June 16, 1964 A. BIBER ETAL 3,137,338

PROCESS AND APPARATUS FOR BURNING LIQUID OR GASEOUS FUEL

Filed May 2, 1960

2 Sheets-Sheet 1

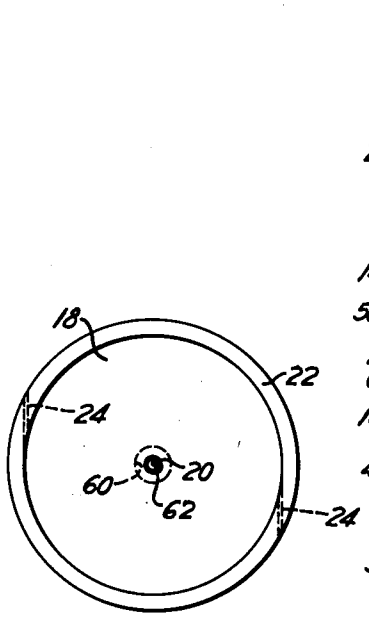


Fig. 2

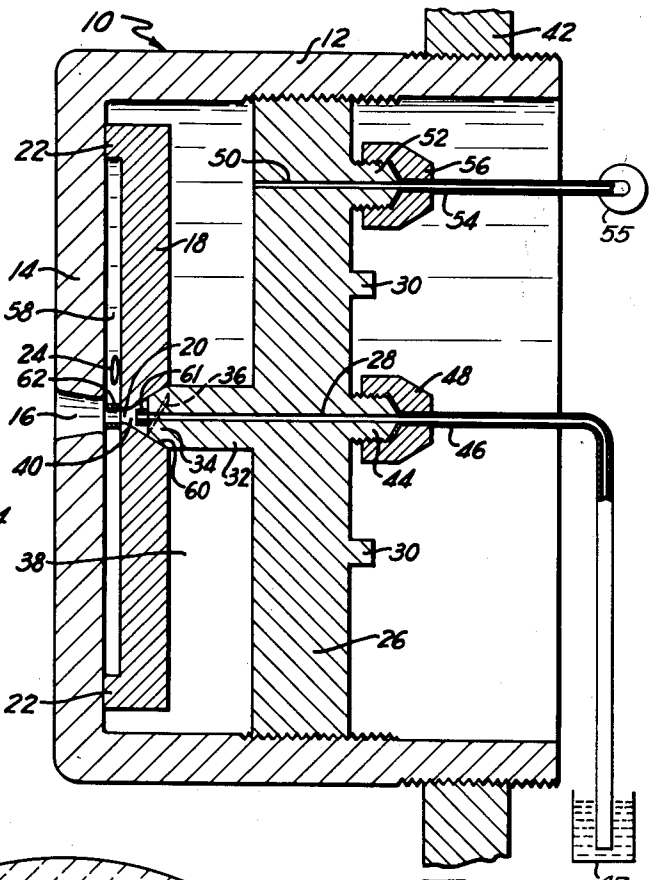


Fig. 1

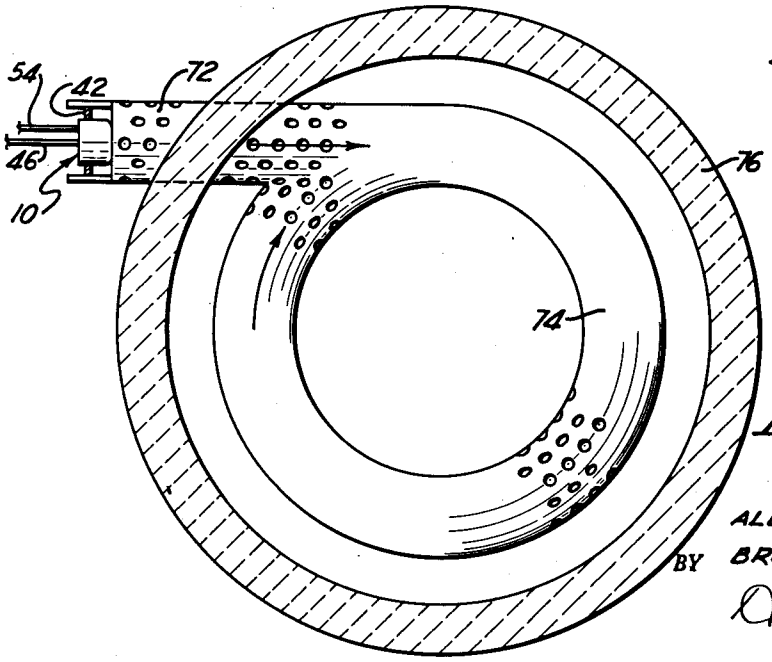


Fig. 3

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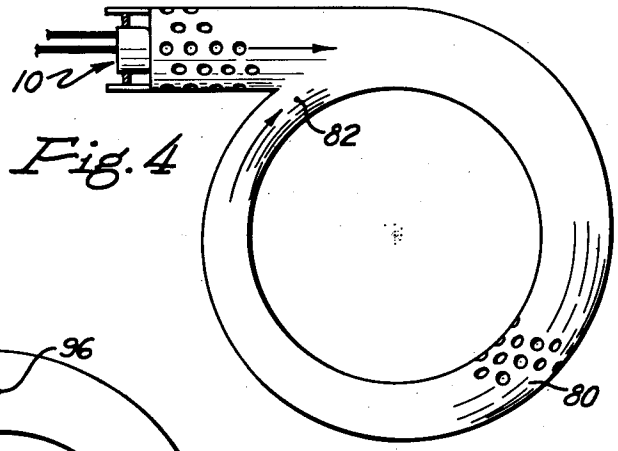


