STEPPED VORTEX CHAMBERS — GEOMETRY

FIG. 3

D/d = 6

FIG. 4

D/d = 3.5

FIG. 5

D/d = 1.5

FIG. 6

FIG. 7

FIG. 8

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ABSTRACT OF THE DISCLOSURE

A liquid atomizer having a cylindrical vortex chamber with at least one tangential inlet, and a concentric outlet tube. A substantially sharp corner marks the transition from the chamber to the outlet tube and the chamber wall through which the outlet tube opens is substantially normal to the latter. A liquid feed tube is provided axially within the outlet tube and has a port for expelling a jet of liquid centrifugally toward the outlet tube walls.

This invention relates to devices for atomizing liquids, and has to do particularly with the application of the rotary vortex to the problem of liquid atomization. A particular application of the device to which this invention is directed relates to the atomization of fuel oils.

This application is a continuation-in-part of U.S. patent application No. 650,342 entitled "Two-Stage Sonic Atomizing Device," Charles F. Pecelli and Edward T. Trycz, filed June 30, 1967, now abandoned.

Before going into the specific objects and advantages of the present invention, it will be helpful to discuss several theoretical points relating to the proper operation of fuel oil burners.

Most kinds of oil fuel require approximately 14.5 pounds of combustion air to burn completely 1 pound of fuel. This ratio is referred to scientifically as the "stoichiometric ratio," and its significance is simply that it takes about 14.5 pounds of air to provide sufficient oxygen to burn all of the carbon, hydrogen and other combustibles in 1 pound of fuel oil. In order to ensure that the fuel oil is completely burned, however, it is standard practice to provide an excess amount of air at the point of burning. This is done because no fuel atomizer is able to create a nebulus spray whose burning characteristics are the same as if the fuel oil were vaporized, and because complete and homogeneous mixing of the combustion air with the atomized fuel is never fully attained. When the necessary excess air is greater than about 5% of the stoichiometric amount, the result will be a substantial amount of oxygen exiting from the burning chamber along with the combustion gases. The problem here arises because of the sulphur present in the oil. Most of the sulphur burns to SO\textsubscript{2}, but if excess oxygen is present, a portion of the sulphur will burn to SO\textsubscript{3} and the latter will combine with water vapour to form sulphuric acid, H\textsubscript{2}SO\textsubscript{4}, which is corrosive to metal surfaces, etc. However, when the stoichiometric excess air is limited to the area of 5% or less, there is a considerable reduction in the SO\textsubscript{2} production, and the evolution of H\textsubscript{2}SO\textsubscript{4} substantially disappears.

In order to permit the stoichiometric excess air to be limited to the area of 5% or less, it is necessary to set up high reaction rates in the combustion chamber, so that some of the hot combustion gases will be caused to recirculate back to the point at which the cool air-fuel mixture enters. The combustion gases mix with the incoming air-fuel mixture, promoting a high rate of evaporation and rapid combustion, and thus improving the efficiency of the burning.

One way of promoting a high recirculation rate of the combustion gases is to provide a fuel atomizer which has a wide spray angle.

In view of the above, it is one object of this invention to provide an atomizer which is capable of producing a wide-angle atomized spray of liquid.

A further object of this invention is to provide an atomizing device utilizing the principle of gas-vortex atomization, which is capable of utilizing a high-pressure vortex medium, and can efficiently atomize certain thick, viscous liquids, such as the heavier fuel oils and pitch fuels.

Essentially, the apparatus of this invention achieves the above objects by utilizing a particular rotary-vortex chamber design to produce a high-speed rotary vortex of an atomizing medium such as steam or air, in combination with a two-stage atomizing technique carried out at the downstream end of an outlet tube in which the atomizing medium is rotating. The special design of the vortex chamber and outlet tube produces a desired ratio of axial to tangential velocity within the outlet tube and results in a wide-angle spray cone, while the two-stage atomizing technique ensures that a high degree of comminution and nebulization of the heavy viscous oil will occur.

