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[54] **INJECTOR FOR GAS TURBINE COMBUSTOR**

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[52] **U.S. Cl.**..... **60/39.51 R**; 60/39.71; 60/39.74 R; 239/129; 239/134

[51] **Int. Cl.**[2]..... **F02C 7/10**; F02G 3/00; B05B 1/24

[58] **Field of Search**..... 60/39.74 R, 39.74 B, 39.06, 60/39.05, 39.51 R, 39.14, 267, 39.71, 270 R; 239/129, 134, 418, 421, 136, 557, 556, 566

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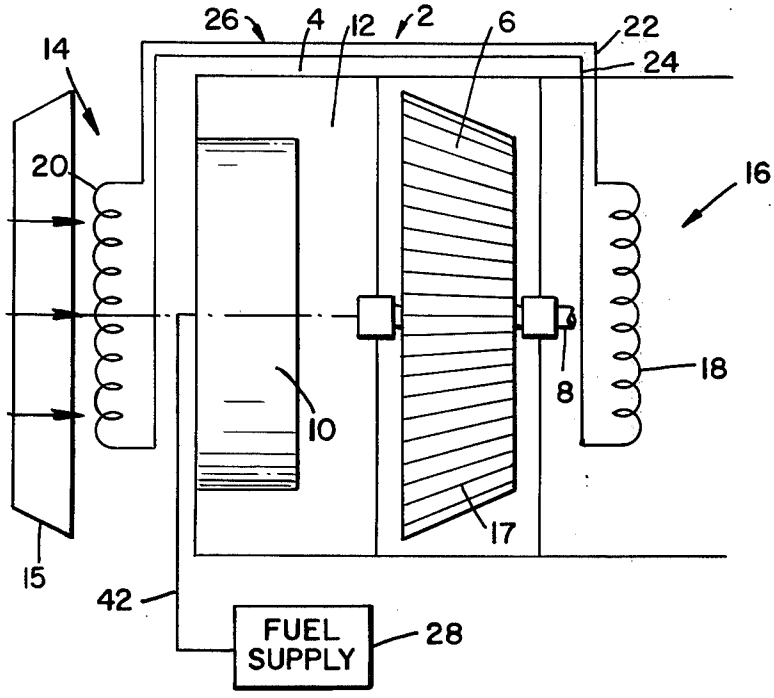
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Assistant Examiner—Thomas I. Ross
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[57] **ABSTRACT**

Liquid fuel is introduced into thin, elongate vanes disposed in the airstream to a fuel combustor of a turbine or heat exchanger. An air heater is positioned upstream of the vanes and heated from heat energy withdrawn from the turbine exhaust gas. The vanes include thin and relatively wide fuel passages which terminate in a plurality of fuel discharge openings facing the turbine combustor. Liquid fuel is centrally introduced into the passages and flows towards the discharge openings. The heated air raises the temperature of the vanes which in turn raises the liquid fuel temperature. The relatively large fuel passage surface area-to-volume ratio assures an intimate and quick heat transfer so that the liquid fuel evaporates before it exits from the discharge openings to thereby effect a homogeneous intermixing of the vaporized fuel and the air prior to combustion.