Fig. 4

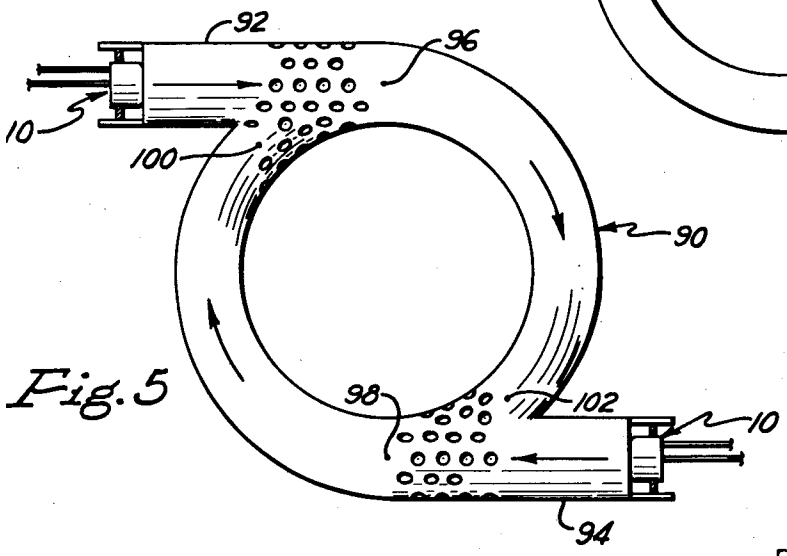


Fig. 5

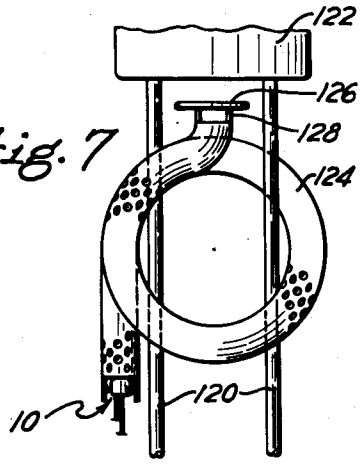


Fig. 7

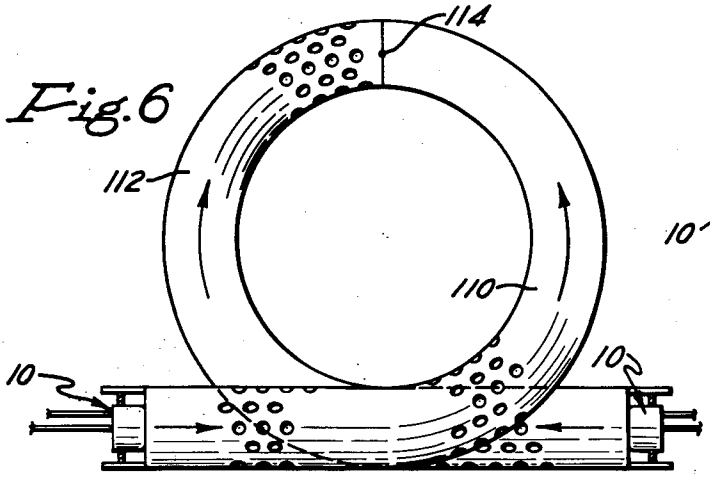


Fig. 6

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3,137,338

PROCESS AND APPARATUS FOR BURNING LIQUID OR GASEOUS FUEL

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Filed May 2, 1960, Ser. No. 26,132
30 Claims. (Cl. 158—76)

This invention relates to process and apparatus involving burner nozzles disposed cooperatively with perforated tubular flame ducts having bent or curved longitudinal axes whereby the flame from a burner nozzle is caused to be bent or curved along the axis of a perforated duct.

We have discovered that the flame produced by combustion of fuel sprayed through a nozzle can be bent or curved to substantially follow the longitudinal axis of a bent or curved perforated tubular duct to which the nozzle is directed. When the fuel being burned is gaseous, the type of nozzle to be employed in cooperation with a bent or curved perforated duct is not critical. The reason for this is that upon ignition of gaseous fuel emitted from any common type of nozzle the flame is relatively compact and elongated. For example, in the case of gaseous fuel the nozzle to be employed can either be of the type that does or does not swirl the fuel and can either be of the type that does or does not admix the gaseous fuel with air prior to spraying.

When liquid rather than gaseous fuel is being burned the type of nozzle to be employed in cooperation with a bent or curved perforated tubular duct is highly critical and in the case of liquid fuel the nozzle must be of the type wherein an aspirating gas passing through the nozzle draws the liquid fuel oil into the nozzle as described below. When charging liquid fuel unless an aspirating type nozzle as described below is employed the flame produced upon combustion of the spray emitted by a nozzle is not sufficiently compact and elongated to follow the axis of a bent or curved perforated tubular duct. Although the aspirating nozzles of this invention are especially adapted to be employed with a liquid fuel and although this invention is particularly directed to the use of liquid fuel if it is so desired gaseous fuel can be employed in place of liquid fuel in any embodiment of the process and apparatus of this invention.

In the combination of a burner nozzle and a perforated tubular flame duct the improvement of this invention comprises employing a nozzle of the aspirating type having a first opening, a second opening and a discharge orifice, a first conduit leading from said first opening to a pressurized gas source, a second conduit leading from said second opening to an oil reservoir on a level lower than said nozzle, said second conduit terminating below the oil level in said reservoir, said second opening being positioned so as to subject the oil in said oil reservoir to an aspirating effect created by the passage of gas from said first opening through said nozzle, said nozzle disposed so that its discharge orifice opens into one end of a perforated tubular duct whose central axis is inclined or nonlineal with respect to the central axis of the burner nozzle over at least a portion of its length, the degree of bending or curvature of the axis of said duct being sufficiently low that the nozzle flame can be substantially contained within the perforated duct without direct impingement upon the walls of the duct. Preferably, a length of the perforated duct in the region of the open end to which the nozzle is directed is straight and the nozzle is disposed coaxially with the duct in this straight region.