More particularly this invention provides a liquid atomizer comprising: means defining a substantially cylindrical chamber having a forward end wall and a rearward end wall, a cylindrical outlet nozzle defining at least part of said forward end wall and having an outlet bore of diameter less than that of said chamber, and extending co-axially away from the chamber, the forward end wall and the outlet bore meeting to define a substantially sharp corner around which gas must pass when moving from said chamber into said outlet bore, at least one substantially tangential inlet to said chamber, means for causing a gas to pass under pressure through said inlet and into said chamber so as to set-up a rotating vortex in said chamber, the said pressure being sufficient to cause the rotational speed of the gas in the chamber at a radius equal to that of the outlet bore to be greater than sonic, whereby the gas exits from the chamber through the outlet bore while rotating at a speed greater than sonic and establishes a rotating vortex along the outlet bore the speed of which decreases, due to friction, to substantially sonic velocity near the downstream end of the outlet bore, and liquid feed means located substantially axially within said outlet bore for expelling at least one jet of liquid centrifugally into the vortex where the latter has substantially sonic velocity.

One embodiment of this invention is shown in the accompanying drawings, in which like numerals refer to like parts throughout the several views, and in which: FIG. 1 is an axial sectional view through the nozzle of an oil burner equipped with a vortex-type atomizer; FIG. 2 is a transverse sectional view taken at the line 2-2 in FIG. 1; FIGS. 3, 4 and 5 are diagrammatic axial views of three vortex chamber designs, utilized in a discussion of comparative energy requirements; FIGS. 6, 7 and 8 are axial sectional views of the vortex chamber designs shown in FIGS. 3, 4 and 5, respectively; and FIG. 9 is a graph showing energy conversion, for the three vortex chamber designs shown in FIGS. 3 to 8, as the atomizing medium passes from the tangential inlet through the device to the downstream end of the outlet tube.

FIG. 1 shows an oil burner nozzle 10, which includes a cylindrical atomizer mounting sleeve 12 into the open end of which is threaded a conical vortex body 14. The
Apex of the conical vortex body 14 has an axial bore 15 which is widened at 16 to define an annular shoulder 17. A gas nozzle 18 is shaped to fit snugly within the bore 15 and the widened portion 16 in the conical vortex body, and is held in position by a vortex chamber housing 20 which is threaded into the conical vortex body 14.

A feed tube 22 extends in sealed relationship through an axial aperture 23 in the vortex chamber housing 20, and passes centrally through the vortex chamber 21 to enter concentrically a co-axial outlet bore 24 in the gas nozzle 18. The diameter of the outlet bore 24 is greater than the diameter of the feed tube 22, so that an annular space 26 is defined therebetween. At its upstream end, the feed tube 22 is connected, by welding or press-fitting, to a tubular connecting element 28 which is in turn connected to a fuel line (not shown) which delivers fuel under pressure to the connecting element 28 and thence to the feed tube 22. The connecting element 28 is secured centrally through a partition 30 which is threaded into the upstream end of the conical vortex body 14.

A pressurized gaseous medium is delivered to the nozzle 18 through a line (not shown) located inside the atomizer mounting base 13 and fastened in eccentric port 31. For the remainder of this description, the medium is considered to be steam, although other gases can be used, as is later discussed. The steam passes into an antechamber 32 defined by the partition 30, the conical vortex body 14 and the vortex chamber housing 20. From the antechamber 32 the pressurized steam enters the vortex chamber 21 through a tangential inlet 34 constituted by a bore hole drilled through the wall of the vortex chamber housing 20, as shown in FIGS. 1 and 2.

Because of the tangential orientation of the inlet 34, the steam rotates within the vortex chamber 21 in a counterclockwise direction, as seen from the downstream end of the chamber. The steam exits from the vortex chamber 21 by way of the annular space 26 defined between the outlet bore 24 and the feed tube 22. The steam, in progressing from the periphery of the vortex chamber 21 toward its centre, undergoes an increase in rotational speed, the increase varying inversely with the square root of the radius. The steam passes into the outlet bore 24 and continues to spin at this higher rotational speed as it passes along the outlet bore 24 slowing slightly due to friction, and it finally spins out into the open at the right-hand end of the outlet bore 24.

