

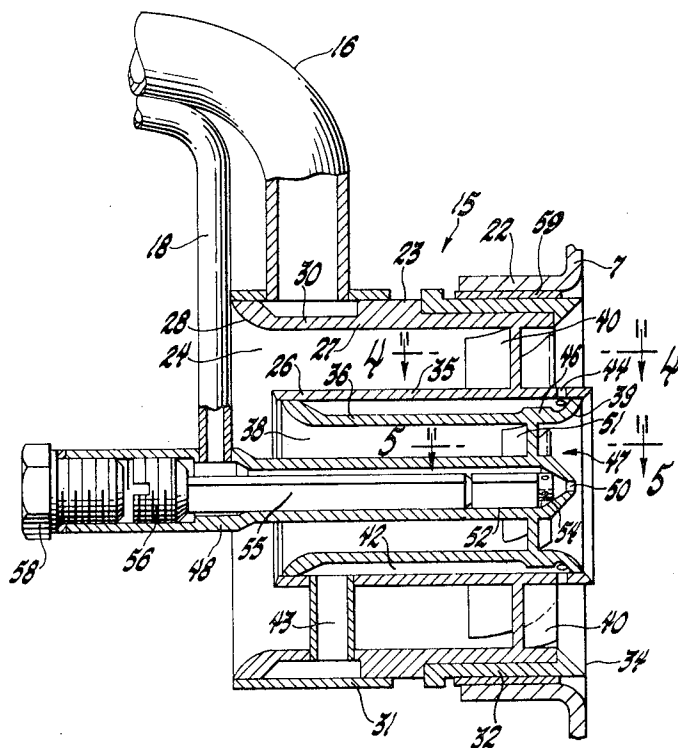
[54] **LIQUID FUEL SPRAY NOZZLES WITH AIR ATOMIZATION**[75] Inventor: **Cecil H. Sharpe**, Brownsburg, Ind.[73] Assignee: **General Motors Corporation**, Detroit, Mich.[22] Filed: **Nov. 27, 1970**[21] Appl. No.: **93,369**[52] U.S. Cl. **239/400, 239/406, 239/431, 60/39.74 R**[51] Int. Cl. **B05b 7/00**[58] Field of Search **239/400-406, 431, 239/432, 434, 434.5; 60/39.74 R**[56] **References Cited****UNITED STATES PATENTS**

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Primary Examiner—M. Henson Wood, Jr.*Assistant Examiner*—John J. Love*Attorney*—Paul Fitzpatrick and Jean L. Carpenter[57] **ABSTRACT**

Fuel spray nozzles particularly suited for gas turbine combustion apparatus have inner and outer walls providing between them an annular passage for combustion air into the combustion chamber. Swirl vanes in the passage cause the air to take on a substantial tangential velocity so that it is discharged in a conical form into the combustion chamber. The fuel is injected into the passage at its outlet from a ring of ports in either the inner or outer wall of the passage so that it is atomized by and carried away with the air. The nozzles also include a pilot nozzle mounted within the inner wall and provide a second air entrance within the interior of the inner wall. Swirl vanes may be provided to swirl the air entering through the inner passage.