We have now discovered that when employing a nozzle wherein fuel oil is aspirated into the nozzle by means of the suction created by the flow of pressurized gas, such as air, the flame created upon ignition of the fuel-air spray mixture emitted by said nozzle can be bent or curved to substantially follow the longitudinal axis of a bent or curved perforated tubular duct and the perforations of such tubular duct allow inward aspiration of the remaining amount of air required for substantially complete combustion. In accordance with this invention the flame is substantially prevented from impinging upon the wall of the duct.

The practice of this invention prevents a burner flame from directly impinging upon the wall of a vessel, such as a furnace, thereby reducing heat loss, avoiding deterioration of materials of construction, avoiding surface accumulation of various deposits such as carbon, coke and corrosive materials as well as avoiding other difficulties arising due to direct flame impingement.

In a preferred embodiment of the apparatus of this invention the curved axis of the perforated duct enters an endless and unobstructed circuitous path or loop, every portion of said circuitous path or loop having a sufficiently large radius of curvature in relation to the volume of the flame produced by the burner nozzle employed so that the flame follows the axis of the duct without substantial impinging upon the walls of the duct. The circuitous path can comprise a single loop or be in another form such as a spiral coil or as a helical coil. In a modification of the apparatus of the preferred embodiment the perforated duct whose axis follows an endless, unobstructed circuitous path, which may be circular, has a plurality of peripheral openings each having an access perforated duct in which is disposed a burner nozzle, each of said access perforated ducts being positioned with respect to said endless perforated duct so that the flame discharged from the respective burner nozzles are cocurrent in said endless perforated duct. Advantageously, said access ducts are straight and are joined to the openings in the endless duct in a tangential manner.

As a further precaution against direct flame impingement upon any portion of the duct the cross-section of the duct at all points along its axis must be unobstructed since any obstruction in the duct will act as a flame spreader and tend to disperse the flame through the perforations thereby preventing inward aspiration of air and generally tending to destroy the advantage of the invention. Furthermore, the inner surface of the duct should be relatively smooth and free of burrs, for example at the perforations, since surface irregularities such as burrs tend to accumulate large deposits of soot.

The tubular duct of this invention can have perforations substantially uniformly distributed over its entire periphery. However, along curved lengths of the duct it is preferred that the perforations be limited to the surface of the duct included by about 60 to 90 percent of the circumference closest to the center of curvature. The reason for leaving an outer unperforated rim remote from the center of curvature along duct lengths in the region of curvature is that combustion products, in curving during flow through the duct, are subject to centrifugal force which creates a tendency for them to escape from the duct, an unperforated region as described tending to avoid such an escape.

In terms of process the preferred embodiment of this invention comprises passing pressurized gas, preferably air, into a nozzle, allowing the movement of said air in said nozzle to aspirate fuel oil into said nozzle to form an oil-air mixture which is emitted from the nozzle as a spray, igniting said spray, passing the flame resulting from the ignition of said spray into a first length of a continuous perforated tubular flame duct, allowing air to aspirate inwardly through said perforations along the entire length of said flame duct and continuously recycling

the extremity of the burner flame to an opening in said first length of duct through a curved second length of said duct.

The process is carried out in the substantial absence of loss of both unburned fuel and incompletely burned combustion gases and therefore substantially complete combustion occurs. The substantial absence of loss of unburned fuel or uncompletely burned combustion gases is realized due to the aspiration of air inwardly through the duct perforations which aspiration operates not only to feed air to the flame but also to contain within the flame what otherwise would be lost as unburned droplets of fuel and incompletely burned gases. The substantial absence of loss of unburned fuel, which would otherwise be evidenced by oily deposits, or of incompletely burned combustion prouct is further realized by employing a duct whose radius at points of curvature is sufficiently large in relation to the volume of the gases emitted by the burner nozzle employed so that impingement of the flame upon the wall of the duct is substantially avoided.

In operating the preferred embodiment of this invention the velocity of the emission of fuel and air from the nozzle can be advantageously controlled to effect a surprisingly uniform distribution of heat along the circuitous duct. At low nozzle emission velocities, which are achieved by charging air to the nozzle at about 3 pounds per square inch gauge, it is observed that the access duct becomes intensely hot as evidenced by a bright coloration while the endless circuitous duct remains relatively cool as evidenced by complete absence of such coloration. However, upon increasing the nozzle emission velocity by increasing the air pressure to between 7 and 10 pounds per square inch gauge, it has been observed that the endless circuitous portion of the duct becomes heated to a uniform bright coloration while the access duct becomes cooled to an extent that no such coloration exists. This represents a highly advantageous feature of a circuitous duct since, first, the region in the duct of the most intense heat can be removed from the zone of the nozzle thereby avoiding heat loss since nozzles are necessarily located near the wall of fire chambers and, secondly, because the zone of intense heat is generally distributed over the entire circuitous region of the duct whereby even heat distribution within a fire chamber is accomplished.

The cross section of the perforated duct should generally conform in shape with the cross section of the flame which it encloses. For example, when the flame from a single burner nozzle is directed into a perforated duct the cross section of the duct should be generally circular while if two or more nozzles are employed which are disposed in close parallel relationship so that the flames they emit are longitudinally in contact a perforated duct of generally elliptical cross section should be employed. It was found that when employing a perforated duct having a cross section which did not generally conform with the cross section of the flame, such as introducing the flame from a single nozzle into a duct of rectangular cross section, there was considerable impingement of the flame upon the walls of the duct due in part to uneven air aspiration through the perforations.