10 Claims, 4 Drawing Figures



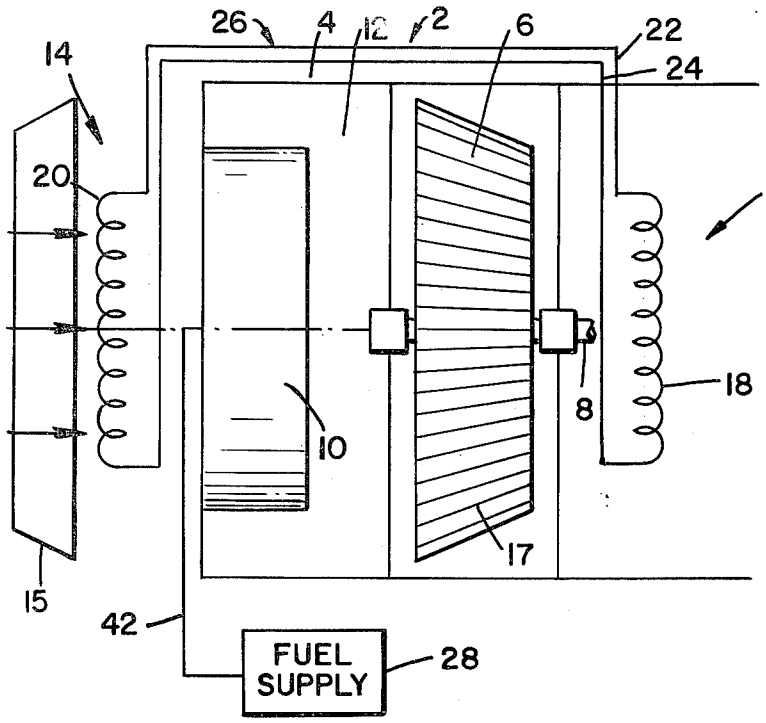


FIG_1

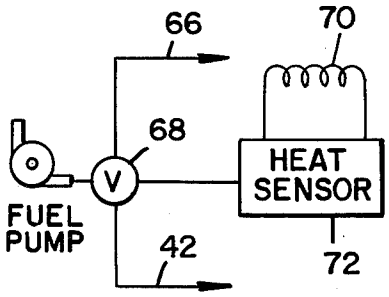


FIG_2

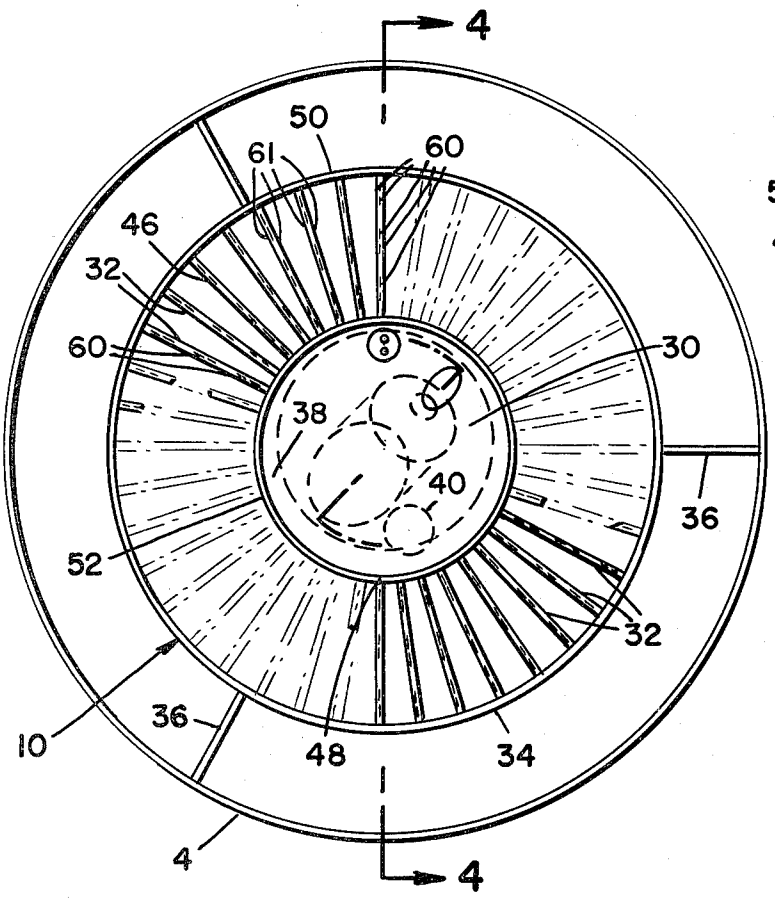


FIG_3

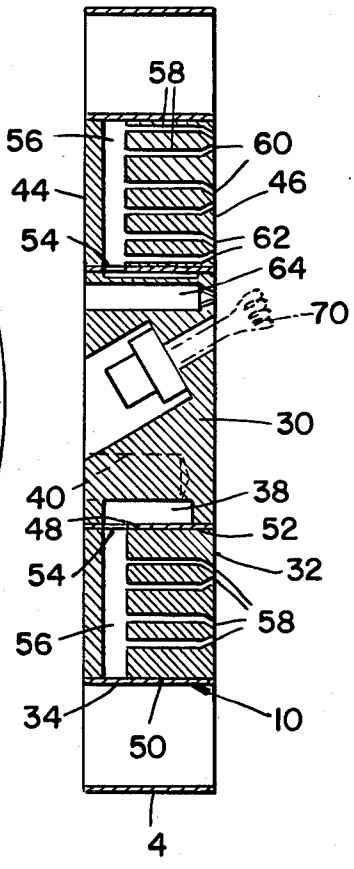


FIG_4

INJECTOR FOR GAS TURBINE COMBUSTOR

BACKGROUND OF THE INVENTION

The present invention generally relates to fuel injectors and, in particular, for liquid fuel injectors which evaporate liquid fuel before mixing it with air or another oxygen-carrying medium. The injector of the present invention is particularly applicable for use in Brayton and Rankine cycle heat engines and in rocket engines.

In external combustion engines the fuel is mixed with air and oxidized, i.e., combusted in a combustion chamber that is immediately upstream of the turbine's rotor or heat exchanger. In the past, the admixture of the air and the fuel was usually accomplished in one of two ways. Liquid fuel was either sprayed into the combustion chamber to form a fine dispersion of tiny liquid fuel droplets which were vaporized prior to combustion or the liquid fuel was passed through pre-vaporization tubes in which the fuel was premixed with and evaporated in a fraction of the combustion air prior to their injection into the combustion chamber.

Liquid fuel spray systems normally employed a single spray nozzle which required a high fuel supply pressure to effect the desired fuel atomization. The necessary high pressure could adversely affect the ease with which the injector can be regulated. The point source injection made even distribution of the fuel within the air stream extremely difficult. Also, the prior art systems injected the spray into the moving airstream and relatively long stay times were required to assure the complete vaporization of the fuel droplets before entry of the gas into the turbine rotor to assure as complete a combustion as possible. The long stay times of such prior art