Nov. 23, 1954 F. T. HAGUE 2,694,899

LIQUID FUEL VAPORIZING APPARATUS

Filed June 9, 1950 2 Sheets-Sheet 1

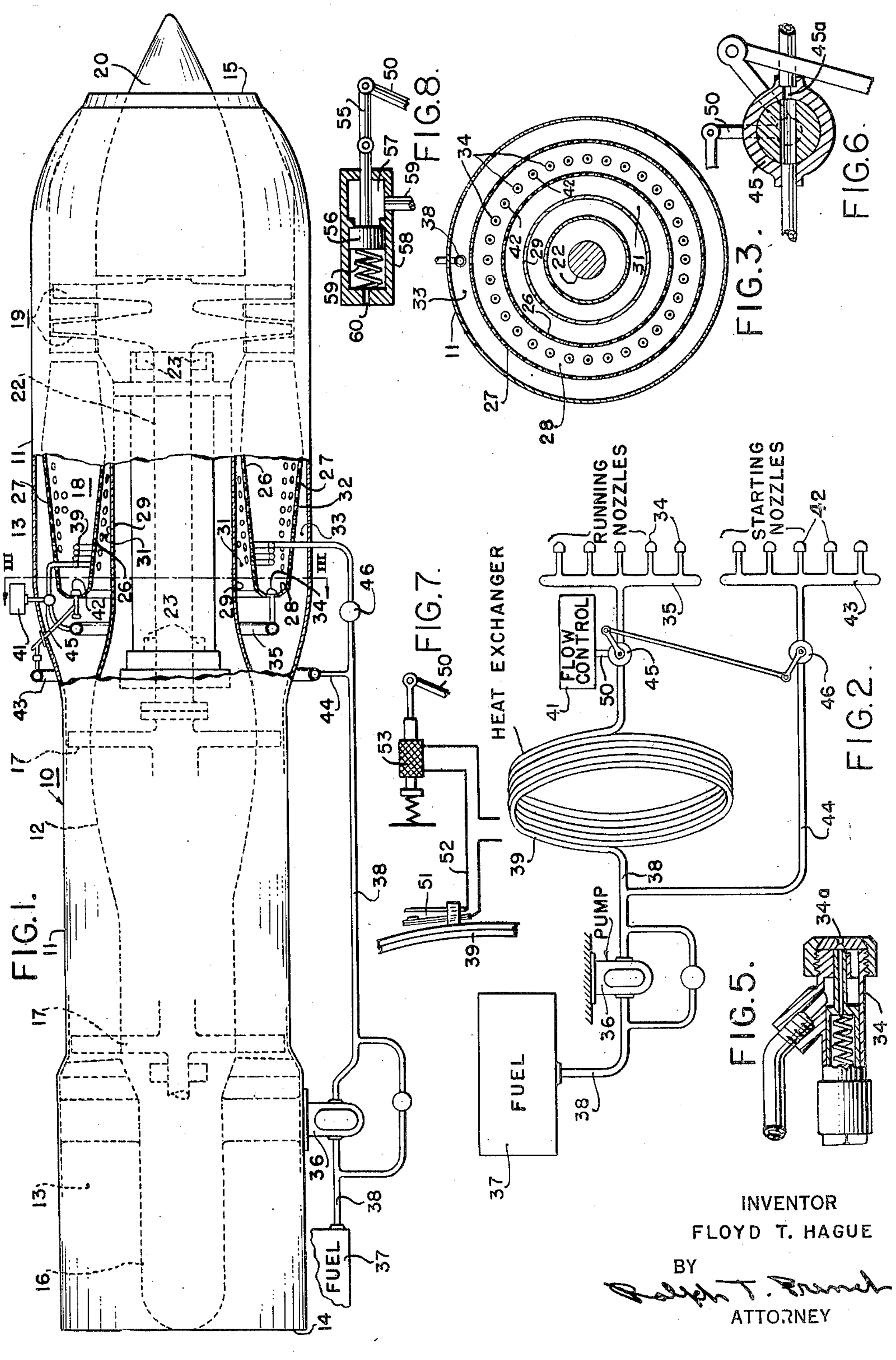

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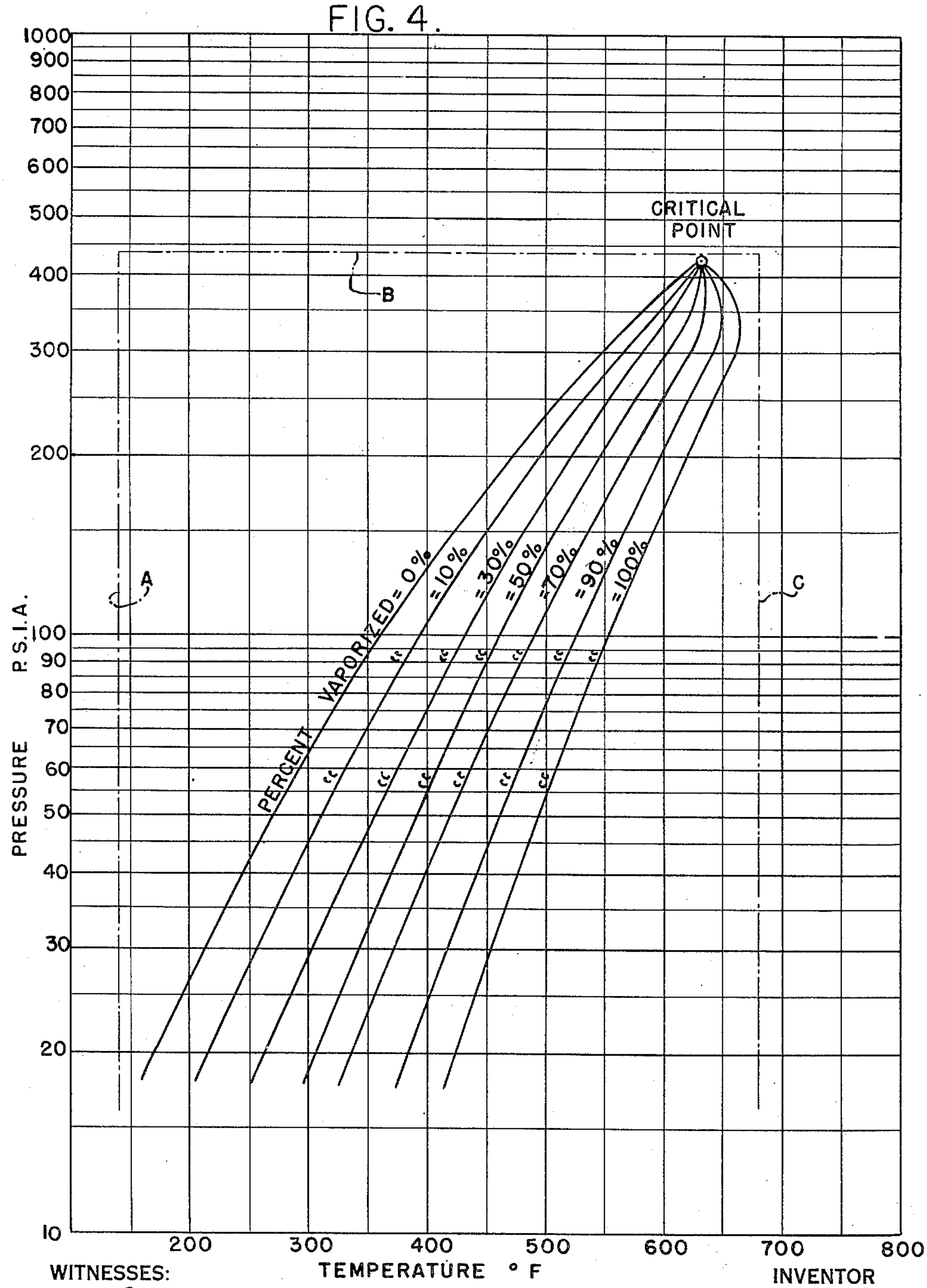
FIG. 4.



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VAPORIZATION CHART
FOR MIL-F 5624 FUEL

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LIQUID FUEL VAPORIZING APPARATUS

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2 Claims. (Cl. 60—39.14)

This invention relates to combustion apparatus of the continuous-combustion type, for example, such as are used in turbojets, propjets and athodyds for propulsion of aircraft, and has for an object to provide improved and novel apparatus of this character.