4 Claims, 9 Drawing Figures

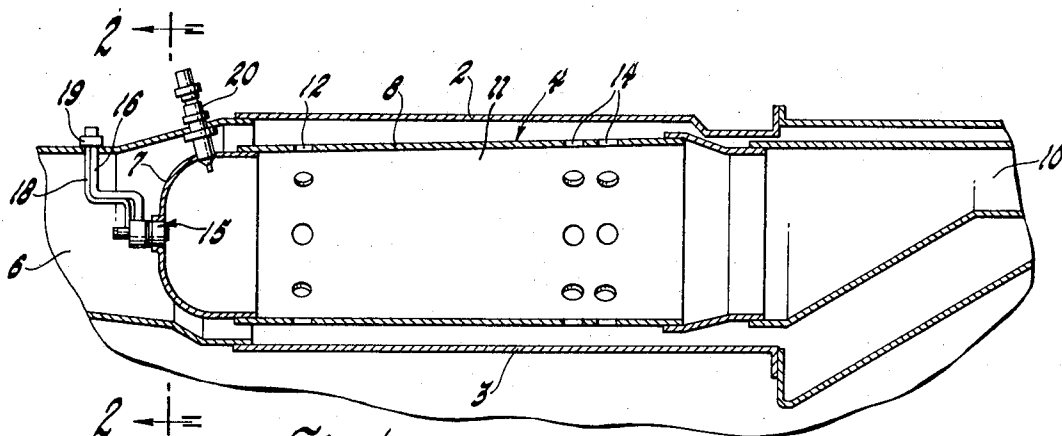


Fig. 1

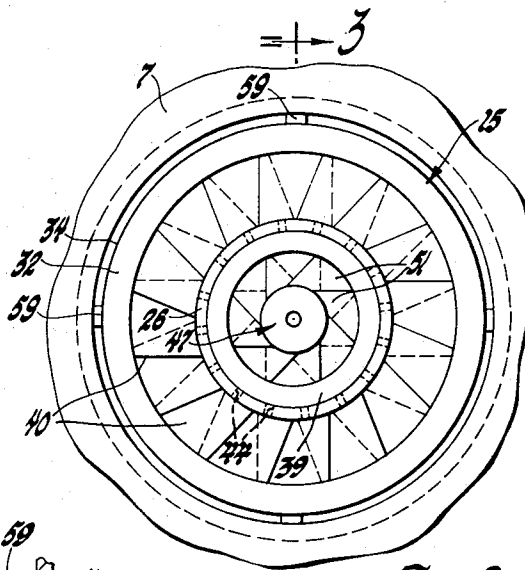


Fig. 2

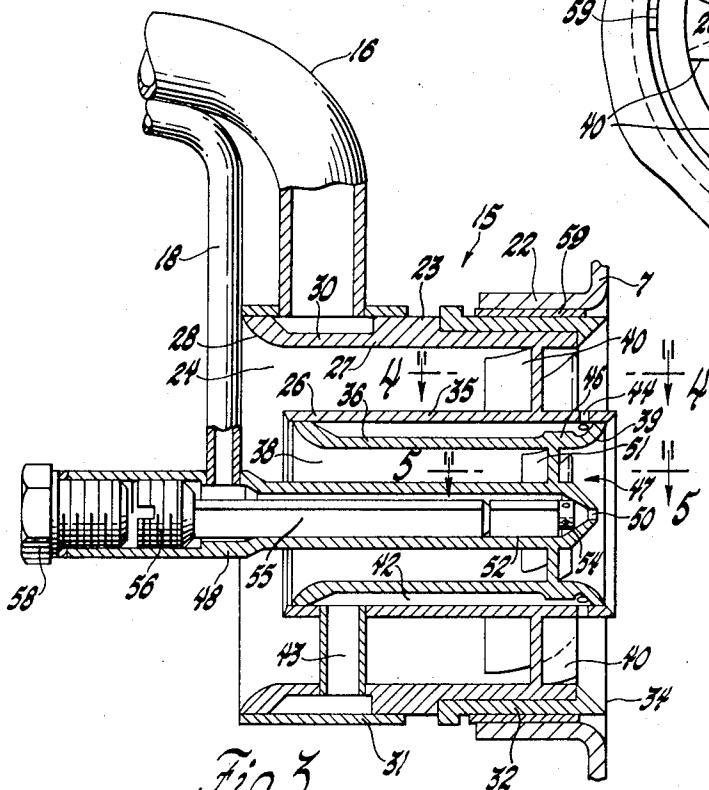


Fig. 3

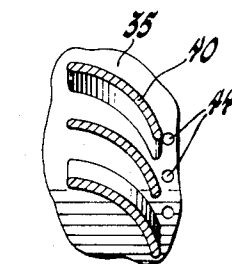
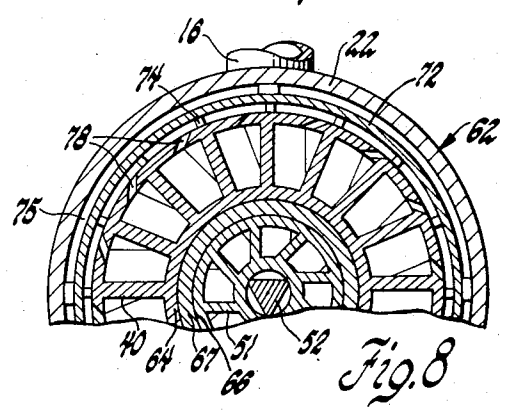
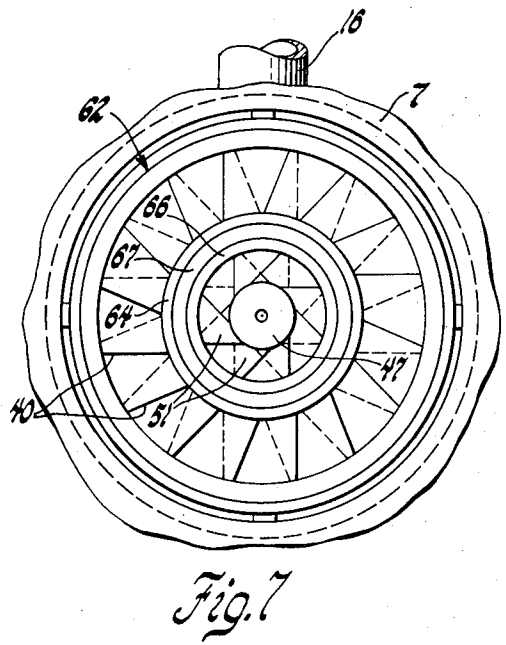
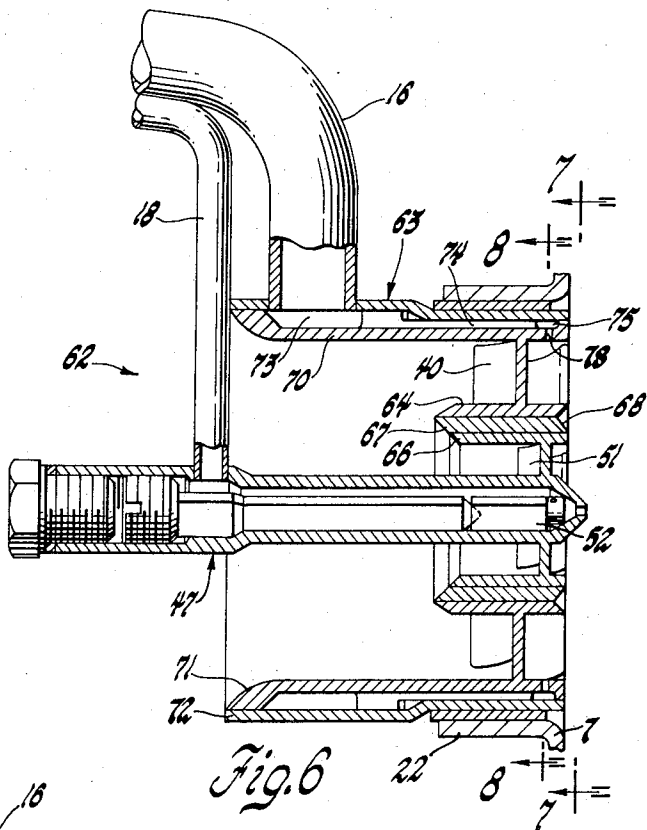
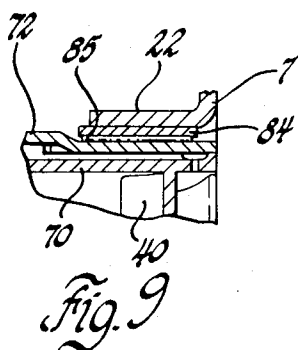
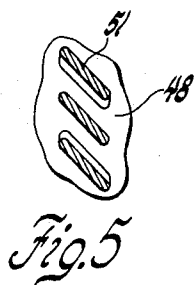


Fig. 4

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LIQUID FUEL SPRAY NOZZLES WITH AIR ATOMIZATION

The invention described herein was made in the course of work under a contract or subcontract thereunder with the Department of Defense.

DESCRIPTION

My invention relates to nozzles adapted to spray fuel for combustion in devices of the nature of gas turbine combustion chambers. Typically, such devices include a metal shell or combustion liner which defines a space into which air and fuel are introduced and in which combustion takes place at high temperature in a relatively small volume. Successful combustion depends upon consistent fine droplet atomization of the fuel. Achieving this is complicated by the wide range of fuel flow and air flow in the usual gas turbine engine.

While air-assisted fuel nozzles have been used to some extent in gas turbines, particularly air assist to help in atomization at low fuel flows, the typical gas turbine fuel nozzle is a device which depends upon imparting a relatively high pressure to the fuel and injecting it through tangential ports into a swirl chamber from which it flows through a circular or annular outlet, forming a cone of fine particles as it flows outward from the nozzle under the influence of centrifugal force due to rotation. Because of the wide fuel flow range, such nozzles ordinarily are of a duplex type, including a small primary flow nozzle for low fuel flows and a large or secondary nozzle structure for a greater volume of flow at higher fuel flow rates.