injectors resulted in relatively high exhaust emission levels because relatively long stay times are conducive to the generation of NO_x, a primary exhaust emission pollutant. Moreover, the distribution of the atomized fuel droplets is not always as uniform as desired, resulting in inefficient, i.e., at times maldistributed combustion, and emission of significant NO_x levels.

A premixture of the liquid fuel with air and fuel vaporization in vaporizing tubes in accordance with the prior art requires complex apparatus. Tube sizes and configurations limit such injectors to a relatively small number of vaporization tubes. This results in a coarse injection pattern which, in turn, has a tendency to lead to a more inefficient combustion and/or requires a more thorough fuel-air mixing in or just upstream of the combustion chamber. This can lead to an overall efficiency reduction due to excessive turbulence and, in any event, substantially complicates the combustion chamber configuration and thus increases its cost.

SUMMARY OF THE INVENTION

The present invention provides a liquid fuel injector for use in external or rocket combustion engines and the like in which the fuel is vaporized before it is brought into contact with the air or oxidizer. Vaporization is effected through heating the fuel. The necessary heat energy can be obtained from the exhaust gas. To this end a heat exchange system is provided which heats the combustion air to the desired temperature upstream of a fuel injector.

For the purposes of the specification and the claims the term "combustion air" is intended to and does include either the oxidizer or the fuel in a rocket engine and the term, "air flow," "air stream," "combustion air flow," "combustion air stream" and the like are intended to and do include the oxidizer or fuel "flow" between the vanes of the present invention when the invention is incorporated in a rocket engine.

