance with the particular control function desired. The offset in the P_0 curve is observed when the two pressures are approximately equal. The rise in P_0 is believed to be attributable to the start of liquid flow through the stabilizer section. The liquid is believed to partially occlude the stabilizer, thus changing its effective diameter and creating a greater back-pressure.

The baffle member 26 is provided in order to prevent gas from flowing from the gas stream into the liquid in conduit 34, and thus to prevent the pulsating, uneven atomization that would result. This is done, it is believed, by providing the relatively long liquid feed passageway 40 extending generally in the same direction as the flow of gas through the nozzle. It is believed that this arrangement makes it difficult for the high-speed gas flowing past the exit opening 42 to flow back into the passageway 40 and through the holes 36, even when P_0 is substantially greater than P_L .

Although it is not absolutely necessary to set the point at which liquid starts flowing through the holes 36 as the one at which P_0 equals P_L , it is extremely convenient to do so since these parameters can be measured and controlled readily. In order to attain this end, it is believed that the liquid pressure at the exit opening 42 should be approximately equal to the gas pressure at that position when P_L equals P_0 . The gas pressure, of course, decreases as it moves to the right through the converging nozzle section 16 provided by the baffle 26. With typical input pressures P_0 of 10 to 60 p.s.i.g., the gas pressure is believed to be still greater than atmospheric pressure at the opening 42. At a position further downstream, in the stabilizing section 18, a plane is reached at which the gas pressure equals atmospheric pressure, and at all points downstream from that plane, the pressure is below atmospheric. In the diverging section 20, the gas pressure can be very much below atmospheric pressure and can be so very low that it is negligible compared to the liquid feed pressure P_L .

It is believed that the reduction in gas pressure experienced at the exit opening 42 is offset by a reduction in the liquid pressure at that point of approximately the same amount. The liquid pressure reduction is accomplished simply by making the total cross-sectional area of the conduit 40 greater than the total cross-sectional area of the holes 36 by an amount sufficient to reduce the liquid pressure to the approximate value of the gas pressure at point 42. Keeping these principles in mind, the length and shape of the baffle 26 and the spacing of the converging wall section 39 from the wall of the nozzle member 24 can be varied as desired, as long as the length of passage 40 is not made so short that gas at its maximum pressure differential over the liquid flows back through the holes 36. It is believed that the baffle 26 enhances the symmetry of the spray pattern by spreading the fuel flow evenly around the nozzle periphery.

The structure shown in the drawing can be modified by providing additional sets of feed holes at different points along the length of the nozzle structure in order to give further variability in the control of flow through the nozzle. The position, size and shape of the holes can be selected so that the pressure variations at the outlets of the holes will be such as to allow liquid to flow through the holes when the liquid pressure at the outlets is greater than the gas pressure, and to prevent such flow when the gas pressure is greater than the liquid pressure.

The location of the holes 38 can be varied, but it is preferred to have the hole exits located where the gas pressure is sub-ambient so that liquids always will be drawn through the holes. The exits can be located, for example, from the downstream end of section 18 to and even beyond the downstream end of the diverging section 20.

The atomizer 70 shown in FIG. 4 has substantially the same construction as the atomizer 10 shown in FIGS. 1 and 2, except that the downstream feed holes 38 have been omitted from the atomizer 70, and the dimensions of the nozzle and resonator are different. The atomizer 70 is particularly desirable for use where extremely high turn-down ratios are not needed, but where it is desired to use very high inlet gas pressure P_0 . The use of the baffle 26 directs the liquid into the gas generally in the direction of the gas flow and prevents the gas from flowing back into the liquid feed conduit. Also, the annular shape of the opening 42 spreads the liquid around the nozzle and produces a symmetrical spray pattern.