To obtain the most benefit from any combustion process one should strive to take advantage of all natural laws and specifically avoid being handicapped by any of them. The burning of liquid and gaseous types of fuels depends on several factors, not the least of which is the characteristic property of a liquid's inability to support flame. Liquids cannot burn; they must first be converted into gases or solids, either of which may burn.

This statement of fact is generally accepted, but such acceptance does not carry any assurance that all the significance of this fact is fully appreciated. The essentially necessary "time of conversion" of liquid fuel to gas, which must proceed ignition, involves the processes of (1) subdivision into small particles (usually called atomization) and (2) the absorption of the latent heat of evaporation by these particles in order to evolve the gaseous state which is pre-requisite to burning. Thus the combustion of liquid fuel in an atomizing combustor involves two additional time consuming operations as compared to a gas combustor. Gas combustion is fundamentally faster than liquid fuel combustion and a full understanding of this fact will explain why the additional "time delay" in ignition all of the fuel in an atomizing combustor is responsible for a loss in combustion efficiency under certain limiting conditions which prevail in combustors at high altitudes.

Loss of combustion efficiency means that the finally evolved gas is incompletely combusted as it leaves the combustor. The time to complete the combustion reaction is lengthened as the altitude increases. In an aviation combustor, because of its geometry, the burning gas-air mixture may at altitude be quenched by dilution air before the combustion reaction is completed, or in other instances the time delay in evolving the gaseous state from the liquid fuel may result in some of the gas-air mixture being formed in the so-called "quench section" of the combustor, where the temperature level is too low to fully complete the combustion reactions and as a result partially combusted gas leaves the combustor. The downstream distribution pattern of atomized fuel is a particularly adverse situation in any high altitude combustor because the largest size fuel droplets travel the farthest before being converted to the gas state.

All factors which limit the time that the finally evolved gas is in the "complete combustion zone" of a combustor combine to reduce the combustion efficiency in a major way under high altitude conditions. In an otherwise perfectly proportioned liquid fuel atomizing combustor, these factors include (1) fineness of atomization, particularly at partial load fuel flows and at cruising speed, (2) combustor overall length, (3) velocity of gases through the combustor, (4) distribution pattern of atomized fuel particles, (5) degree and type of turbulence in the "complete combustion" zone and many less important factors.

An evaluation study of atomizing combustors and of vaporizing combustors indicates that the atomizing aviation combustor is handicapped from attaining optimum performance by natural laws whereas the same laws can assist a vaporizing combustor. The time delay factors of downstream distribution of atomized fuel and absorption of latent heat of vaporization before ignition have not been found to be of sufficient practical importance to deserve much consideration except in short aviation combustors for high altitude operation and cruising fuel flow conditions. In these combustors the air pressure at altitude drops to a small fraction of an atmosphere. Atomization of fuel from a nozzle becomes coarser as the air pressure level lowers. It also becomes progressively coarser as the fuel flow rate is reduced. In these combustors a particle of gas or air passes through the entire length of a combustor in about thirty-five thousandths of a second. "Time delays" of the type outlined can amount to a large percentage of this very short residence time—so large in fact that under the altitude conditions outlined the efficiency of combustion can be very adversely affected. Low combustion efficiency precedes combustor blowout and all existing combustors can be blown out by exceeding their design conditions under certain conditions. Consequently, the vaporizing combustor would appear to be the shortest and most efficient type of combustor under high altitude conditions since there is no "time delay" in evolving the gas in the combustion chamber.

Vaporizing combustors have been proposed previously, but have been subject to various disadvantages. One such prior vaporizing combustor passed a mixture of air and liquid fuel through a heated vaporizing tube. In another, liquid fuel alone was passed through a heated vaporizing tube. In the latter construction cracking of the liquid fuel occurred as result of lack of sufficient pressure to prevent a two-state condition. The liquid portion tends to stay in the lower portion of the heat exchanger tube while the gaseous portion tends to collect in the upper portion of the tube. Due to the relatively poor heat exchange between the tube and gas the upper portion of the tube overheats and when droplets of fuel come in contact therewith, cracking occurs, resulting in deposits accumulating on the interior walls of the tube with consequent stoppage of the latter. While in the former, passing air through the vaporizing tube with the fuel reduced the amount of cracking to a suitable degree, the large size of heat exchange apparatus required for the air-fuel combination in present large combustors renders heating of both air and fuel impractical.

