TWO-STAGE SONIC ATOMIZING DEVICE

Filed April 14, 1969 3 Sheets-Sheet 1

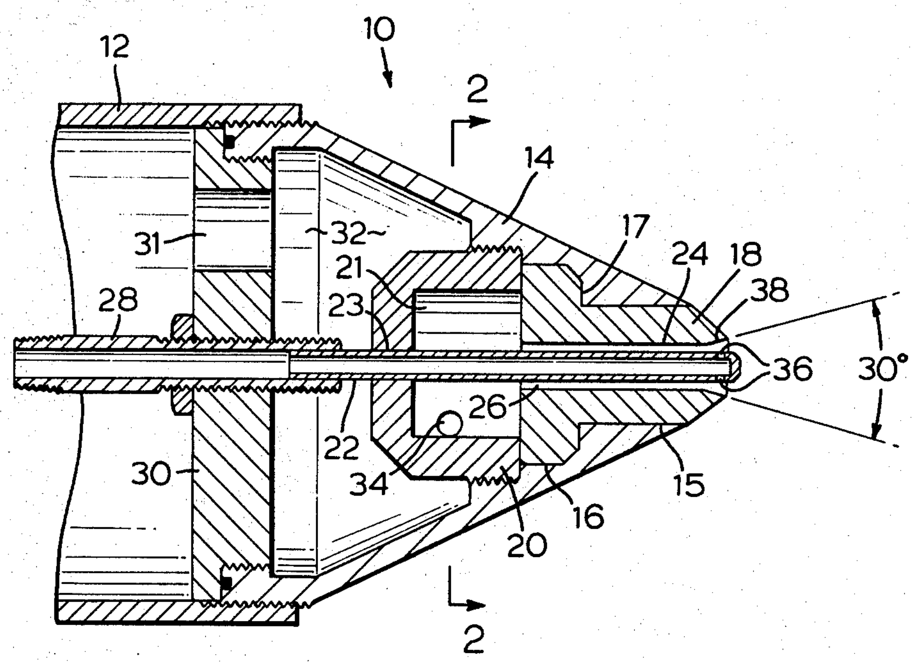

FIG. 1

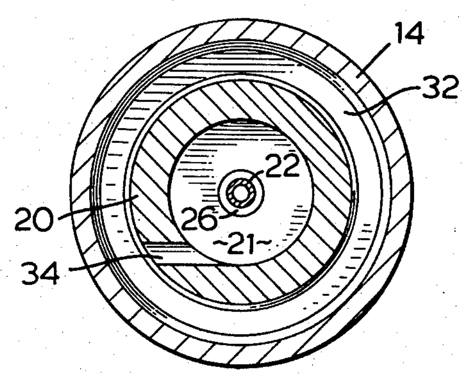

FIG. 2

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PATENT AGENT

STEPPED VORTEX CHAMBERS — GEOMETRY

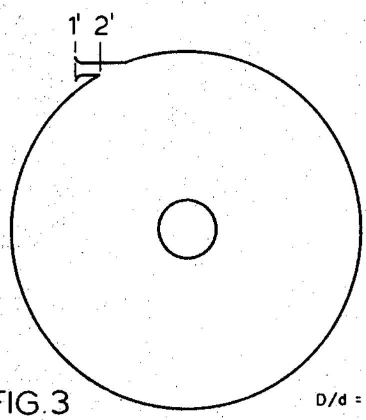

FIG.3

D/d = 6

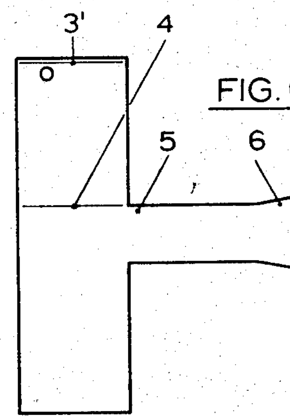

FIG. 6

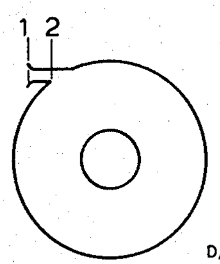

FIG. 4

D/d = 3.312

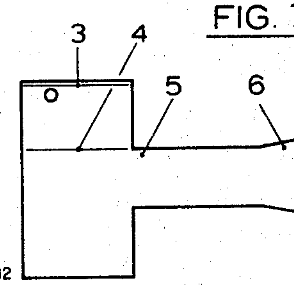

FIG. 7

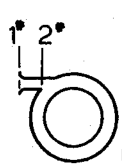

FIG. 5

D/d = 1.5

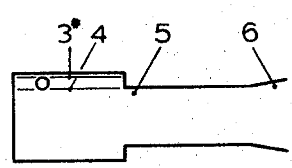

FIG. 8

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TWO-STAGE SONIC ATOMIZING DEVICE