It is possible, of course, to provide any number of tangential inlets 34, provided their total cross-sectional area is suited to the required flow. Also, a slight deviation from the strictly tangential direction is unlikely to have a significant effect on atomization.

This invention provides a two-stage atomization of the liquid to be atomized. The first stage involves forcing the fuel under pressure through one or more restricted ports 36 drilled in the periphery of the feed tube 22. The downstream end of the feed tube 22 is closed as shown, and the ports 36 are drilled in the feed tube 22 closely adjacent the closed downstream end. The ports 36 function as nozzles which send thin jets of the liquid centrifugally outwardly into the periphery of the vortex created by the spinning steam. Because of the high rotational speed of the vortex, most of the steam is thrown outwardly and forms a rotating film or layer adjacent the walls of the axial bore 24. As the thin jets of the liquid entering the rotating steam layer, they are further broken up, and more finely atomized.

To achieve the best atomization, the size, number, orientation and axial position of the ports should be properly selected. The size of the ports should be such that there is no danger of the liquid clogging or blocking the ports. The number of ports should be such that the required liquid flow is achieved at the desired pressure. The orientation of the ports, although here considered to be radial, can also be partially or fully tangential to the feed tube 22 and/or tilted in the axial direction at an angle between 0° and 90°, where conditions warrant it. Even angles exceeding 90° (i.e., the liquid jet is directed, partially, against the flow of the vortex medium) may be of advantage under certain circumstances. As used in this disclosure and in the appended claims, the word "centrifugally," as applied to the ports 36 and to the direction of the liquid sprayed from the feed tube 22, is meant to include all tangential angles and all axial inclinations. The location of the ports is dependent upon several considerations. Firstly, the ports should be inside of the outlet bore 24 to ensure that the liquid particles spend a long enough time in the region of violent disturbance to become properly atomized. However, since the liquid particles are swirled around in an ever increasing spiral path due to both the radial component of liquid velocity and the centrifugal force, the ports 36 must be close enough to the downstream open end of the annular space 26 to ensure that most of the particles leave the nozzle before they contact the walls of the outlet bore 24.

The presence of the rotating layer of steam adjacent the wall of the outlet bore 24 helps to ensure that contact between the liquid particles and the wall will be minimal.

Air was delivered to the tangential inlets at 48 p.s.i.g. pressure and at negligible velocity, and the transform...
of the total available pressure energy as the air travelled through the prototype was determined primarily on the basis of pitot tube measurements, and plotted on the solid line in FIG. 9. Attention is now directed to FIG. 9.

In FIG. 9, the total energy available in the pressurized medium prior to entering the tangential inlets is indicated by the upper circled dot with the number 1. At this point, the energy available in the pressurized medium is 42½ B.t.u.'s per pound. At this point, the medium is considered to be momentum free, so the kinetic energy is zero, as shown by the circled dot at the bottom bearing the number 1.

As the medium passes through the tangential inlets to the position 2 (see FIG. 4) where it is about to enter the vortex chamber, it is accelerated to 880 feet per second, and there is a slight loss in available energy on account of friction. This loss of available energy is shown by the drop in the upper line to the circled dot number 2, at which the total available energy is reduced to 41.5 B.t.u.'s per pound. Frictional losses account for the 1 B.t.u. per pound difference. At the same time, the kinetic energy increased steeply rise in the bottom line from 1 to 2. The pressure energy in the air at this point is represented by the distance between the two dots marked 2, but the kinetic energy is shown to be about 15.5 B.t.u.'s per pound.

The air next enters the vortex chamber, and in doing so, passes from point 2 to point 3 in FIGS. 4 and 7 and in the graph of FIG. 9. Due to the sudden change of cross-section and also to the change of direction (from straight to rotation), there is an appreciable energy loss. It is seen in FIG. 9 that the irreversible frictional losses have reduced the total available energy to about 35 B.t.u.'s per pound, that the pressure energy available has been reduced slightly, and that the kinetic energy has been reduced significantly.