The present invention provides for placing the liquid fuel under a pressure above its critical pressure, heating the pressurized fuel to above its critical temperature, and then expanding the heated fuel through fuel emission devices to the combustor. When the fuel is at a temperature and pressure above its criticals, it is in a composite condition characterized by the absence of either a separate liquid or a separate vapor state. In this critical state it uniformly fills any enclosure that contains it and it also uniformly "wets" the wall surfaces of such enclosure. In this condition heat transfer from walls to gas is uniform.

In accordance with the present invention liquid fuel is supplied at a pressure in excess of its critical to a heat-exchanger associated with a combustion chamber where the heat of combustion raises the temperature of the fuel to above its critical, resulting in gasification of the fuel. Flow-control mechanism operates during starting of the power plant to prevent flow of fuel from the heat-exchanger to the gas nozzles of the combustion chamber until the temperature of the fuel in the heat-exchanger exceeds the critical. In the meantime the flow-control mechanism provides for passage of liquid fuel to other atomizing starting nozzles to initiate combustion.

Accordingly, another object of the invention is to provide means for obtaining completely gasified fuel without coking or cracking.

A further object of the invention is to provide completely gasified fuel in the absence of air.

Yet another object of the invention is to provide a gasified fuel system including gas running nozzles and atomizing starting nozzles, together with means for automatically switching from the starting nozzles to the running nozzles when the gaseous fuel is available.

These and other objects are effected by the invention as will be apparent from the following description and claims taken in connection with the accompanying drawings, forming a part of this application, in which:

Fig. 1 is a side elevational view of a gas turbine power plant for jet propulsion of aircraft and incorporating the present invention;

Fig. 2 is a diagrammatic view of the novel gasifying fuel system;

Fig. 3 is a transverse sectional view, taken along the line III—III of Fig. 1, lookng in the direction indicated by the arrows;

Fig. 4 is a vaporization chart for MIL—F 5624;

Fig. 5 is an enlarged fragmentary, sectional view of one of the running nozzles **34** of Fig. 2;

Fig. 6 is an enlarged fragmentary, sectional view of the valve **45**;

Fig. 7 is a schematic view of a thermostatic flow control; and,

Fig. 8 is a similar view of a time delay flow control.

Referring to Fig. 4, there is shown a vaporization chart for MIL—F 5624, as illustrative of a typical fuel for use in aircraft power plants. If the fuel were at a pressure below its critical pressure of approximately 425 p. s. i. a. and was heated to a temperature sufficient to vaporize it 100 per cent, it would cross all of the curves of the chart. As a result, in passing from the 0 per cent vaporized curve to the 100 per cent vaporized curve the fuel would be in two states, that is, partially liquid and partially gaseous. It is while the fuel is in two states that cracking may occur, resulting in formation of deposits on the walls of the heat-exchanger.

The present invention provides for vaporization of the fuel without passing it through this dangerous two-state stage.

Referring again to the chart of Fig. 4, the two state stage, which exists between the first and last curves of the chart, is avoided by completely by-passing the curves. This is done by first raising the pressure of the fuel to above its critical, that is, to above 425 p. s. i. a. on the chart while its temperature is less than 150 degrees F. This is indicated by the dotted line A. At this point the fuel enters the heat exchanger and its temperature is increased to above its critical, that is, to above about 670° F., as indicated by the dotted line B. At the right hand end of dotted line B, the fuel is in a critical or single state and is ready to leave the heat exchanger and pass to the fuel nozzles or other fuel-emission devices and hence to the combustion chamber. In so doing its pressure will drop, as indicated by the dotted line C, but at the right of the 100 per cent vaporization curve.

Referring now to Figs. 1, 2 and 3, for illustration only, and not by way of limitation, the invention is shown in connection with an aircraft power plant **10** comprising an annular outer casing **11** and an inner coaxial composite core structure **12**, the two being radially spaced to provide therebetween an annular passage **13** for flow of air and gases substantially straight through from an inlet **14** at the front, or left as viewed in Fig. 1, to an exhaust nozzle **15** at the rear or opposite end.