It appears to me that the development of such swirl-type fuel nozzles has reached a plateau from which no great advance can be predicted and that further advance in atomization, and therefore in combustion, in such engines must come from a change in type of nozzle. My investigations of fuel injection and combustion in gas turbine engines have shown that further advance in the art can result from the use of a nozzle of a type in which the atomization of the fuel is effected primarily by a high velocity flow of air, and in which the distribution or spray pattern is controlled by imparting swirl to the air before its impingement upon the fuel.

According to my invention, the fuel nozzle structure comprises a preferably annular air entry with means in the entry to cause the air to swirl at a substantial circumferential velocity in addition to the substantial axial velocity through the entry resulting from the pressure drop of the air as it enters the combustion liner. The fuel to be atomized or nebulized is injected at low velocity through a large number of ports or the equivalent distributed around the annular air passage so that the swirling air shears off, picks up, and atomizes the fuel, the resulting fuel spray adopting a conical pattern conforming to the flow of swirling air as it leaves the nozzle. I have also found that it appears preferable to have an additional flow of air within the fuel spray cone, which also may be swirled. For practical reasons, it is desirable to have a pilot fuel nozzle mounted within the inner passage.

Among the advantages of a nozzle according to my invention, as compared to those known to me and commonly used heretofore, are the fact that, as with other air-assisted nozzles, a relatively low fuel pressure drop into the combustion chamber is used, thereby reducing

pump wear and tear incidental to providing the fuel supply. Since the atomization does not depend upon passing the fuel at a very high velocity through very small orifices, the system is more tolerant of dirt in the fuel which, in some cases, is of high importance. A further point of very considerable importance is that the energy provided to atomize the fuel is the result of air flow rather than fuel flow, which makes the device more satisfactory at low fuel flows than a nozzle in which the energy is taken from the fuel. The reason for this is that as the energy output of the gas turbine is reduced the rate of flow of fuel diminishes more rapidly than the rate of flow of air. Thus, for example, at half power the velocity of air flow into the combustion apparatus is a substantially greater fraction of the velocity at full power than the ratio of fuel flow at half power to fuel flow at full power. This not only provides better atomization, but also a more consistent spray pattern is obtained at low power conditions of the engine, where in some cases combustion is more critical than at higher power levels.

A result of the better controlled atomization and more consistent atomization which stems from the improved nozzle structure of my invention is cleaner combustion of fuel with less smoke and less atmospheric contamination from the power plant.

The objects of my invention are to provide a fuel nozzle of superior performance and one better adapted to the requirements of practice, and a fuel nozzle which is capable of realizing all or most of the advantages referred above.

The nature of my invention and the manner in which the advantages are obtained will be clear to those skilled in the art from the succeeding detailed description of preferred embodiments of the invention and the accompanying drawings thereof.

FIG. 1 is a somewhat schematic representation of a gas turbine combustion apparatus taken on a plane extending longitudinally of the apparatus from the fuel inlet to the combustion products outlet.

FIG. 2 is an elevation view of the downstream end of one form of fuel nozzle taken on the plane indicated by the line 2—2 in FIG. 1.

FIG. 3 is a longitudinal sectional view of the same taken on the plane indicated by the line 3—3 in FIG. 2.

FIG. 4 is a detail sectional view illustrating the outer cascade of swirl vanes, taken on the plane indicated by the line 4—4 in FIG. 3.

FIG. 5 is a detail sectional view taken on the plane indicated by the line 5—5 of FIG. 3 showing the inner cascade of swirl vanes.

FIG. 6 is a view similar to FIG. 3 of a second form of fuel nozzle.

FIG. 7 is an elevation view of the downstream end of the same taken on the plane indicated by the line 7—7 in FIG. 6.

FIG. 8 is a transverse sectional view of the same taken on the plane indicated by the line 8—8 in FIG. 6.

FIG. 9 is a fragmentary sectional view of a modification.

A suitable environment for my fuel nozzles may be explained with reference to FIG. 1, which is a somewhat schematic or simplified representation of a conventional combustion apparatus of the can-annular type for a gas turbine aircraft engine. The combustion

apparatus includes an outer wall 2 which is part of the casing of the engine and an inner wall 3, defining between them an annular space. A number of combustion liners 4 are disposed in generally parallel relation between the walls 2 and 3. Compressed air from a compressor, not shown, enters the apparatus through an annular diffusing passage 6. The combustion liner includes a forward end or dome 7, a cylindrical side wall 8, and a transition section 10 which discharges into a segment of a turbine nozzle (not illustrated). The dome 7 may include entrances for a small amount of air into the combustion space 11 within the liner 4 but this is not significant to my invention.