The atomizer 70 has the further advantage that it produces an elongated spray or flame pattern which is highly desirable for many purposes. The use of the baffled liquid feed arrangement into the upstream portion of the nozzle rather than the downstream portion makes the elongated spray pattern possible by enabling the resonator diameter D_R to be considerably less than the metal throat diameter D^* without any noticeable effect upon the atomization quality produced by the device. It is believed that this is true because the evenly distributed sheet of liquid flowing through the stabilizing section 18 restricts the section and makes its effective diameter approximately the same as that of the resonator. The reduced cavity diameter allows the resonator member itself to be reduced in size, with the resultant narrowing and longitudinal extension of the spray pattern.

Most of the parameters of the nozzle and resonator structures disclosed above are described in the prior art. However, for the sake of completeness, some of the more important parameters will be discussed next.

In order to attain maximum atomizing power, the diameter D_R of the resonator cavity 22 should be approximately equal to the effective diameter D^* of stabilizing section 18. The depth L_R of the resonator cavity 22 preferably is equal to either $\lambda/2$ or $\lambda/4$, where λ is given approximately by the following equation:

$$\lambda = 1.307 D^* \sqrt{M_R^2 - 1}$$

in which M_R is the Mach number of the gas flowing at the exit of the diverging section 20 of the nozzle, and D^* is the nozzle throat diameter.

The half-angle of the diverging section should be maintained within the range of from about 3° or 4° to about 25°. The angle (b) shown in FIG. 2 is around 15°,

and the angle (d) in FIG. 4 is around 4°. The value of the half-angle of convergence of the converging section 16 ordinarily is not particularly critical and can vary widely, as is well known in the art. However, in order to align the passageway 40 approximately in the direction of the flow of gas through the nozzle, it is desired to keep the convergence angle relatively small. The angle (a) shown in FIG. 2 of the drawings is approximately 20°, and the angle (c) shown in FIG. 4 is approximately 5°.

The resonator support members 14 can have any shape desired, but preferably they consist of three relatively thin, symmetrically-positioned stainless steel wires.

It has been found that the atomizers constructed and operated in accordance with the present invention will produce very high turn-down ratios with high quality atomization throughout the range of flow rate variation. What is more, the control of the liquid flow rate is simple and positive, and the flame pattern produced by the device when used as a burner nozzle is quite symmetrical.

Applicants have discovered that atomizers with a structure quite similar to that shown in FIGS. 1 through 4, but with different fluid feed arrangements offer distinct advantages in many uses. One such atomizer 80 is shown in FIG. 5, in which corresponding parts are given the same reference numerals as before. The main difference between the atomizer 80 and the atomizers shown in FIGS. 2 and 4 is that liquid is fed through the center of the nozzle instead of at the periphery of the nozzle, and gas is fed through the holes 36 through which liquid is fed in the embodiments shown in FIGS. 2 and 4. Gas is pumped by a compressor 88 and is fed through an inlet tube 84 to an annular manifold 82, through the holes 36, along the baffle 26, and into the liquid at the entrance to the throat section 18. The liquid is pumped by a pump 86 through a conduit 90, through the throat section 18 and the diverging section 20, to form a jet which impinges upon the cavity-bearing resonator member 12.

The gas is pumped into the atomizer under relatively high pressures, e.g., 30 to 100 p.s.i.g., and mixes intimately with the liquid in the nozzle before the liquid-gas mixture emerges from the nozzle and strikes the cavity 22 in member 12.

The convergence and divergence angles of the nozzle of atomizer 80 are the same as those of the nozzle shown in FIG. 2. However, the throat section 18 is considerably longer than the corresponding throat section in the FIG. 2 structure. Another difference is that the diameter D_1 of the throat section 18 is larger than the diameter D_2 of the opening 16 of the baffle member. For example, the diameter D_1 in a typical nozzle which has been tested successfully is 0.344 inch, whereas the diameter D_2 is 0.312 inch. The spacing between the inner wall of the baffle 26 and the converging wall of the nozzle is 0.022 inch.