The composite core structure may include a fairing cone **16** at the inlet end, an axial flow compressor **17**, combustion apparatus indicated in its entirety by the reference character **18**, a gas turbine **19** and a tail cone **20** which cooperates with the rear end of the outer casing **11** to define the exhaust nozzle **15**. The turbine **19** is connected to the compressor **17** and drives the latter through shaft **22** journaled in suitable bearings **23**.

A power plant of this character operates in accordance with well known principles, which may be summarized as follows: Air entering the inlet **14** is compressed in the compressor **17** and passes to the combustion apparatus **18** where its temperature is raised by combustion of fuel therein. The heated air and hot products of combustion are expanded through the blading of the turbine **19** to motivate the latter and in turn the compressor **17**, the exhaust from the turbine being discharged from the power plant through the exhaust nozzle **15** in the form of a jet for propelling the aircraft in, or on which, the power plant is mounted.

The combustion apparatus, indicated in its entirety by the reference character **18**, comprises inner and outer annular walls **26** and **27**, respectively, joined at their upstream ends by an annular transverse wall **28**. The inner wall **26** is radially spaced from a shaft enclosing wall **29**, throughout the major portion of the length of the former to define therebetween an annular space **31** for flow of compressed air in blanketing relation to the combustion chamber **32** between the inner and outer walls **26** and **27**.

Similarly, the outer wall **27** is radially spaced throughout the major portion of its length from the outer casing **11** to define therebetween an airflow space **33** blanketing the combustion chamber **32** at the outer side of the latter. Preferably, the inner and outer walls **26** and **27** are provided with openings at axially-spaced points for admission of air from the blanketing spaces **31** and **33** to the combustion chamber **32**.

Fuel is admitted to the upstream portion of the combustion chamber **32** through an annular series of running nozzles **34** carried by the chamber end wall **28** and supplied with gasified fuel from the common manifold **35**.

A fuel pump **36** delivers liquid fuel at a pressure above its critical from a reservoir **37** via conduit **38** to a heat-exchanger **39**, preferably disposed in the combustion chamber **32**, where the liquid fuel is heated to a temperature above its critical by the heat of combustion occurring within the chamber **32** while at a pressure above its critical. Passage of gasified fuel from the heat exchanger **39** to the manifold **35** is controlled by the flow-control mechanism **41**, to be hereinafter more fully described.

For starting the power plant and obtaining sufficient heat to initiate gasification of fuel in the heat-exchanger, a plurality of starting nozzles **42** are provided, these starting nozzles preferably alternating with the running nozzles **34**, as best shown in Fig. 3. Liquid fuel is supplied directly to the starting nozzles through manifold **43** by the pump **36** through a branch **44** of the conduit **38**. in bypassing relation to the heat-exchanger.

The flow-control mechanism **41** may involve a thermostatic device (Fig. 7) functioning to retain the valve **45** between the heat-exchanger and the running nozzles in closed position until the temperature of the heat-exchanger exceeds the critical temperature of the fuel therein, when the valve **45** will open and permit flow of gasified fuel to the running nozzles. The thermostat **51**, mounted on the heat exchanger **39**, will close the circuit **52** when the desired temperature is reached, thereby operating the solenoid **53** to move the valve **45**, through arm **50**, to open position, and the valve **46** to corresponding closed position. While the valve **45** in the communication to the running nozzles is retained closed a corresponding valve **46** in the branch conduit **44** to the starting nozzles will be held open for passage of liquid fuel to the latter nozzles. The flow control mechanism may also include an orifice **45*a*** (Fig. 6) for restricting flow therethrough to maintain the desired pressure of fuel in the heat-exchanger. However, the fuel nozzles **34** may be provided with conventional orifices **34*a*** for this purpose (Fig. 5).