The liner 4 includes openings such as 12 for primary combustion air and 14 for dilution air. The details of the combustion liner and of the air entrance openings are subject to variation and may follow known practice. The liner may be fully annular. A great many varieties of combustion liners are known to those skilled in the art.

A fuel nozzle 15 is mounted at the center of the dome for the purpose of spraying fuel into the forward portion of the liner for combustion. This nozzle is supported by fuel pipes 16 and 18 from a fitting 19 fixed to the outer wall 2 and to which fuel manifolds for supply of fuel to the nozzles are connected. An igniter 20 is provided for starting the flame in the combustion apparatus. The structure so far described may be regarded as conventional. It has been described to provide a clearer basis for an understanding of the improved fuel nozzle of my invention.

Referring now also to FIGS. 2 and 3, the dome 7 of the combustion liner has a forwardly projecting flange or ferrule 22 which defines a circular opening for the fuel nozzle and the fuel nozzle serves as a support for the forward end of the combustion liner. The fuel nozzle 15 includes a generally cylindrical outer shell or ring 23 which provides the outer wall of an annular air passage 24. The inner wall of air passage 24 is defined by an inner shell or ring 26 which has a cylindrical outer surface.

The outer shell is a composite structure including a generally cylindrical body 27 defining a bell-mouthed air inlet 28. It has a channel 30 in its outer surface extending around the body to provide a fuel conduit bounded also by a sleeve 31 which is slipped over the brazed to the body 27. The main fuel inlet pipe 16 is brazed into an opening in the sleeve 31. The outer wall also includes an outlet ring 32 disposed over the downstream end of the body and having a conical rear face terminating in a sharp edge 34 to inhibit any buildup of fuel or carbon deposits at the outlet of the fuel nozzle.

The inner shell 26 is defined by a cylindrical wall 35 and an inner spool-shaped body 36 which provides the outer boundary of an inner air passage 38 with a rounded converging entrance and a flaring outlet at 39. The sheet 35 and body 36 are brazed together adjacent the forward and rearward ends of these parts to form a unitary structure.

The body 27 is joined to the wall 35 by a ring of swirl vanes 40 which impart a substantial circumferential or tangential component of velocity to the air flowing through passage 24 into the combustion liner 4. The parts 23, 35 and 40 are preferably a precision casting but could be an assembled structure.

The two parts 35 and 36 of the inner shell 26 are spaced to define between them an annular fuel passage 42. Fuel is supplied to this passage through three pipes 43 brazed into holes in the body 23 and wall 35. The pipes 43 also contribute to the support of the inner shell 26. The fuel is discharged from the passage 42 through a ring of fuel ports 44 extending through the outer wall 35 downstream of the swirl vanes 40. The fuel is discharged from each port 44 as a solid stream. That is, the fuel is discharged as a continuous jet bearing only whatever contaminants enter the passage 42 with the fuel and without being atomized into or mixed with some carrier in a gas or vapor state. In the structure illustrated there are 16 vanes 40 and 16 ports 44. Preferably each port 44 is located in the line of the flow from the downstream end of a vane 40.

In the operation of the device the air, which flows through the passage 24 at speeds of the order of 300 to 400 feet per minute at full power, and is flowing past the downstream end of sheet 35 at approximately this velocity and with a substantial swirl component, blows away and nebulizes the fuel as it emerges from the ports 44. This is the main fuel nozzle which satisfies all normal fuel requirements of the combustion apparatus, except that it is corrected for the small pilot nozzle fuel flow. The atomization of the fuel does not depend upon any significant velocity of flow from the ports 44, and this velocity is not intended to be high. Because of the ample size of the entire flow path for the fuel and particularly the considerable overall total area of the ports 44, no significant amount of pressure above that of the air flowing through the nozzle is required to supply the fuel to the combustion apparatus. Incidentally, since the ports 44, although numerous, are of relatively large size, they are less likely than the usual swirl ports to be subject to plugging by any debris which might be in the fuel being pumped to the engine. In the particular nozzle illustrated, the ports 44 are substantially 0.02 inch in diameter. The overall diameter of the nozzle at shell 31 is 1.18 inches. This is a nozzle adapted for a maximum fuel flow rate of 400 lb./hr.

Additional protection against plugging of fuel ports 44 is preferably provided by a circumferential rib 45 on the outer surface of body 36 which defines a narrow annular gap between it and the cylinder 35. This full annular gap may be made very slightly narrower in width than the diameter of ports 44 so as to trap large particles of debris, generally in accordance with the principles of U.S. Pat. No. 3,617,001 of Grundman and Sharpe.