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STEPPED VORTEX CHAMBERS — ENERGY vs LOCATION

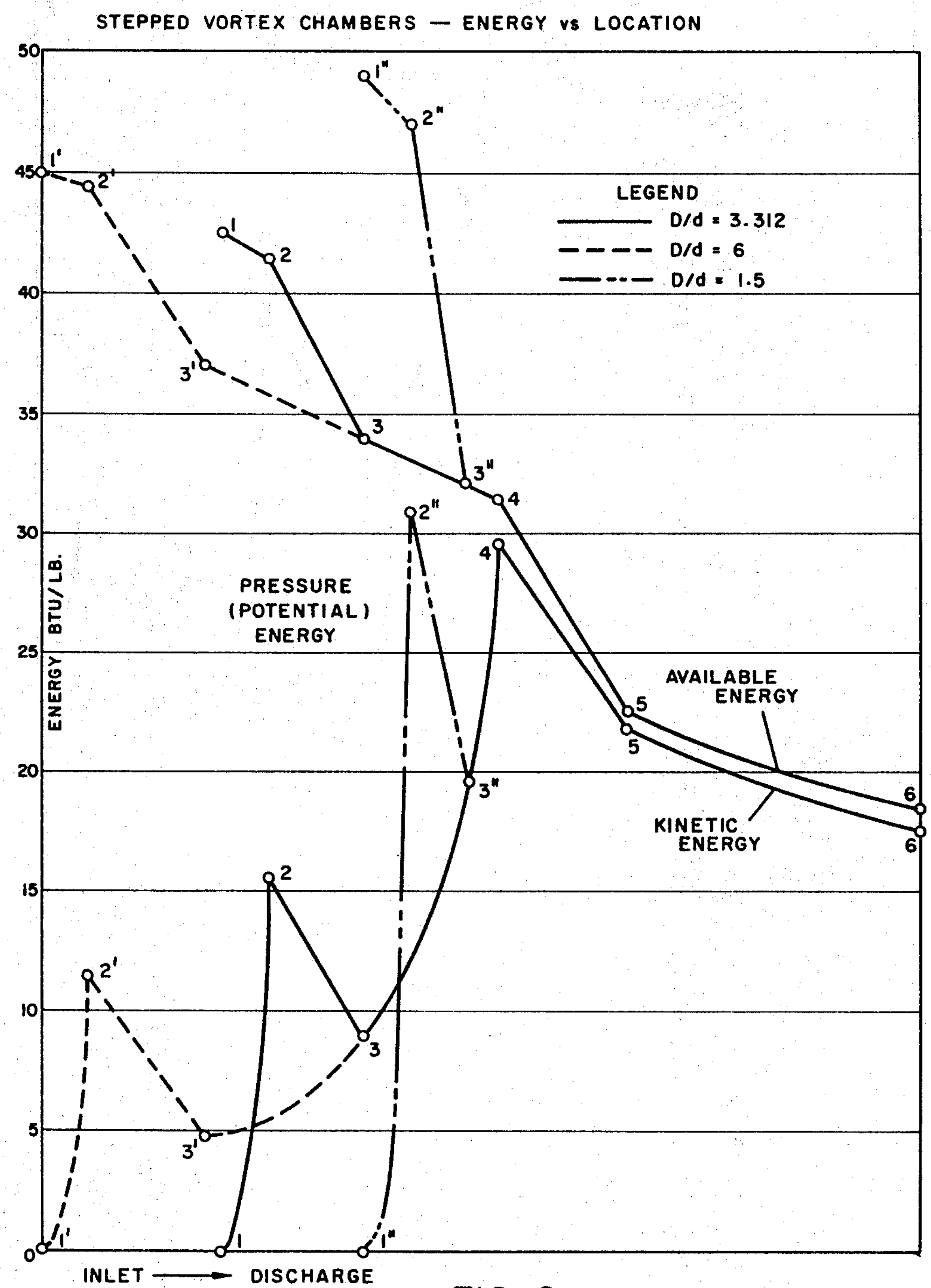

FIG. 9

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Thomas ... [signature]