The rotating air next moves spirally inwardly toward the centre of the vortex chamber, and its kinetic energy increases in inverse ratio to the diameter. The axial component is zero, the radial component is negligible, and the tangential component increases from 666 feet per second on the periphery to 1215 feet per second on the one inch diameter line. This stage is shown in the FIGS. 4 and 7 and in the graph of FIG. 9 as a progression from point 3 to point 4. Irreversible frictional losses result in a slight reduction in the total available energy to about 31.3 B.t.u.'s per pound, while nearly all of the available pressure energy is converted to kinetic energy through the increase of speed, as will be seen by the closeness of the two points marked 4 in FIG. 9.

The next stage is the entry of the rotating air into the outlet bore; 4-5 in FIG. 9. As the air moves along the outlet bore from point 5 to point 6, it is stabilized. Friction losses, however, increase the volume of the air by heating it and causing its pressure to drop, and thus more tangential velocity is converted into axial velocity. In this process, the energy loss is appreciable, as can be seen by the steep drop of the two lines 4-5 in FIG. 9.

As the air moves along the outlet bore, the ratio of tangential velocity to the axial velocity becomes constant. In the atomizing section the air velocity is found to be sonic at 1,046 feet per second, with a tangential component of 768 and an axial component of 538 feet per second. Virtually all of the air is discharged on the periphery, in a layer of 0.10 inch thickness. In the central core, the density is small and the axial velocity is negligible.

The foregoing discussion relates to vortex atomizers with different D/d ratios. It was assumed that these must match the prototype described above in capacity and in the quality of atomization, and it was therefore assumed that identical conditions would be required downstream.

For the case in which the D/d ratio is 1.5 (FIGS. 5 and 8), the increase in velocity in the process 3-4 (the radial inward movement in the vortex chamber) will be small. To make up for this, the discharge velocity in the tangential inlets (process 1-2) must be significantly higher, and works out to be in the neighborhood of Mach 1.5. But, if this very high velocity stream enters a smaller diameter vortex chamber, the energy losses in the process 2-3 will be extremely high. Thus, the initial energy requirement in B.t.u.'s per pound must be higher than that for the tested prototype worked out above which had a D/d ratio of 3.312. Refer in FIG. 9 to the broken lines identified by the circled numerals with asterisks.

Conversely, if the diameter of the vortex chamber is in a larger ratio to the outlet bore than is the case with the prototype described above, for example, 6 inches to 1 inch (FIGS. 3 and 6), then the velocity increase in the process 3-4 is higher. To compensate for this, the discharge velocity from the inlet (process 1-2) is proportionately lower. But, since part of the work of converting pressure to kinetic energy was transferred from a more efficient to a less efficient process, the required supply pressure is higher, and thus the required energy content in B.t.u.'s per pound of the atomizing medium must be higher. Refer in FIG. 9 to the broken lines identified by the circled numerals 1', 2', 3', etc.

To avoid confusion on this point, it is to be emphasized that neither the quality of the atomization, nor the consumption of the atomizing medium, depends on the D/d ratio. However, with ratios of 1.5 or lower, it is considered that the required supply pressure for the medium becomes prohibitively high. With ratios of 6 or higher, the increase in supply pressure is moderate, but the size of the atomizer itself is unduly large. For these reasons, it is considered that ratios between 1.5 and 6 are preferable for practical applications.

The cylindrical outlet bore is considered an essential part of this invention, because it is necessary for the stabilization of the flow. Without the discharge nozzle, the conditions in the region of atomization would be so unstable that uniform atomization would not be possible.

In order to avoid excessive conversions of pressure velocity to axial velocity where the atomizing medium passes from the vortex chamber into the outlet bore, it is considered essential to provide a substantially sharp corner with an approximate right-angular orientation. It is considered that the degree of sharpness of the corner is a more important criterion than the exact perpendicularity, and in fact it is likely that the operation of the device described herein would not be adversely affected by a small departure from perpendicularity of the order of 5° or 10°, or even more.