The fuel nozzle assembly also includes a small pilot fuel nozzle 47 mounted on the axis of the nozzle 15. The pilot fuel nozzle, the details of which are immaterial to the invention, comprises, as illustrated, a tubular body 48, the downstream end of which converges to a fuel spray discharge port 50. The pilot or primary fuel line 18 is brazed into an opening in the side of body 48. The forward end of body 48 is supported from the body 36 by a ring of eight swirl vanes 51 (See also FIG. 5). Body 48, vanes 51, and body 36 are preferably a unitary precision casting.

The pilot nozzle 47 includes a swirler 52 which has the form of a cylinder with three flats cut from it and thus is roughly triangular in cross section (see FIG. 8) so that fuel can flow past it. The swirler has a cylindrical forward portion which is pressed against the conical

interior of the tip of nozzle body 48. Three tangential swirl ports 54 jet fuel with a circumferential component of motion into the swirl chamber in the tip of body 48 from which it spills over the lip of port 50 and flares out in the usual cone. The swirler 52 is held in place by a retainer 55, the major part of which is of the approximately triangular cross section previously referred to, and which has a threaded end portion 56 with a screwdriver slot so that the retainer 55 may be threaded into a threaded socket in the pilot nozzle to hold the swirler 52 in place. A threaded plug 58 closes the left end of the pilot nozzle body as shown. It will be understood that only a relatively small part of maximum fuel flow is fed to the pilot nozzle. The pilot nozzle is useful in starting the engine and in maintaining combustion at minimum fuel flow, such as during deceleration of an engine at high altitude. The major pattern of the fuel supplied to the engine, which varies widely with the operating conditions, is supplied through the line 16 and through the ports 44.

Referring again to FIG. 4, it will be seen that, in the preferred form, the swirl vanes 40 are cambered and that the fuel ports 44 are located immediately downstream of the vanes approximately on the mean camber line extended of the vanes. Specifically, in the form illustrated with 16 vanes and 16 fuel ports, the fuel ports are set $7\frac{1}{2}^\circ$ circumferentially from the trailing edge of the swirler vanes. While there does not appear to be any critical quantitative values about the location of the fuel ports with respect to the swirler vanes, if they are too far downstream with the type of structure illustrated, there might be a tendency for the air flow to lift off the surface of the shell 26 away from ports 44. It is important that the atomization take place downstream of any structure which might tend to accumulate fuel and agglomerate the fine droplets which are created by the blast of air passing over the ports 44 and shearing the flow fuel. The inner set of swirler vanes 51 may be substantially uncambered, as indicated in FIG. 5. In the example illustrated there are eight of these vanes. The vanes 51 cause the air admitted through the inner air passage 38 to fan out along the inside of the spray from the main nozzle as a result of the swirl. Whether or not the air admitted through the center is swirled, it appears highly desirable to admit air there to provide an ample supply of air to the interior of the fuel spray cone developed by the main nozzle to minimize smoking due to incomplete combustion. There are other means to direct air to the interior of the fuel spray cone, but I consider it preferable to admit it through the fuel nozzle.

The cone angle of the main fuel spray desired may vary, depending upon the particular combustion chamber. The cone angle depends upon the air which carries the fuel spray with it, and the greater the swirl component of velocity of the air relative to its axial component through the nozzle passage, the greater the cone angle becomes. This is a function of vane design.

It will be understood that the supply of fuel to the combustion chamber, and particularly the supply respectively to the pilot nozzle or nozzles 47 and the main nozzle or nozzles 15, will be controlled by suitable apparatus, which may be of any suitable type and, therefore, will not be described here.

It is desirable with the nozzle of this invention, as with prior art nozzles, to provide a film flow of air over the exterior of the nozzle body to prevent a tendency for buildup of carbon around the periphery of the nozzle body; that is, in the neighborhood of the outlet edge 34. This requirement is satisfied in the device illustrated by four spacer ribs 59 extending axially of the nozzle and fixed either to the outlet ring 32 or to the flange 22 of the combustion liner.

The form of fuel nozzle just described is the presently preferred embodiment of my invention. FIGS. 6, 7, and 8 illustrate a modified form which is simpler in structure and is attractive for this reason, and which in some environments may be more suitable than the form just described.