United States Patent Office

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Patented Nov. 3, 1970

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3,537,650

TWO-STAGE SONIC ATOMIZING DEVICE

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Continuation-in-part of application Ser. No. 650,342, June 30, 1967. This application Apr. 14, 1969, Ser. No. 825,091
Int. Cl. B05b 7/10
U.S. Cl. 239—405 5 Claims

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 "Two-Stage Sonic Atomizing Device," Charles F. Peczeli 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 nebulous 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_2, but if excess oxygen is present, a portion of the sulphur will burn to SO_3, and the latter will combine with water vapour to form sulphuric acid, H_2SO_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_3 production, and the evolution of H_2SO_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 recirculation 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 liquid, 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 nebularization 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 vertex 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 outside diameter of the feed tube **22**, such 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 **10** through a line (not shown) located inside the atomizer mounting sleeve **12** 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 counter-clockwise sense as seen in FIG. 2. 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 expel 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 impinge upon 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.

Although in the embodiment shown, the ports **36** are all at the same axial location, it is conceivable that two or more sets of ports could be provided at different axial locations, or that the individual ports could be arranged along the feed tube **22** in a random distribution, both axially and radially.

It has been found helpful to provide a slight outward conical taper **38** at the downstream end of the outlet bore **24**. A preferred angle for the conical taper is 30°, although this is not critical.

A discussion now follows of the reasons why an abrupt and clearly defined step between the vortex chamber and the outlet tube is considered an essential part of this invention.

Firstly, from the point of view of efficiency, it is considered that the atomizing medium should be moving at sonic velocity at the point of atomization. Supersonic velocities, as a rule, generally involve heavy energy losses, while subsonic velocities require an unduly high consumption for a given energy requirement.

Secondly, in order to achieve an acceptable recirculation pattern of the atomizing medium-fuel spray components within the combustion chamber, it is necessary to ensure that the ratio of tangential to axial velocity at the discharge is in the neighbourhood of 1:1 or higher.

Thirdly, the layer of the atomizing medium in the discharge of the outlet bore, described above, must be sufficiently thick to prevent the penetration of the fuel, since penetration leads to agglomeration on the inside wall, and thus to the formation of large particles. It will be obvious, then, that with a 1:1 velocity ratio, there will be a mathematical inter-relationship between the diameter of the discharge nozzle, the flow rate of the atomizing medium, and its axial velocity component.

The energy requirement, in B.t.u.'s per pound of atomizing medium, can be minimized by selecting a D/d ratio within a given range, where

D is the diameter of the vortex chamber, and
d is the diameter of the outlet bore **24**.

To illustrate these points, attention is directed to FIGS. 3 to 9. FIGS. 4 and 7 show the comparative diameters in an actual experimental prototype which was built and tested under working conditions. The D/d ratio was 3.312, and the actual dimensions of the prototype were as follows:

Vortex chamber diameter, D=3.312 inches.
Outlet bore diameter, d=1.000 inch.
The vortex chamber had six tangential inlets, each one being 0.125 inch in diameter.

Air was delivered to the tangential inlets at 48 p.s.i.g. pressure and at negligible velocity, and the transformations 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 as 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 motionless, and 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 numbered **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 increases as shown by the steep 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 34 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 increase 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 **24**, and at this stage a part of its tangential velocity is converted to 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 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.

At stage **6**, representing the divergent section of the outlet bore, the ratio of tangential velocity to axial velocity becomes constant. In the atomizing section the air velocity was 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 following 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

of stage **4**. It was also assumed that the diameter of the outlet bore would be the same. Starting with these assumptions, the necessary graph points were calculated backwards from stage **4** for a D/d ratio of 1.5 and for a D/d ratio of 6.

For the case in which the D/d ratio is 1.5 (FIGS. 5 and 8), the increase of 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 intial 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 conversion of tangential 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 not 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 generation 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 1,005 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 tube.

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LLOYD L. KING, Primary Examiner

U.S. Cl. X.R.

239—425, 426