Whatever the transverse cross section of the perforated duct which is employed its cross sectional area should not be so small in relation to the cross section of the flame as to create the likelihood of flame impingement upon the wall of the duct while its cross sectional area should not be so large in relation to the cross section of the flame as to interfere with the creation of the necessary vacuum, caused by the flow of flame gases in close proximity past the perforations in the duct, which vacuum creates the air aspiration effect. Employment of a cross sectional area within these extremes provides for substantially optimum aspiration of air through the perforations of the duct so that the duct can effectively channel the path of the flame most closely to its central axis. In this regard, since the cross section of a flame progressively decreases in its travel away from a burner nozzle it is preferred to employ a perforated duct whose cross section correspondingly diminishes along its length corresponding to the diminution of cross section of the flame which it encompasses, the greatest cross section being at the end of the duct closest to the nozzle.

It is not necessary that the central axes of the flame ducts of this invention possess uniform curvature but these flame ducts can comprise a plurality of joined straight sections, each succeeding straight section having a central axis bent with respect to the preceding straight section in the direction in which it is desired to conduct the flame. The lengths of each straight section and the angle of bending between succeeding straight sections should be such that the flame can be conducted without excessive impingement upon the wall of the ducts. For example, to accomplish a 90 degree turn, three 30 degree bends can be employed.

It is essential in the practice of this invention that an aspirating type nozzle be employed of the type wherein superatmospheric gas, preferably air, is charged to the nozzle and fuel oil under essentially atmospheric pressure is aspirated into the nozzle. Aspirating oil into the nozzle by means of pressurized air provides a spray mixture relatively rich in air which burns as a compact, elongated flame and which can be confined and bent in a perforated tubular duct of this invention. In contrast, charging oil under pressure to a nozzle, even if the oil also aspirates air into the nozzle, results in a spray relatively poor in air which has a wide divergence and which upon ignition produces a broad, widely dispersed, smoky flame which would be extremely difficult to contain within even a straight perforated tube much less one which was bent or curved.

A preferred nozzle of this invention employs two chambers; oil is aspirated into the first chamber by swirling air to form an oil-air mixture and this mixture is further enriched by the addition of swirling air from the second chamber. In this nozzle, air under a pressure slightly above atmospheric is swirled in a first swirl chamber having a substantially circular transverse cross-section to create a swirling air vortex, fuel is aspirated into said first swirl chamber at an intermediate point on the axis of said chamber by the suction created by the swirling air vortex to form a first mixture of incompletely dispersed fuel in air, said first mixture is passed through a first orifice from which it is introduced axially into the throat of a second orifice, a second stream of air under a pressure slightly above atmospheric is swirled in a second swirl chamber and passes through said second orifice, said second air stream swirling through said second orifice creating a suction tending to aspirate said first mixture into said second air stream at said orifice and thereby intermix said first mixture and said second air stream to produce a second mixture which is richer in air as compared to said first mixture and in which the fuel is more uniformly and more highly dispersed than in said first mixture, and said second mixture is discharged through said second orifice into a perforated flame duct of this invention.

In order to accomplish the most superior dispersion of fuel in the second mixture, the secondary air charge to said second swirl chamber is swirled countercurrently with respect to the mixture emerging from the first swirl chamber. In this manner the secondary air creates a maximum amount of turbulence upon contact with the mixture from the first swirl chamber and produces a more uniform, more highly atomized fuel-air spray mixture. Such countercurrent swirling in the second swirl chamber produces a resulting spray whose divergence is advantageously reduced as compared to the divergence of the spray emerging from the nozzle when the secondary air is swirled concurrently with respect to the mixture emerging from the first swirl chamber. Such reduction in spray divergence produces a more compact, elongated flame

highly suited for confinement in the flame duct of this invention. The divergence and velocity of the spray can be further controlled by adjusting the pressure of the air supplied to the nozzle and, for maximum control of nozzle operation, the pressure of the air supplied to each swirl chamber can be independently controlled so that the air pressure within each swirl chamber is different.

The preferred nozzle apparatus to be employed comprises a first and a second coaxial chamber in series, each of said chambers being generally circular in cross section, an axial inlet port for the admission of fuel oil extending from the rear wall of the first chamber through a portion of the length of said chamber, said first chamber also having a substantially tangential opening for the admission of aspirating gas, preferably an oxygen containing gas such as air, the forward portion of said first chamber having a first axial orifice opening leading into the rear of said second chamber, said second chamber having a substantially tangential opening for the admission of secondary air, said second chamber having a second axial orifice opening on its forward portion and an axial duct extending from said first orifice through said second chamber and terminating at the throat of said second orifice, the terminus of said duct being free of contact with said second orifice. More preferably, the nozzle apparatus of this invention comprises a first and a second generally conical chamber disposed coaxially in series, the base of said first chamber having an axial inlet port for the admission of oil extending from the rear of the first chamber through a portion of the length of said chamber, said first chamber also having a substantially tangential opening for the admission of air, the apex of said first chamber comprising an orifice leading axially into the base of said second chamber, said second chamber having a substantially tangential opening for the admission of secondary air, the apex of said second chamber comprising an orifice, and an axial duct extending from the apex of said first chamber through said second chamber and terminating at the apex of said second chamber, said duct being free of contact with the apex of said second chamber. If desired, one or both of said chambers can be cylindrical rather than conical. Advantageously, the orifice opening of said second chamber is larger than the orifice opening of said first chamber.

The substantially tangential openings in each of said swirl chambers can either take the form of a bore through the wall leading to the respective swirl chambers and opening into the curved wall of each chamber in a substantially tangential manner or, when the swirl chambers are conical, one or both of the chambers can employ a frusto-conical swirl stem having one or more slots which are slanted with respect to the central axis of the swirl chambers as described below. Also, a helically threaded stem can be employed to impart a swirling motion to the air entering a swirl chamber. In any case, the cross section and length of the tangential air openings leading to one swirl chamber should be generally comparable with the cross section and length of the tangential air openings leading to the other swirl chamber so that the pressure drop of the air passing through each will be approximately the same.