The fuel nozzle assembly of FIG. 6 is the same in most respects as that of FIG. 3, the major difference being that the main fuel is supplied through ports in the inner surface of the outer shell of the nozzle. Insofar as feasible, parts in FIGS. 6 to 8 which correspond to those of FIGS. 2 to 5 are given the same reference numerals and will not be described in detail. The nozzle 62 of FIGS. 6 to 8 includes an outer shell 63, swirl vanes 40, and inner ring 64. The pilot fuel nozzle 47, which is as previously described, bears the swirl vanes 51, which extend to an outer ring or shroud 66. The rings 64 and 66 are integrally connected by a spacer sleeve 67 brazed to both. The structure 64, 66, and 67, which may be termed the inner shell 68, may be relatively short in this form, the greater length in the form of FIG. 3 being due primarily to the need to space the fuel pipes 43 a substantial distance from the swirler vanes 40 so as to minimize disturbances or inequalities in flow around the circumference of the swirler.

Considering now the structure of the outer shell 63 of FIG. 6, this comprises an inner wall or body 70 providing a flaring inlet 71, and an outer sleeve or wall 72. This pilot fuel pipe 18 is preferably supported by being brazed in a hole in the wall 72. The main fuel pipe 16 is brazed into wall 72 and discharges into a space 73. The sleeve 72 extends over the entire length of the body 70 and is spaced from it at a plurality of axially extending fuel passages defined by slots 74 in body 70 and a fuel annulus or manifold 75 adjacent the outlet of the air passage through the swirler 40. The sleeve 72 may be brazed in place over the body 70. The main fuel flows from space 73 through slots 74 and the annulus 75, through an annular row of ports 78, one for each vane preferably, that is, 16 in this case. These ports 78 may be drilled before the sleeve 72 is put in place. In this case, an option is exercised to incline the ports 78 so as to impart a small tangential component of motion to the fuel in the direction of swirl of the air.

In the structure of FIG. 6, the pilot fuel nozzle 47 works at low fuel flow levels only or continuously, as previously described, and the main fuel nozzle works continuously but with widely varying levels of fuel flow in most cases. The air entering the nozzle flows through the swirlers 40 and 51. The flow through swirl vanes 40 shears off the fuel entering as solid streams through the ports 78 and distributes it in a conical pattern with the air flow. The flow through swirl vanes 51 provides additional air to fill the inside of the cone and take part in the combustion process. While the pilot nozzle, as in the other form of the invention, can be cut off at high

fuel flow, it is normal practice to maintain the pilot nozzle in operation.

It may be noted that the pilot fuel nozzle, being of a type in which atomization is effected by the pressure of the oil apart from air flow and being of small capacity, is adapted for operation at extremely low levels of engine operation.

It may be also noted in the nozzle of FIGS. 2 through 5 that the main fuel flow issuing from ports 44, which is directly picked up and atomized by the flow through the outer air passage 24, is delivered into a swirling air flow coming from both the swirlers 40 and 51 and thus is entering into a swirling air flow at a point between the inner and outer boundaries of the swirling air flow. However, if the swirlers are omitted from the inner air passage 38 or this passage is omitted, the atomization is effected on the interior of the swirling air flow. In the form of FIGS. 6 through 8, the atomization is effected at the outer boundaries of the swirling air flow.

The annular cascades of swirl vanes such as 40 and 51 appear to be the most satisfactory arrangement to attain the desired swirl of the air supplied through the fuel nozzle. However, other modes of attaining swirling air flow through a passage are known and such may be suitable or more suitable in certain types of installations.

The fuel nozzles described herein which, as stated, have an overall diameter of about 1.18 inch to fit a known combustion chamber (that of the T56 turboprop engine) are adapted for a maximum fuel flow of approximately 400 lb./hr. With this flow, the flow through 16 0.02-inch diameter ports 44 or 78 in the preferred embodiments of the invention will reach a maximum velocity of about 65 ft./sec. This is a low pressure nozzle, operating on a maximum pressure drop of 100 psi.

Operating tests of the nozzle according to the invention have demonstrated its capacity to achieve a very finely atomized fuel spray, with droplets ranging from 40 to 80 microns in diameter, with the predominance being near 40 microns. The present state of the art in dual orifice swirl nozzles gives a droplet size range of about 100 to 120 microns.

It has been stated that it is desirable in the installations described above to provide a film of air flowing over the outer surface of outer shell 32 or 63 to prevent buildup of carbon around the face of the air swirler. This is also desirable with some combustion liner dome structures to help control the contour or formation of the spray cone. It prevents the development of a low pressure area between the dome 7 and the fuel spray cone which reacts on the fuel cone to pull it toward the dome.

In the structures shown in FIGS. 2 to 8, the entrance for this air film is provided by the gap maintained by spacers 59 between the outer shell and the combustion liner flange 22.