Generally speaking, the fuel injector of the present invention comprises a vane or platelet that is positioned in the airstream downstream of the heat exchanger. For the purposes of this invention, the term "vane" means a thin, relatively wide plate which normally has, but does not have to have, an elongate configuration. An edge of the vane faces the airstream for minimum air resistance, and the relatively wide platelet surfaces are parallel to the direction of the airstream or flow past it, and they assure a good heat transfer between the airstream and the vane. The interior of the vane includes at least one fuel passage connected to a liquid fuel supply and terminating in a discharge opening that faces downstream and ejects fuel into a combustion chamber. As the liquid travels through the passage towards the discharge opening, it is heated and evaporizes. Consequently, vaporized fuel only is discharged by the vane.

The vane is a very narrow plate which neither causes turbulence nor an appreciable obstruction to the airstream. Consequently, a relatively large number of vanes can be evenly distributed in the airstream and each vane can include a plurality of discharge openings which further may be staggered with respect to discharge openings on other, adjacent vanes to effect a substantially homogeneous fuel injection for an efficient combustion process, a low exhaust pollutant emission level and a uniform temperature distribution. The uniform fuel vapor distribution across the primary air flow field results in a rapid combustion so that a combustion chamber may be employed which, as compared to the prior art, has a very short stay time. Consequently, there is an insufficient fuel stay time in the combustion chamber for generating excessive NO_x. The fine, even distribution of the vaporized fuel further results in a well-mixed combustion product and hence a minimum quantity of CO and UHC. The fuel injector of the present invention therefore significantly reduces the emission of primary exhaust pollutants and thus significantly contributes to the preservation of clean air since it may be incorporated in stationary, automotive, marine and aircraft power plants. It is further particularly useful in engines which employ heat regenerators to heat incoming combustion air since the injector of the present invention and the vane in particular is heated to vaporize the fuel prior to its injection into the combustion chamber.

Structurally, the injector of the present invention preferably comprises a hub that is coaxially disposed within a cylindrical air duct and from which a multiplicity of thin vanes extend radially away. The central hub includes an annual fuel supply cavity connected to a liquid fuel supply which, in turn, fluidly communicates with the fuel passages in the vanes. To assure an even fuel supply to each vane passage, the annual cavity in the hub has a cross section so that the fuel speed therein is substantially constant at all points.

The vane fuel passages have a high surface area-to-volume ratio. That is, the fuel passages have a width, parallel to the width of the vane and the air flow direction, which is many times greater than their respective

thicknesses for an efficient, high speed heat transfer from the heated vane to the fuel and efficient fuel evaporation in the vane passage before the fuel is discharged into the combustion chamber.

The fuel injector of the present invention also includes an engine start-up liquid fuel circuit which preferably comprises a liquid fuel injection nozzle in the hub and a liquid fuel igniter, such as a spark plug, heated wire or the like mmounted to the hub and disposed just downstream of the nozzle. This nozzle is coupled to the fuel supply via a branch line and suitable control valving. To start the engine, fuel is injected from the liquid nozzle and ignited. After the exhaust gases have reached the desired temperature to effect the necessary heating of the vanes, the valving interrupts the fuel supply to the liquid fuel discharge nozzle and initiates the fueling of the vane evaporation passages for steady-state, full power operation of the injector. The nozzle has small diameter orifices thereby to produce a finely atomized liquid fuel spray and thereby minimize the emission of large pollutant quantities in the exhaust gas even during the start-up state.