This invention is illustrated more particularly by reference to the accompanying drawings of which

FIGURES 1 and 2 illustrate an embodiment of the preferred nozzle to be employed in this invention.

FIGURE 3 is a plan view of a furnace employing a circular perforated flame duct or tube of this invention.

FIGURE 4 is a view of a circular perforated flame duct of this invention having a tapered cross section.

FIGURE 5 is a view of a circular perforated flame duct of this invention having more than one access port.

FIGURE 6 is a view of two perforated flame ducts of this invention disposed cooperatively.

FIGURE 7 is an illustration of a specific use for a curved perforated flame duct.

A specific embodiment of the preferred nozzle is shown in FIGURES 1 and 2. The nozzle structure shown in FIGURES 1 and 2 comprises a generally tubular body having an enclosure on its front end, an axial orifice opening in the center of said enclosure, a circular plug secured within and in sealing engagement with said tubular body, said circular plug having a centrally disposed stud coaxial with and extending toward said orifice, said stud terminating with a frusto-conical swirl stem, said swirl stem having at least one surface groove extending the length of the stem, said groove being non-parallel or slanted with respect to the central axis of the plug, a circular orifice plate having an over-all diameter smaller than the internal diameter of said tubular body disposed between said plug and the front end enclosure of said tubular body, the space defined generally between said orifice plate, said tubular body and said plug constituting an air chamber, a conically bored opening in the center of said circular orifice plate, the forward tip of said conical bore being the apex and the portion to the rear of the apex being the base, said frusto-conical swirl stem being complementary to and received by the base of said conical bore defining a first swirl chamber in the apex of said bore, a forwardly extending circular peripheral rim on said orifice plate in sealing engagement with the inner surface of said end enclosure and serving to space the main body of said plate apart from the inner surface of said enclosure whereby a second swirl chamber is formed between said enclosure and said orifice plate, an axial duct extending from the apex of said conical bore through said second swirl chamber and terminating at the axial orifice opening of the enclosure, said duct being free of contact with the orifice opening of the enclosure, passage means through the rim of said orifice plate connecting said air chamber with said second swirl chamber and opening substantially tangentially into said second swirl chamber, passage means to said air chamber for supplying air to said chamber, and axial passage means through sid plug and swirl stem terminating a portion of the distance along the length of said first swirl chamber for supplying oil to said first swirl chamber. To obtain the most complete mixing of oil and air in the second swirl chamber the tangential opening for the air in the second chamber should approach the second chamber countercurrently with respect to the grooves on the swirl stem serving as air ducts to the first swirl chamber.

Referring to FIGURE 1, a longitudinal cross-sectional view of a nozzle designated generally as **10** is shown having a tubular body portion **12** which is internally and externally threaded as shown. The forward end of body portion **12** terminates with a substantially flat integral enclosure **14** which is on a plane transverse to the axis of tubular body **12**. Enclosure **14** has an axial tapered central orifice opening **16**. Orifice plate **18** immediately inside of and adjacent to enclosure **14** has an over-all diameter less than the internal diameter of tubular body **12** and has an axial orifice **20**. Orifice **20** is the apex of an axial conical bore **60** as shown. The diameter of orifice opening **16** is larger than the diameter of orifice opening **20** and a duct **62** extends from orifice **20** to partially obstruct the entrance to orifice **16**. The forwardly protruding peripheral rim **22** of orifice plate **18** contains one more borings **24** as shown in FIGURE 2, which is an elevation view of plate **18**, which open in a tangential manner into swirl chamber **58** which is formed by virtue of rim **22** setting apart the rearward surface of enclosure **14** and the forward surface of orifice plate **18**.

A plug **26** having external threads and an axial bore **28** is equipped with two or more prongs **30** on its rear face so that it can be screwed into the interior of tubular body **12** and urge orifice plate **18** in sealing engagement against the inner surface of enclosure **14** so that orifice opening **20** is axially disposed. Plug **26** has a central forwardly projecting stud **32** terminating with a frusto-conical swirl stem **34** which holds orifice plate **18** in place by abutting

firmly against the complementary internal surface of the base portion of conical bore 60 leaving unoccupied the apex of conical bore 60, said unoccupied apex constituting a swirl chamber 40. Swirl stem 34 is equipped with one or more peripheral slots 36 extending the length of the stem and providing passage between air chamber 38 and swirl chamber 40. Slots 36 are generally comparable in cross section and length with borings 24 so that the pressure drop through each is generally the same. In one example, slots .030 inches square are employed. Bore 28 which is coaxial with the axis of tubular body 12 constitutes a connecting passageway for the suction of oil from an oil reservior on a lower level, not shown, and swirl chamber 40. Bore 28 is extended through a portion of the length of swirl chamber 40 by means of tube 61.

After the orifice plate 18 is secured in position by tightly screwing plug 26 into place as shown in FIGURE 1, the entire resulting nozzle assembly is secured into position for use, for example, by screwing tubular body 12 into a supporting frame 42. After the nozzle is assembled and secured into place, an oil reservoir 47 on a level lower than the nozzle is connected to the nozzle at externally threaded boss 44 extending rearwardly from the center of plug 26 and coaxial with oil passageway 28. Suitable flared tubing 46 extends from below the level of oil in the reservoir and is attached in sealing connection to boss 44 by means of nut 48. Passage of compressed air to chamber 38 from vessel 55 is provided by passageway 50 through plug 26 terminating with rearwardly extending externally threaded boss 52 to which flared tubing 54 is attached in sealing connection by means of internally threaded nut 56.