If, however, the forward wall of the vortex chamber is a cone with an enclosed angle of considerably less than 180°, for example from 30° to 90°, then the dominant velocity component in the vortex chamber will be an axial one, and this will be the case even more so in the outlet bore, resulting in a very narrow angle spray which would produce a recirculating type of pattern in the combustion chamber. Furthermore, because of the higher axial velocity, the flow rate of the atomizing medium would have to be significantly higher to provide an acceptable layer thickness around the inside wall of the outlet tube at its discharge end.

Since this invention relates essentially to an atomizer utilizing a high-pressure medium, it is particularly adapted for use with high-pressure steam. In most burner installations, either compressed air or steam is used for the atomization of heavy oil fuels. Of these two, steam is the most common for economic reasons. In the gener-
ation of steam, the largest portion of the required energy (heat) is used for the evaporation of the water, and the pressure of the steam requires only a small portion of energy by comparison. For example, to generate 1 pound of steam (100% quality) at 5 p.s.i.g., requires 976 B.t.u.'s, while the generation of 1 pound of steam at 75 p.s.i.g. requires 1,065 B.t.u.'s.

Since the atomizer discharges steam of 100% quality, the energy released by the steam as its expands to atmospheric pressure is highly dependent upon the steam pressure. For example, 5.7 B.t.u.'s per pound is available from 5 p.s.i.g. steam and 35 B.t.u.'s per pound is available from 75 p.s.i.g. steam.

To illustrate this point in a slightly different way, atomization energy of 100 B.t.u.'s can be derived from either

(a) 17.5 pounds of 5 p.s.i.g. steam, generated at the cost of 17,100 B.t.u.'s of heat, or
(b) 2.85 pounds of 75 p.s.i.g. steam, generated at the cost of 3,000 B.t.u.'s of heat.

It is obvious from the above that the use of high-pressure steam is far less costly than the use of low-pressure steam. The use of low-pressure steam for atomization is justified only if it is available at virtually no cost (such as, for example, the 50 p.s.i.g. turbine exhaust).

What we claim as our invention is:

1. A liquid atomizer comprising:
   means defining a substantially cylindrical chamber having a forward end wall and a rearward end wall,
   a cylindrical outlet nozzle defining at least part of said forward end wall and having an outlet bore of diameter less than that of said chamber and extending co-axially away from the chamber, the forward end wall and the outlet bore meeting to define a substantially sharp corner around which gas must pass when moving from said chamber into said outlet bore,
   at least one substantially tangential inlet to said chamber,
   means for causing a gas to pass under pressure through said inlet and into said chamber so as to set up a rotating vortex in said chamber and along the outlet bore, the said pressure being sufficient to cause the velocity of the gas at the downstream end of the outlet bore to be substantially sonic, and liquid feed means located substantially axially within said outlet bore for expelling at least one jet of liquid centrifugally into the vortex where the latter has substantially sonic velocity.

2. A liquid atomizer as claimed in claim 1, in which the downstream end of the outlet tube has an outward conical flare in the downstream direction.

3. A liquid atomizer as claimed in claim 1, in which a ratio $D/d$ is greater than 1.5, where
   $D$ is the internal diameter of the cylindrical chamber, and
   $d$ is the internal diameter of the outlet bore.

4. A liquid atomizer as claimed in claim 1, in which said liquid feed means comprises a feed tube which extends from a liquid source co-axially through said cylindrical chamber and into said outlet bore to a point adjacent the downstream end of the outlet bore, the downstream end of the feed tube having at least one jet port for expelling said jet of liquid centrifugally into the vortex.

5. A liquid atomizer as claimed in claim 4, in which a ratio $D/d$ lies between 3 and 4, where
   $D$ is the internal diameter of the cylindrical chamber, and
   $d$ is the internal diameter of the outlet bore.

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