As already briefly mentioned, the present invention is equally advantageously employed in rocket combustion engines. In such an engine either the fuel or the oxides is passed through the vanes with the other one being preheated and passed between the vanes. Preheating is done conventionally by either monopropellant decomposition or stage combustion.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic side-elevational view of a turbine engine employing a fuel injector constructed in accordance with the present invention;

FIG. 2 is a schematic flow diagram for operation of the engine illustrated in FIG. 1 in its start-up mode and its steady state or power mode;

FIG. 3 is an end view of the fuel injector illustrated in FIG. 1; and

FIG. 4 is a cross-sectional view of the injector and is taken on line 4—4 of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIG. 1, all external combustion engines such as a gas turbine 2 generally comprises a tubular, e.g. cylindrical housing 4, a suitably journalled turbine rotor 6 that includes a power output shaft 8, a fuel injector 10, a combustion chamber 12 between the injector and the rotor, and air intake 14 with a compressor 15 and an exhaust conduit 16. The overall operation of such a turbine is well known and need not be described here in detail. It suffices to say that the fuel injector injects the fuel into the incoming airstream. The resulting fuel-air mixture is then ignited in the combustion chamber and hot gases enter the rotor, flow past impeller blades 17 to turn the rotor.

The temperature of the exhaust gases, though substantially lower than the temperature in the combustion chamber, is still relatively high and contains a substantial amount of heat energy that is normally discharged into the atmosphere and, therefore, lost. The present invention provides a first heat exchanger 18 downstream of the rotor that is coupled to a second heat exchanger 20 upstream of the fuel injector via heat transfer conduits 22, 24 to form a heat exchange system 26 which transfers part of the exhaust gas heat energy to the incoming combustion airstream and thus heats the incoming air upstream of the fuel injector. In accordance with well known principles of heat transfer which need not be described here, the incoming combustion air can be heated to a desired temperature as high as several hundred degrees C. The heat exhange system is so designed that it heats the incoming air substantially above the vapor temperature (at the applicable pressure) for the liquid fuel supplied to injector 10 from a fuel supply 28. As is more fully described below, the fuel injector is designed so that liquid fuel is vaporized before its discharge into combustion chamber 12 for the above-described advantages and an efficient, substantially pollutant-free combustion of the fuel.

Referring now to FIGS. 1–4, the injector 10 is defined by a central hub 30 that is disposed coaxially within the cylindrical housing 4, a multiplicity of equally spaced, thin vanes 32 that extend radially away from the hub and terminate in free ends anchored to a peripheral ring 34. Brackets 36 position and mount the injector to housing 4. The hub includes an annular fuel supply cavity 38 and a fuel supply aperture 40 for connection to a fuel line 42 (shown in FIGS. 1 and 2, not shown in FIGS. 3 and 4) so that liquid fuel can be supplied to the annular cavity. For purposes further described below, the annular cavity 38 has a maximum cross section at or adjacent the point at which it communicates with the supply aperture and a cross section that continually decreases from there in both directions to a minimum cross section at an opposite point of the cavity spaced 180° from the point of maximum cross section. As is further described below, fuel is fed into passages in each vane. The decreasing fuel supply cavity cross section assures a constant fuel speed in the cavity and thus an equal fuel flow into each vane for a uniform fuel injection into combustion chamber 12.

The vanes 32 are thin plates constructed of a material having a relatively high thermal conductivity, such as a metal. They can be made in accordance with a variety of manufacturing processes. Thus, they can be machined, rolled, stamped or cast, for example.

Each vane has upstream and downstream edges 44 and 46, respectively, facing in the direction of the combustion air flow in cylindrical housing 4 to minimize air flow resistance. Inner and outer edges 48 and 50, respectively of the vane are suitably secured, e.g., welded, brazed, bonded or the like, to peripheral ring 34 and to an inner mounting ring 52 pressed or otherwise secured over the periphery of hub 30. In a preferred embodiment of the invention the annular hub cavity 38 has its outer periphery defined by mounting ring 52, and the mounting ring includes apertures 54 which communicate the cavity with radially extending passages 56 in the vanes. Each passage 56 may be stepped in crosssectional width (FIG. 4) to provide for uniform fuel flow rate into each adjacent passage 58.