In operating the nozzle shown in FIGURE 1 air under a pressure between about 3 and 10 pounds per square inch gauge, pressures in the upper portion of this range being employed when it is desired to aspirate greater quantities of fuel oil than are aspirated at air pressures in the lower portion of this range, is charged to air chamber 38 from which it passes through groove 36 and enters swirl chamber 40 substantially tangentially and swirls in swirl chamber 40. The swirling air draws oil from reservoir 47 which is on a lower level than the nozzle by suction through passageway 28 into swirl chamber 40 where a fuel-air mixture is formed which passes through orifice 20 and duct 62 to a second orifice 16. Tube 61 allows the air to assume an adequate swirling pattern prior to aspirating in oil and prevents air back pressure against the oil from the reservoir. Secondary air from air chamber 38 passes through tangential inlet ducts 24 to second swirl chamber 58 from which it swirls through orifice 16 where it increases in velocity and aspirates into itself the fuel-air mixture from duct 62 to form a new mixture in which the oil is more highly atomized and which is richer in air. The new mixture is discharged in a swirling pattern through orifice opening 16.

FIGURE 3 shows aspirating type nozzle 10 attached to supporting frame 42. Nozzle 10 is positioned so that its axis lies along the axis of access duct 72. Access duct 72 enters the circular duct 74 tangentially as shown and the point of entrance of access tube 72 into circular duct 74 is unobstructed. As shown ducts 72 and 74 are both perforated and the circular perforated duct 74 is concentrically disposed within a furnace chamber 76. The circular duct 74 possesses a uniform cross section throughout its entire length.

FIGURE 4 shows a perforated circular duct 80 similar to the circular duct shown in FIGURE 3 with the additional advantageous feature of having a gradual taper leading to progressively small cross sections in the direction of approach to the furthest extremity of the flame from the nozzle. The smallest cross section is shown in the region 82 which is the point at which recycle material approaches freshly introduced flame gases.

FIGURE 5 shows a circular perforated duct shown generally as 90 having two access perforated ducts 92 and 94 positioned so that they approach central perforated duct 90 tangentially and discharge flame into central perforated duct 90 so that flow of flame through each access induces unidirectional flow within the central duct. As shown central duct 90 is tapered so that maximum cross section occurs in the region where fresh flame is charged as at zones 96 and 98 and minimum cross section occurs at the zones where tail end gases are being charged to fresh flame as at 100 and 102.

FIGURE 6 shows an adaptation where flames are emitted into a circular path in a countercurrent manner. As shown in FIGURE 6 a first flame is introduced into tube 110 while a second flame is emitted from a second nozzle into tube 112. Tubes 110 and 112 have open ends which meet at point 114. The flame from each nozzle is adjusted so that they just meet at point 114.

FIGURE 7 illustrates an application wherein it is advantageous to employ a spiral or helical perforated tube. As shown in FIGURE 7, a single flame is employed to both preheat a fluid flowing to a storage vessel and to maintain the temperature of the preheated fluid in the vessel. Fluid flows through feeder tubes 120 to storage vessel 122. During transit the fluid in tubes 120 is preheated by a flame located in perforated tube 124 which encircles feeder tubes 120. At the end of tube 124 furthest from the nozzle is disposed a perforated flame spreader 126 which tends to disperse the flame at the end of tube 124. Flame spreader 126 is elevated from the end of perforated tube 124 by means of spacers 128 so that it can spread the flame upwardly rather than sideways. In this manner the flame within tube 124 tends to preheat fluid flowing in tubes 120 while the residual flame from tube 124 striking perforated flame spreader 126 serves to maintain fluid in vessel 122 at an elevated temperature.

Various changes and modifications can be made without departing from the spiritt of this invention or the scope thereof as defined in the following claims.

We claim:

1. An apparaus comprising a fuel spray nozzle, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough along its entire length, the longitudinal axis of said tubular duct being non-lineal with respect to the longitudinal axis of said nozzle over at least a portion of its length, the longitudinal axis of said nozzle directed substantially tangentially toward said non-lineal axis portion, said tubular duct being free of interior obstructions over its entire length, said tubular duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

2. An apparatus comprising a fuel spray nozzle, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough along its entire length, the longitudinal axis of said tubular duct being curved with respect to the longitudinal axis of said nozzle over at least a portion of its length, the longitudinal axis of said nozzle directed substantially tangentially toward said curved axis portion, said tubular duct being free of interior obstructions over its entire length, said tubular duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

3. An apparatus comprising a fuel spray nozzle, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough along its entire axial extent, the longitudinal axis of said

tubular duct being straight along a first length thereof, the longitudinal axis of said tubular duct being non-lineal along another length thereof with respect to the longitudinal axis of said first length, said straight longitudinal axis approaching said non-lineal longitudinal axis substantially tangentially, said nozzle disposed axially in said first length of tubular duct and directed to spray fuel toward said other length of tubular duct, said tubular duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

4. An apparatus comprising a fuel spray nozzle, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough along its entire axial extent, the longitudinal axis of said tubular duct being straight along a first length thereof, the longitudinal axis of said tubular duct being curved along another length thereof, said straight longitudinal axis approaching said curved longitudinal axis substantially tangentially, said nozzle disposed axially in said first length of tubular duct and directed to spray fuel toward said other length of tubular duct, said tubular duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

5. An apparatus comprising a spray nozzle of the aspirating type having a longitudinal axis, a first passageway, a second passageway, and a discharge orifice, a first conduit and a pressurized gas source, said first conduit extending to said nozzle from said pressurized gas source for supplying pressurized gas to said first passageway, a second conduit and a liquid fuel oil reservoir under atmospheric pressure, said second conduit extending to said nozzle from said fuel oil reservoir for supplying oil under atmospheric pressure to said second passageway, said nozzle adapted so that flow of pressurized gas therethrough aspirates fuel oil, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough substantially uniformly along its entire length, the longitudinal axis of said tubular duct being non-lineal with respect to the longitudinal axis of said nozzle over at least a portion of its length, the longitudinal axis of said nozzle directed substantially tangentially toward said non-lineal axis portion, said tubular duct being free of interior obstructions over its entire length, said tubular duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