It may be preferable in many cases to provide structure in the fuel nozzle assembly to admit the exterior air film. As illustrated in FIG. 9, the structure of FIG. 6 is modified to provide this feature. A sleeve 84 concentric with sleeve 72 is spaced from it by circumferentially-spaced wires 85 (approximately 0.020 diameter) extending axially of the nozzle and brazed to sleeves 72 and 84. Sleeve 84 fits closely within flange

22 of dome 7. The same arrangement may be used with the spray nozzle of FIGS. 2 and 3.

It will be apparent to those skilled in the art from the foregoing description that I have devised a fuel nozzle particularly adapted to the requirements of combustion chambers of the nature of those used in gas turbine engines.

The detailed description of preferred embodiments of the invention for the purpose of explaining the principles thereof is not to be considered as limiting or restricting the invention, since many modifications may be made by the exercise of skill in the art.

I claim:

1. A fuel spray nozzle for dispersing liquid fuel in a gas turbine combustion apparatus or the like comprising, in combination, an outer ring, an inner ring mounted within the outer ring, the rings defining between them an annular combustion air passage into the combustion apparatus, an annular cascade of swirl vanes extending between the rings adapted to deliver the air into the combustion apparatus with a substantial tangential velocity component so that the air follows an expanding conical path upon discharge from the nozzle, the inner ring having a smooth unbroken outer surface extending downstream from the swirl vanes, means for supplying liquid fuel into the inner ring, means for delivering the said fuel into the passage from the inner ring in solid streams at a plural number of outlets distributed around the ring through the said surface immediately downstream from the swirl vanes and adjacent the air discharge end of the ring so that the fuel is nebulized by, and distributed from the nozzle in a conical spray pattern with, the air flowing through the said air passage, and means for supplying additional air into the combustion apparatus through the interior of the inner ring into the interior of the spray pattern.

2. A fuel spray nozzle for dispersing liquid fuel in a gas turbine combustion apparatus or the like comprising, in combination, an outer ring, an inner ring mounted within the outer ring, the rings defining between them an annular combustion air passage into the combustion apparatus, an annular cascade of swirl vanes extending between the rings adapted to deliver the air into the combustion apparatus with a substantial tangential velocity component so that the air follows an expanding conical path upon discharge from the nozzle, means for supplying liquid fuel into the inner ring, means for delivering the said fuel into the passage from the inner ring in solid streams at a plural number of outlets distributed around the ring immediately downstream from the swirl vanes and adjacent the air discharge end of the ring so that the fuel is nebulized by, and distributed from the nozzle in a conical spray pattern with, the air flowing through the said air passage, the said outlets being located in the lines of air flow from the downstream ends of the swirl vanes, and means for supplying additional air into the combustion apparatus through the interior of the inner ring into the interior of the spray pattern.

3. A fuel spray nozzle for use with pressurized combustion apparatus adapted to atomize the spray liquid fuel primarily through energization by combustion air flowing to the apparatus, the nozzle comprising, in combination, an outer shell adapted for mounting in an opening in a combustion chamber wall, an inner shell

spaced from the outer shell and defining with the outer shell an outer combustion air passage into the combustion chamber, the inner shell defining an inner combustion air passage into the combustion chamber through the inner shell, swirl vanes in each passage effective to swirl the air in the passages in a common direction, means for supplying liquid fuel into the inner shell, and means for discharging the said fuel from the inner shell around the downstream margin of the inner shell in solid streams for atomization and distribution by the swirling air flowing past the inner shell, the discharging means comprising a ring of ports in the inner shell, the ports being located immediately downstream of the swirl vanes approximately on the mean camber lines extended of the vanes.

4. A fuel spray nozzle for use with pressurized combustion apparatus adapted to atomize and spray liquid fuel primarily through energization by combustion air flowing to the apparatus, the nozzle comprising, in combination, an outer shell adapted for mounting in an

opening in a combustion chamber wall, an inner shell spaced from the outer shell and defining with the outer shell an outer air passage into the combustion chamber, the inner shell defining an inner air passage into the combustion chamber through the inner shell, swirl vanes in each passage effective to swirl the air in the passages in a common direction, means for supplying liquid fuel into the inner shell, the inner shell having a smooth unbroken outer surface extending downstream from the outer passage swirl vanes and means for discharging the said fuel from the inner shell around the downstream margin of the inner shell in solid streams for atomization and distribution by the swirling air flowing past the inner shell, the discharging means comprising a ring of ports through the said surface of the inner shell, the ports being located immediately downstream of the swirl vanes approximately on the mean camber lines extended of the vanes.

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