Instead of relying on a thermostatic device in the flow-control mechanism, a simple time delay device may be utilized. In such a device, the operating arm **50** of the control valve **45** may be moved to valve opening position by a link or rod **55** connected thereto at one end and carrying at its other end a piston **56** slidable in the chamber **57** of the housing **58**. A spring **59** normally maintains the piston **56** in the position shown in Fig. 8. When the fuel pump **46** is started, it directs fuel under pressure through a branch conduit **59** to the space at the right-hand side of the piston **56**, thereby moving the latter to the left, as viewed in Fig. 8, against the pressure of the spring **59** until the latter is completely compressed. Inasmuch as the space at the left of the piston **56** is vented to atmosphere through a relatively small bleed port **60**, the movement of the piston **56** will consume a period of time which is predetermined by the size of the bleed port **60**, this period being so predetermined that upon its completion the temperature of the heat exchanger will be such that the fuel passing thereto and therethrough will be vaporized at a temperature at, or above, the critical temperature of the particular fuel utilized. With such a device, upon positioning of the throttle for starting the valve **45** would be closed and the valve **46** opened. As clearly indicated in Fig. 2, this delayed movement of the valve **45** controls admission of vaporized fuel to the running nozzles **33** will produce a corresponding closing of the valve **46**, thereby shutting off flow of liquid fuel to the starting nozzles **42**.

As used in this application, the expression "condition-responsive flow control mechanism" is intended to include flow control mechanism operated in response to either a thermostatic device or a time delay device, as disclosed above, the two types of devices being substantial equivalents insofar as their use in the present invention is concerned.

While for theoretically perfect functioning of the present invention, critical pressures and temperatures should be utilized, it is recognized that commercially satisfactory results may be obtained at pressures and temperatures as much as 10 to 20 per cent below critical, due primarily to the approaching similarity of conditions of the two states at temperatures and pressures near the critical, and the high turbulence.

While the invention has been shown in but one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various changes and modifications without departing from the spirit thereof.

What is claimed is:

1. In a power plant of the continuous-combustion type, wall structure defining a combustion chamber; one or more running fuel nozzles associated with the combustion chamber for admission of gaseous fuel thereto during operation of the power plant other than starting; one or more starting fuel nozzles associated with the combustion chamber for admission of liquid fuel thereto during starting of the power plant; a source of liquid fuel; pumping mechanism for delivering fuel to the starting nozzle or nozzles and to the running nozzle or nozzles at a pressure near or above the critical pressure of the fuel; a heat-exchanger associated with the combustion chamber and adapted to receive heat from combustion taking place in said combustion chamber; communication means for passage of fuel from the source to the running nozzle or nozzles via the heat-exchanger, whereby the fuel may be heated to a temperature near or above its critical; said communication means also providing for passage of fuel from the source to the starting nozzle or nozzles in bypassing relation to the heat exchanger; and flow-control mechanism associated with the communication means operable during starting of the power plant to prevent passage of fuel to the running nozzle or nozzles and to permit passage of fuel to the starting nozzle or nozzles, and operable after starting of the power plant to shut off flow of fuel to the starting nozzle or nozzles and effect passage of fuel

to the running nozzle or nozzles via the heat-exchanger, whereby the fuel is delivered to the running nozzle or nozzles at a temperature near or above the critical temperature of said fuel.

2. In a power plant of the continuous-combustion type, wall structure defining a combustion chamber and including an annular outer wall; one or more starting nozzles associated with the combustion chamber for admission of fuel thereto during starting of the power plant; one or more running nozzles associated with the combustion chamber for admission of fuel thereto after the power plant is operating; a source of fuel; pump mechanism for delivering fuel to the starting nozzle or nozzles and to the running nozzle or nozzles at the pressure near or above the critical pressure of the fuel; a conduit for passage of fuel from the source to the running nozzle or nozzles, said conduit including a coiled portion associated with the combustion chamber whereby the fuel passing therethrough from the source to the running nozzle or nozzles is heated by combustion occurring in said combustion chamber, said conduit including a branch at a region upstream of the coiled portion, said branch providing for passage of fuel to the starting nozzle or nozzles; condition-responsive flow-control mechanism associated with the conduit at a region downstream of the coiled portion thereof and operable upon starting of the power plant to permit passage of fuel to the starting nozzle or nozzles only via the conduit branch until combustion reaches a degree sufficient to heat fuel in the coiled portion of the conduit to a temperature near or above the critical temperature of the fuel, and thereafter to permit passage of fuel to the running nozzle or nozzles only via the coiled portion of the conduit, and means for maintaining the pressure of the fuel in said coiled portion of the conduit near or above its critical.

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