6. An apparatus comprising a spray nozzle of the aspirating type having a longitudinal axis, a first passageway, a second passageway, and a discharge orifice, a first conduit and a pressurized gas source, said first conduit extending to said nozzle from said pressurized gas source for supplying pressurized gas to said first passageway, a second conduit and a liquid fuel oil reservoir under atmospheric pressure, said second conduit extending to said nozzle from said fuel oil reservoir for supplying oil under atmospheric pressure to said second passageway, said nozzle adapted so that flow of pressurized gas therethrough aspirates fuel oil, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough substantially uniformly along its entire length, the longitudinal axis of said tubular duct being curved with respect to the longitudinal axis of said nozzle over at least a portion of its length, the longitudinal axis of said nozzle directed substantially tangentially toward said curved axis portion, said tubular duct being free of interior obstructions over its entire length, said tubular duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

7. An apparatus comprising a spray nozzle of the aspirating type having a longitudinal axis, a first passageway, a second passageway, and a discharge orifice, a first conduit and a pressurized gas source, said first conduit extending to said nozzle from said pressurized gas source for supplying pressurized gas to said first passageway, a second conduit and a liquid fuel oil reservoir under atmospheric pressure, said second conduit extending to said nozzle from said fuel oil reservoir for supplying oil under atmospheric pressure to said second passageway, said nozzle adapted so that flow of pressurized gas therethrough aspirates fuel oil, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough substantially uniformly along its entire axial extent, the longitudinal axis of said tubular duct being straight along a first length thereof, the longitudinal axis of said tubular duct being non-lineal along another length thereof with respect to the longitudinal axis of said first length, said straight longitudinal axis approaching said non-lineal longitudinal axis substantially tangentially, said nozzle disposed axially in said first length of tubular duct and directed to spray fuel toward said other length of tubular duct, said tubular duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

8. An apparatus comprising a spray nozzle of the aspirating type having a longitudinal axis, a first passageway, a second passageway, and a discharge orifice, a first conduit and a pressurized gas source, said first conduit extending to said nozzle from said pressurized gas source for supplying pressurized gas to said first passageway, a second conduit and a liquid fuel oil reservoir under atmospheric pressure, said second conduit extending to said nozzle from said fuel oil reservoir for supplying oil under atmospheric pressure to said second passageway, said nozzle adapted so that flow of pressurized gas therethrough aspirates fuel oil, a perforated tubular duct having a longitudinal axis, said tubular duct having perforations extending therethrough substantially uniformly along its entire axial extent, the longitudinal axis of said tubular duct being straight along a first length thereof, the longitudinal axis of said tubular duct being curved along another length thereof, said straight longitudinal axis approaching said curved longitudinal axis substantially tangentially, said nozzle disposed axially in said first length of tubular duct and directed to spray fuel toward said other length of tubular duct, said tubular duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

9. An apparatus comprising a perforated tubular duct having a longitudinal axis, the longitudinal axis of said duct being looped so that said duct forms an endless circuitous path, said tubular duct having perforations extending therethrough along its entire length, said duct having a peripheral opening, a fuel spray nozzle having a longitudinal axis, the longitudinal axis of said nozzle directed substantially tangentially toward the longitudinal axis of said duct through said peripheral opening, said nozzle being directed to spray fuel through said peripheral opening, said tubular duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

10. Claim 9 wherein said perforations extend through said tubular duct along its entire length substantially uniformly over the surface of the duct included by about 60 to 90 percent of the circumference closest to the center of curvature.

11. Claim 9 wherein said circuitous path is a circular path.

12. Claim 9 wherein said nozzle is an aspirating nozzle adapted for spraying fuel oil under substantially atmospheric pressure.

13. An apparatus comprising a first perforated tubular duct having a curved longitudinal axis, said longitudinal axis curved so that said first duct forms an endless circular path, said first tubular duct having perforations extending therethrough substantially uniformly along its entire length, said first duct having a peripheral opening, a second perforated tubular duct having a straight longitudinal axis leading to said peripheral opening, the straight longitudinal axis of said second duct approaching the curved longitudinal axis of said first duct substantially tangentially, said second duct having perforations extending therethrough substantially uniformly along its entire length, a fuel spray nozzle axially disposed in said second duct directed toward said first duct, both of said tubular ducts being free of interior obstructions over their entire lengths, said perforated ducts having access to the atmosphere along their entire lengths through the perforations therethrough and said apparatus adapted for both inward aspiration of air from the atmosphere through the perforations of said ducts and outward discharge of combustion products to the atmosphere through the perforations of said ducts upon combustion of the spray from said nozzle.

14. Claim 13 wherein said nozzle is an aspirating nozzle adapted for spraying fuel oil under substantially atmospheric pressure.

15. A process comprising passing pressurized gas into a nozzle, exposing liquid fuel oil under substantially atmospheric pressure to said nozzle, the movement of said gas in said nozzle aspirating said fuel oil into said nozzle to form an oil-gas mixture which is discharged from the nozzle as a spray, igniting said spray, passing the flame resulting from the ignition of said spray tangentially into an unobstructed tubular duct having a curved longitudinal axis and having perforations extending therethrough over its entire length, establishing the pressure of said gas so that air is aspirated inwardly through the perforations of said duct and products of combustion are discharged outwardly through the perforations of said duct.

16. A process comprising passing pressurized air into a nozzle, exposing liquid fuel oil under substantially atmospheric pressure to said nozzle, the movement of said pressurized air in said nozzle aspirating said fuel oil into said nozzle to form a pressurized air-oil mixture which is discharged from the nozzle as a spray, igniting said spray, passing the flame resulting from the ignition of said spray tangentially into an unobstructed tubular duct having a curved longitudinal axis and having perforations extending therethrough over its entire length, establishing the pressure of said pressurized air so that atmospheric air is aspirated inwardly through the perforations of said duct and products of combustion are discharged outwardly through the perforations of said duct.

17. A process comprising passing pressurized air into a nozzle, exposing liquid fuel oil under substantially atmospheric pressure to said nozzle, the movement of said air in said nozzle aspirating said fuel oil into said nozzle to form a pressurized air-oil mixture which is discharged from the nozzle as a spray, igniting said spray, passing the flame resulting from the ignition of said spray tangentially into an endless, circuitous, perforated, unobstructed tubular duct, establishing the pressure of said pressurized air so that atmospheric air is aspirated inwardly through the perforations of said duct and products of combustion are discharged outwardly through the perforations of said duct.

18. A process comprising spraying a pressurized gaseous fuel, igniting said spray, passing the flame resulting from ignition of said spray tangentially into an unobstructed tubular duct having a curved longitudinal axis and having perforations extending therethrough over its entire length, establishing the pressure of said gaseous fuel so that air is aspirated inwardly through the perforations of said duct and combustion products are discharged outwardly through the perforations of said duct.

19. A process comprising spraying a pressurized gaseous fuel, igniting said spray, passing the flame resulting from ignition of said spray tangentially into an endless, circuitous, perforated, unobstructed tubular duct, establishing the pressure of said gaseous fuel so that air is aspirated inwardly through the perforations of said duct and combustion products are discharged outwardly through the perforations of said duct.

20. An apparatus comprising a perforated tubular duct having a longitudinal axis, the longitudinal axis of said duct being looped so that said duct forms an endless circuitous path, said tubular duct having perforations extending therethrough along its entire length, said duct having a peripheral opening, a fuel spray nozzle having a longitudinal axis, the longitudinal axis of said nozzle directed substantially tangentially toward the longitudinal axis of said duct through said peripheral opening, said nozzle being directed to spray fuel through said peripheral opening, said tubular duct having a gradual taper so that the spray is directed into progressively smaller tubular duct cross sections, said tubular duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmoshpere through said perforations upon combustion of the spray from said nozzle.

21. An apparatus comprising a perforated tubular duct having a longitudinal axis, the longitudinal axis of said duct being looped so that said duct forms an endless circuitous path, said tubular duct having perforations extending therethrough along its entire length, said duct having a plurality of peripheral openings, fuel spray nozzle means having a longitudinal axis disposed at each of said peripheral openings, the longitudinal axis of each of said nozzle means directed substantially tangentially toward the longitudinal axis of said duct through its associated peripheral opening, each of said nozzle means directed so that all fuel spray is concurrent within said duct, said perforated duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle means.

22. Claim 21 wherein said circuitous path is a circular path.

23. Claim 21 wherein said each nozzle means is an aspirating nozzle adapted for spraying fuel oil under substantially atmospheric pressure.

24. An apparatus comprising a primary perforated tubular duct having a longitudinal axis, the longitudinal axis of said primary duct being looped so that said duct forms an endless circuitous path, said primary tubular duct having perforations extending therethrough along its entire length, said primary duct having a plurality of peripheral openings, secondary perforated tubular duct means having a straight longitudinal axis at each of said peripheral openings, the straight longitudinal axis of each of said secondary duct means approaching the curved longitudinal axis of said primary duct substantially tangentially, each of said secondary duct means having perforations extending therethrough substantially uniformly along its entire length, fuel spray nozzle means disposed in each of said secondary duct means directed toward said primary duct, each of said secondary duct means directed so that all nozzle fuel spray is concurrent within said primary duct, each tubular duct in said apparatus being free of interior obstructions over its entire length, each tubular duct in said apparatus having access to the atmosphere along its entire length through the perforations extending therethrough, and said apparatus adapted for both inward aspiration of air from the atmosphere and outward discharge of combustion products to the atmosphere through the perforations of said primary duct upon combustion of the spray from each of said nozzle means.

25. Claim 24 wherein said circuitous path is a circular path.

26. Claim 24 wherein each of said nozzle means is an aspirating nozzle adapted for spraying fuel oil under substantially atmospheric pressure.

27. An apparatus comprising a perforated tubular duct having a longitudinal axis, the longitudinal axis of said duct being curved in the form of a spiral, said tubular duct having perforations extending therethrough along its entire length, said duct having a peripheral opening, a fuel spray nozzle having a longitudinal axis, the longitudinal axis of said nozzle directed substantially tangentially toward the longitudinal axis of said duct through said peripheral opening, said nozzle being directed to spray fuel through said peripheral opening, said tubular duct being free of interior obstructions over its entire length, said perforated duct having access to the atmosphere along its entire length through said perforations and said apparatus adapted for both inward aspiration of air from the atmosphere through said perforations and outward discharge of combustion products to the atmosphere through said perforations upon combustion of the spray from said nozzle.

28. Claim 27 wherein said nozzle is an aspirating nozzle adapted for spraying fuel oil under substantially atmospheric pressure.

29. An apparatus comprising a first perforated tubular duct curved to form a spiral, said first tubular duct having perforations extending therethrough substantially uniformly along its entire length, said first duct having a peripheral opening, a second perforated tubular duct having a straight longitudinal axis leading to said peripheral opening, the straight longitudinal axis of said second duct approaching the curved longitudinal axis of said first duct substantially tangentially, said second duct having perforations extending therethrough substantially uniformly along its entire length, a fuel spray nozzle axially disposed in said second duct directed toward said first duct, both of said tubular ducts being free of interior obstructions over their entire lengths, said perforated ducts having access to the atmosphere along their entire lengths through the perforations extending therethrough, and said apparatus adapted for both inward aspiration of air from the atmosphere and outward discharge of combustion products to the atmosphere through the perforations of said first duct upon combustion of the spray from said nozzle.

30. Claim 29 wherein said nozzle is an aspirating nozzle adapted for spraying fuel oil under substantially atmospheric pressure.

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