The atomizer 80 has several advantages. One significant advantage is that, because of its relatively large liquid feed passages, very badly contaminated liquids can be atomized without clogging the nozzle. This advantage is exemplified by the schematic showing, in FIG. 5, of a gas scrubber 87. In the scrubber 87, one or more atomizer 80 is used to atomize and spray water into an enclosure 95, which is, for example, a chamber receiving smoke-laden air from a furnace, in order to

"scrub" smoke or dust 97 out of the air. The smoke flows downwardly into the enclosure 95, and out through an opening 85. The smoke-and-debris-laden water 99 falls and collects at the bottom of the enclosure 95, and is pumped to a settling pond 93 by a pump 101 through a conduit 103. The debris-laden water enters the pond at one end, and is re-used by pumping it out through a conduit 91 at the other end of the pond, presumably after the debris has settled out in the pond. However, such water, when used, for example, to clean air from smoke in an asphalt-making plant, invariably has debris in it when it is re-used. Such debris includes pebble-sized cinders which will clog the feed holes of most atomizers. However, not so with the atomizer 80. Thus, the atomizer 80 is an extremely clog-free atomizer.

The baffle 26 and the inclined gas feed passageway it provides also help to prevent inoperativeness due to clogging. The inclination of the gas feed passageway towards the direction of gas flow minimizes the likelihood of objects becoming lodged in the passageway. Furthermore, the enlargement of the central passageway due to the change from diameter D_2 to diameter D_1 is believed to create suction on the gas passageway which tends to keep it open and clean.

Another advantage of the atomizer 80 is that it produces good atomization, quite sufficient to produce excellent gas scrubbing, and yet requires a relatively low gas flow rate for satisfactory operation. This can result in considerable savings in compressor equipment costs. The even spread of the gas when it is injected into the water at the edge of the baffle 26 is believed to assist in obtaining good atomization.

Alternative forms of the invention can be made by using gas feed holes 92 in the throat section 18, or inclined holes 94 in the diverging section, instead of the baffle 26 and feed holes 36.

The atomizer 80 also has been found to be particularly advantageous in aeration of liquids, or the dissolving of gases in liquids. Such a use of the atomizer 80 is illustrated in FIG. 6 of the drawings.

FIG. 6 shows a tank 98 with a body of liquid 100 in the tank. Submerged in the liquid is the atomizer 80. Gas is pumped to the atomizer 80 through a pipe 96. The pump 86 pumps liquid in the tank through the atomizer 80, in the manner illustrated in FIG. 5. The atomizer 80 intimately mixes the gas with the liquid, and issues the gas in tiny bubbles which thus come into intimate contact with the liquid. If the gas is soluble in the liquid, it often dissolves before reaching the surface of the liquid.

The gas which is dissolved in the liquid can vary considerably. For example, in the ozonization of water, ozone is fed into the atomizer 80 and dissolved in the water in the tank to kill algae, etc., in the water. Air, of course, chlorine, etc., are other examples of gases which it is useful to percolate through the liquid.

FIG. 7 illustrates another atomizer 110 which is essentially the same as the atomizer shown in FIGS. 1 and 2, except that only one row of diverge-section feed holes 38 is provided, and a barrier 111 is provided to separate the annular feed passageways and provide separate chambers 112 and 116 to feed the holes 38 and 36, respectively.

The atomizer 110 is used in a gas turbine engine, in the manner shown in U.S. Pat. No. 3,320,144, in which the main gas flow through the center of the nozzle is

created by the pressure difference between the combustion chamber interior and the compressor of the turbine. Since, during starting of the engine, the pressure on the gas fed to the atomizer is relatively low, higher pressure air is fed through a conduit 118 from a compressor 120 into the nozzle through the chamber 116 and holes 36. Pressurized liquid fuel is fed to the holes through the conduit 114. Then, when the rotational speed of the compressor of the turbine increases to a sufficient level, the separate air source 120 is removed, and the only air flow is through the center of the nozzle.