The radial vane passages are relatively thin and wide, that is, their width (parallel to the vane width and the combustion air flow) is many times greater than their thickness (perpendicular to the combustion air flow) so that the surface area of the passages is relatively large as compared to its volume to effect an efficient and rapid heat transfer between fuel in the passage and the vane. A plurality of reduced cross section passages 58 extend perpendicularly away from radial passage 56 in a downstream direction and terminate in like pluralities of fuel discharge openings 60 facing downstream into

combustion chamber **12.** The discharge openings are preferably defined within vane edge **46.** If desired, they may extend to or be wholly within flat vane sides.

It is preferred that the relative radial location of the discharge openings on adjacent vanes be staggered, as is illustrated in FIG. **3,** and that the number of discharge openings in such adjacent vanes be varied so that fuel is uniformly and equally discharged into the primary combustion airstream flowing through the annular space defined by hub **30** and peripheral holding ring **34.** To enhance the intimacy with which the discharged fuel is mixed with the combustion airstream, end portions **62** of the small fuel passages are angularly inclined relative to the direction of the airstream so that the fuel is discharged and impinged upon itself and thus spread into the airstream for the formation of a more uniform and homogeneous fuel-air mixture.

Turning now to the steady state or power mode operation of the fuel injector of the present invention, fuel is supplied to hub cavity **38** and from there flows into radial vane passages **56.** Turbine exhaust gas heats combustion air entering intake **14** via the heat exchange system **26** and the heated combustion air in turn correspondingly raises the temperature of vanes **32.** When the combustion air temperature is above the liquid fuel vapor temperature and as a result of the large surface area to volume ratio in the vane passages the liquid fuel evaporates and exits from discharge openings **60** in vapor form. The angular fuel discharge effects an immediate, thorough and uniform admixture of the combustion air and the fuel vapor for immediate ignition, a short stay time and a correspondingly short combustion chamber for the above-described better combustion efficiency and a significant exhaust pollutant reduction.

On start-up of the engine the exhaust gas temperature is very low so that the evaporation described above does not take place. A discharge of liquid fuel from discharge openings **60,** designed for the discharge of vaporized fuel, would be inefficient. Consequently, a liquid fuel discharge nozzle **64** is provided in hub **30** which is coupled to a start-up fuel branch line via a control valve **68.** An ignitor, such as a spark plug or a heated coil **70** (shown in phantom lines in FIG. **4**) suitably coupled to a source of electric current (not shown in the drawings) is provided for igniting liquid fuel discharged by nozzle **64.** The nozzle is a single self-impinging doublet fuel nozzle employing small orifice diameters to produce a fine spray and prevent the formation of large droplets which would not combust completely in the short combustion chamber **12** and which would therefore result in the emission of excessive exhaust pollutants during the start-up cycle.

To start up, control valve **68** is set to feet liquid fuel to fuel discharge nozzle **64** and heating coil **70** is energized to ignite the discharged and atomized liquid fuel droplets. The ensuing combustion initiates the rotation of rotor **6** and a heat transfer through the heat exchange system **26** to heat exchanger **20** upstream of injector **10.** A heat sensor **72** is placed in the heated combustion airstream between heat exchanger **20** and injector **10** and is used to operate valve **68** to close branch circuit **66** and open main fuel supply line **42** when the combustion air temperature reaches the desired level at which fuel evaporation in vane passages **54, 58** is assured for steady state, power operation of the injector and the turbine. Heat sensor **72** also deactivates heating coil **70** at that point for normal power operation of the turbine with liquid fuel passing from the fuel supply past control valve **68,** main supply line **42** to annular hub cavity **38** and hence to vane passages **56** and **58** for evaporation and discharge of the fuel in vapor form through discharge openings **60.**

We claim:

1. A liquid fuel injector for forming a combustible, substantially homogeneous mixture comprising in combination an airflow conduit leading from an air source to a combustion chamber, heat exchanging means disposed upstream of the chamber for raising the combustion air temperature above the liquid fuel vapor temperature, a multiplicity of thin vanes disposed in the conduit between the heating means and the chamber, the vanes having a relatively flat cross section in a direction parallel to the airflow defined by sides positioned parallel to the airflow, an upstream edge facing the airflow, and a downstream edge facing the chamber, the vanes including interior passages terminating in discharge openings, the passages having a relatively flat cross-section complementary to the cross-section of the vanes to effect an efficient heat transfer between the vanes and a liquid in the passages, and means for supplying the passages with the liquid fuel whereby heat transferred from the air to the vanes evaporates the liquid in the passages for the emission of vaporized fuel from the discharge openings.

2. An injector according to claim **1** wherein the vanes are radially oriented with respect to an axis of the conduit, and wherein the liquid supply means includes centrally disposed hub means comprising means for connecting to a liquid supply, and an interior substantially annular liquid distributing groove communicating the connection means with the passages.

3. An injector according to claim **2** wherein the annular liquid supply groove extends over **360°** and has a varying cross section.

4. An injector according to claim **3** wherein the maximum and minimum liquid supply cross sections are substantially **180°** spaced apart.

5. An injector according to claim **2** wherein the liquid comprises liquid fuel, and including an auxiliary liquid fuel discharge nozzle in the hub means for the discharge of liquid fuel to the combustion zone during operation of the injector in its start-up mode, a fuel branch line for supplying liquid fuel to the nozzle, and means for igniting liquid fuel discharged by the nozzle.

6. An injector according to claim **5** including means sensing the temperature of the heated combustion air, and means for initiating the supply of liquid fuel to the passages in the vanes when the heated air temperature reaches a predetermined value and for simultaneously discontinuing the liquid fuel supply in the branch line to the nozzle.

7. An injector according to claim **1** wherein the discharge opening is angularly inclined relative to the direction of the airflow.

8. Apparatus for the high efficiency combustion of liquid fuels comprising an air supply conduit leading to a combustion chamber, hub means, a multiplicity of vanes extending away from the hub means, means for mounting the vanes within the conduit, the hub means including a fuel supply cavity and the vanes including fuel passages communicating with the cavity and terminating in fuel discharge openings facing in a downstream direction with respect to an airstream in the

conduit, means for connecting the cavity to a source of liquid fuel, a first heat exchanger downstream of the combustion chamber and in flow communication with exhaust gases from the combustion chamber, a second heat exchanger in the conduit upstream of the vanes, means connecting the heat exchangers for the passage of a heat transfer medium between the exchangers and a corresponding heating of the airstream of the vanes, the vanes having surfaces in contact with the heated airstream and surfaces in contact with the liquid fuel which are sufficiently large to effect a heat transfer from the airstream to the liquid fuel in the passages and a resulting vaporized fuel exists from the discharge openings for a substantially complete and homogenous intermizing of air and fuel and a subsequent efficient and substantially complete burning of the fuel.

9. Fuel combustion apparatus for use with heat engines using liquid fuel comprising in combination: an air duct for flowIng air, an engine rotor downstream of and in flow communication with the duct, heat exchange means for heating air flowing towards the rotor to a temperature greater than the vapor temperature of the liquid fuel, and a fuel injection disposed a short distance upstream of the rotor in the flow of air heated by the heat exchange means such that a relatively short combustion chamber exists between the injector and the rotor, the fuel injector having a multiplicity of thin vanes, means for mounting the vanes within the conduit, each vane including a fuel passage, means for connecting first ends of the passages with a source of liquid fuel, each passage terminating in at least one second fuel discharge opening, the passage having an extent in the direction of the air flow which is many times greater than its thickness in a direction perpendicular to the air flow, and a length which is sufficient to evaporate the fuel within the passage when the air flow is at said temperature, whereby vaporized fuel is discharged from the openings for an efficient, substantially instantaneous combustion of the fuel in the combustion chamber and prior to its entry into the rotor.

10. Apparatus according to claim **9**, wherein the extent of the vane in the airflow direction is many times greater than its thickness, and wherein the passage is flat and narrow in general correspondence with the vane configuration to effect a large surface area-to-volume ratio for the passage and a maximum heat transfer to the liquid fuel.

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