A significant advantage of both of the nozzles 80 and 110 shown in FIGS. 5 and 7 is that the cross-sectional area provided by the holes 36 is substantially less than the area of the central passageway through the nozzle, with the result that atomization is accomplished with a considerably reduced air flow volume. Thus, the compressors 88 and 120 can have a lower flow capacity and can be less expensive than higher capacity compressors which otherwise might be required.

We claim:

1. A method of controlling the atomization of liquids in a gas-operated resonant pressure wave atomizer producing a high-speed gas stream, said method comprising supplying said liquids to the gas stream under pressure from a common liquid supply to two separate locations in said stream, controlling the rate of flow of said liquids into said stream, regulating the gas pressure at the first of said locations to remain within a range from a minimum gas pressure which is greater than the minimum liquid pressure value, to a maximum gas pressure which is smaller than such maximum liquid pressure value, and regulating the gas pressure at the second of said locations to maintain it at a value always lower than said minimum liquid pressure value.

2. A method as in claim 1 including the step of supplying said liquids to said stream at said first location in substantially the same direction as the flow of said stream.

3. A method as in claim 1 in which said first locations are within a converging-diverging nozzle forming a part of said atomizer, and including the step of supplying a pressurized gas to said converging section of said nozzle, and controlling the supply pressure of said gas to perform said pressure regulation step.

4. A method as in claim 3 in which said gas is injected into said liquid stream at a pressure of over approximately 30 p.s.i.g.

5. A method as in claim 3 in which said stream is directed towards a cavity having a diameter which is approximately equal to the diameter of the throat of said nozzle.

6. A method as in claim 5 in which said nozzle has a straight-walled section of substantially constant cross-sectional area between its converging and diverging sections.

7. A method of controlling the atomization of liquids in a gas-operated resonant pressure wave atomizer, said method comprising supplying said liquids to the gas stream flowing through said atomizer under pressure from a common liquid supply to two separate locations in said stream, controlling the rate of flow of said liquids into said stream, setting the liquid feed pressure at one of said locations approximately equal to the gas stream pressure at said one location when the input gas pressure to said atomizer is approximately equal to the

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common liquid supply pressure, and varying said input gas pressure with the variation in said liquid flow rate so as to make said input gas pressure lower than said common liquid supply pressure at relatively high liquid flow rates, and higher than said common liquid supply pressure at relatively lower liquid flow rates.

8. An atomizing and mixing method comprising the steps of forming a liquid stream by forcing a liquid through converging-diverging nozzle, directing said stream towards a cavity in a cavity-bearing member, and injecting a gas into said liquid stream at a plurality of positions around said stream.

9. A method as in claim 8 in which said cavity has a depth of approximately $\lambda/2$ or $\lambda/4$ where:

$$\lambda = 1.307 D^* \sqrt{M_g^2 - 1}$$

in which M_g is the Mach number of gas flowing at the exit of the diverging section of the nozzle, with only gas flow through the center of the nozzle, and D^* is the nozzle throat diameter.

10. A method as in claim 8 in which said gas is in-

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jected within said nozzle, at a location downstream from the start of the converging section of said nozzle.

11. A method as in claim 10 in which said gas is injected through an annular opening surrounding said stream, at an angle directed towards the flow of said stream.

12. An atomizing and mixing method comprising forcing a liquid through the central passageway of a nozzle, said nozzle having a converging inlet section, a straight-walled connecting section of substantially constant cross-sectional area, and a diverging outlet section, directing the liquid emerging from said passageway into a resonator cavity, and injecting a gas under pressure into the liquid while flowing within said passageway, said resonator cavity having a diameter approximately the same as that of said connecting section, said gas being injected through inlet holes of substantially less cross-sectional area than that of said passageway.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,758,033 Dated September 11, 1973

Inventor(s) Robert E. Schurig and Joseph Korn

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 4, line 1, change "Claim 3" to --Claim 8--.

Claim 5, line 1, change "Claim 3" to --Claim 8--.

Signed and sealed this 23rd day of April 1974.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents