Jan. 30, 1962 J. H. CHESTEK 3,018,626

VAPOR COMBUSTION SYSTEM

Filed Feb. 2, 1960

Fig 1

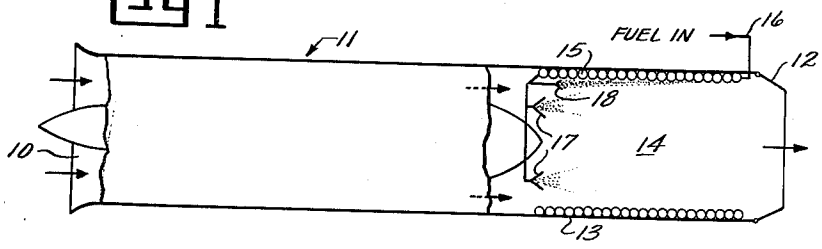


Fig 2

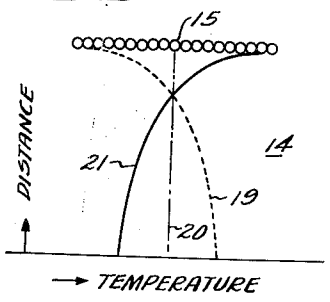


Fig 3

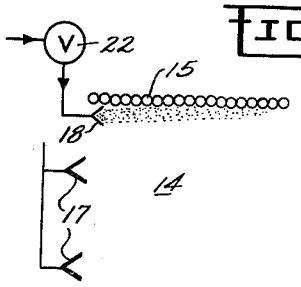


Fig 4

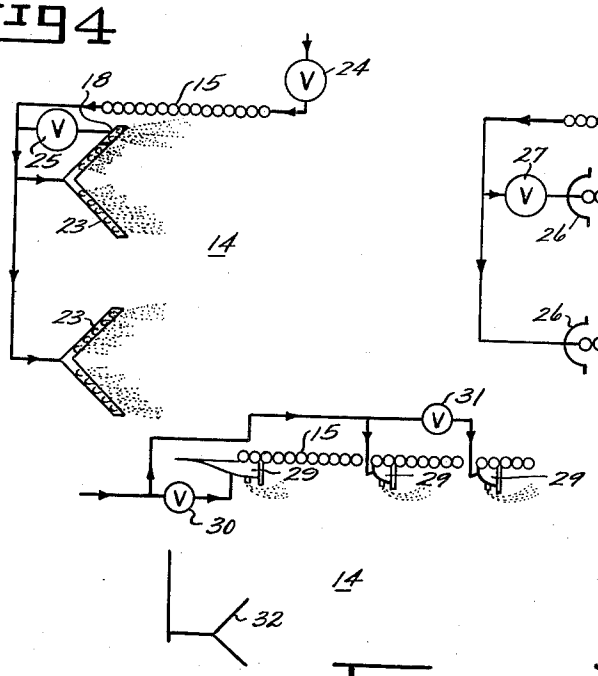


Fig 5

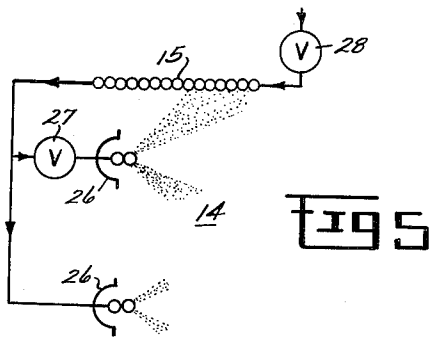


Fig 6

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VAPOR COMBUSTION SYSTEM

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The present invention relates to a vapor combustion system and, more particularly, to such a system for use in jet engines to control the temperature profile across the combustion zone.

The invention is directed to a structural arrangement and method to provide a satisfactory vapor combustion system by means of profile control of the average temperature across the combustion zone. The well known and standard means of fuel injection in combustion systems, such as may be found in jet engines, employ liquid fuel, generally of the hydrocarbon type, which is injected into the combustion area and mixed with air and burned to obtain thrust from the engine. It has long been known that the use of vaporized hydrocarbon fuel in such engines, especially in the reheat or afterburner combustion portion, offer certain advantages in weight and performance when compared with more conventional systems burning only liquid hydrocarbon fuels. Vapor systems per se are not new since such systems are used in many applications. However, vaporized fuel systems for use in jet engines have presented numerous problems because of the wide range and varying operating conditions under which such systems must function.

A vapor combustion system offers much shorter combustion components with higher combustion efficiency and lower pressure drop than is available in the conventional liquid fuel system. Once having decided to vaporize the fuel, it follows that a vaporizing means is required and this may take the form of a tubular heat exchanger. Since any tubes placed across the combustion zone provide drag and interference to the fluid flow resulting in high losses which penalize the performance of the engine, it is desirable to surround the combustion zone with the heat exchanger in order to keep the zone clear for the flow of combustion fluid. Fuel is directed through the heat exchanger walls to be vaporized therein. Such an arrangement permits lighter weight construction, lower pressure drop, and higher combustion efficiencies.

This use of the walls of a burner duct as a fuel vaporizer presents a problem in matching the quantity of heat required to provide the proper degree of vaporization of the fuel as compared with the amount of heat which is available by heat transfer from the combustion gas to the heat exchanger tubes. If the amount of heat required to vaporize the fuel is greater than that provided by the flow of combustion gas over the outside of the heat exchanger tubes, the fuel will be insufficiently vaporized to permit continued operation of the burner. On the other hand, if the amount of heat required to vaporize the fuel is less than the amount of heat available from the combustion gas, the fuel will become overheated and may be decomposed with resulting deposits which will clog up the heat exchanger passages and/or fuel passages downstream of the heat exchanger. If the amount of heat required to achieve the proper degree of vaporization of the fuel is still less as compared with the amount of heat being transferred from the combustion gas, the heat exchanger itself will become overheated to the point where its structural integrity is destroyed. Thus, a heat balance must be obtained at all times.

These problems cannot be overcome entirely by choosing proper size and disposition of the tubes which constitute the fuel vaporizer because of the necessity of an aircraft powerplant to operate properly over extreme variation in air flow, fuel flow, air pressure and combustion gas temperature. The amount of heat required to produce the proper degree of fuel vaporization in a particular system is principally a function of the gross amount of fuel required. The amount of heat which can be transferred from combustion gas is a function of burner pressure, inlet temperature, inlet air flow velocity, and burner output temperature. Because of the wide range of values which each of these parameters may take, it is impossible in many practical systems to design a heat exchanger fuel vaporizer whose physical configuration is suitable for operation over the entire range without some means of varying the operating parameters of the heat exchanger.

The overall operating parameters of such a fuel vaporizer, such as gas and fuel inlet and gas outlet temperatures, fuel flow, air pressure and air velocity, are established by the speed and altitude at which the powerplant is operating combined with the engine power setting selected by the pilot. These overall parameters cannot be modified to satisfy the requirements of heat balance required for satisfactory operation of the fuel vaporizer without incurring unacceptable penalties in the performance and flexibility of the powerplant.

The main object of the present invention is to provide a vapor combustion system and method of combustion by which satisfactory profile burning is obtained to insure complete vaporization of the fuel under all operating conditions.

Another object is to provide such a system and method of operation by which profile fuel injection means are provided to control the temperature of the heat exchanger and thus insure proper vaporization under all conditions.

A further object is to provide such a system and method of operation which insures complete vaporization under widely varying speed, altitude and temperature conditions.

Briefly stated, the invention is directed to a vapor combustion system which has tubular heat exchanger means surrounding and forming a combustion zone. Liquid fuel is directed through the heat exchanger for vaporization and then sprayed into the combustion zone for burning. Additional controlled profile fuel injection means are provided and direct fuel flow, which may be part of the main vaporized fuel or an independent vapor or liquid supply, along the heat exchanger surface to provide temperature control of the exchanger independently of the normal combustion in the combustion zone.

It should be appreciated that the combustion system disclosed herein is applicable to any combustion zone and the description directed to an afterburner is merely illustrative for convenience.

While the specification concludes with claims particularly pointly out and distinctly claiming the subject matter which I regard as my invention, it is believed the invention will be better understood from the following description taken in connection with the accompanying drawing in which:

FIGURE 1 is a schematic illustration of a jet engine showing the location of a typical vapor combustion system;

FIGURE 2 is a chart showing the temperature gradient of the combustion zone using the invention to control the average temperature;

FIGURE 3 is a schematic arrangement of one form of the vapor system;

FIGURE 4 is another schematic showing of a modified form;

FIGURE 5 is still another schematic showing of a modified form; and,

FIGURE 6 is a schematic showing of a modified form using plural profile burners.

Referring first to FIGURE 1, there is shown a general

schematic of a jet engine which may be a turbojet, ramjet, or combination and, as shown, is a turbojet having an air inlet 10 to direct air through a usual compressor section, combustion section, and turbine section all generally indicated at 11 and exhausting through a nozzle 12 to produce thrust in a conventional manner. In order to provide additional thrust, an augmentor or afterburner section 13 may be employed for the injection of additional fuel to provide increased velocity and higher thrust all in a well known manner. As previously stated, there are many advantages to providing vapor fuel injection over liquid fuel injection in the combustion zone 14 found in the afterburner 13. Such vapor systems require a heat exchanger 15 which may be conveniently tubular arranged in a spiral or longitudinal direction, and extending axially of the afterburner section to receive heat from the combustion zone 14 and vaporize fuel. Also, the tubes may form the structural wall of the combustion section. In order to vaporize the fuel to be injected into zone 14, the fuel may be directed through an inlet 16 to pass through the heat exchanger tubes and be vaporized. The vaporized fuel is then directed to the main fuel injectors 17 to be sprayed generally centrally into zone 14 to augment thrust. Such a system, as thus far described, may under some conditions, properly vaporize the fuel within heat exchanger 15 for satisfactory operation. However, it will not supply satisfactory operation under the widely varying conditions required.

In order to provide suitable vaporization, so that all the fuel is completely vaporized under all conditions of operation, I provide additional profile fuel injection means shown schematically at 18 in FIGURE 1.

Referring to FIGURE 2, it can be seen how proper operation of the fuel vaporizer can be obtained by controlling the temperature adjacent the heat exchanger surface, this temperature being one of the most significant parameters in assuring that sufficient heat is available to provide the proper degree of vaporization of the fuel without having such an excess of heat transferred to the heat exchanger that the fuel temperature becomes excessive and clogs and/or the heat exchanger is damaged. In FIGURE 2, the temperature gradient across a typical combustion zone is plotted against the distance from the center line of the zone. The same heat exchanger 15 is shown along the wall of the combustion zone. It can be seen that line 19 represents the temperature gradient with normal central fuel injection into the combustion zone, where the temperature of the wall of the heat exchanger is cooler than the temperature at the center of the combustion zone. The average temperature under this condition is shown by line 20. It will be apparent that, under some conditions of operation, the temperature at the wall 15, as shown by line 20, may be insufficient to completely vaporize the fuel for satisfactory operation. However, the temperature at the center of the combustion zone, as shown by line 19, is considerably higher thus the heat required by the heat exchanger is not being obtained from the available heat present even though the average temperature 20 is constant. In order to correct this defect, the invention disclosed herein provides a means of obtaining line 21 by which it can be seen that the temperature at the wall 15 has been considerably increased whereas, relative to it, the temperature at the center of the combustion zone is reduced but still maintaining the same average temperature. Thus, line 21 shows that the temperature next to the heat exchanger at the combustion zone periphery is quite high thus promoting rapid transfer of the heat required to vaporize the fuel whereas line 19 shows the temperature next to the heat exchanger is low thus reducing the amount of heat transferred into the fuel vaporizer and preventing overheating of the fuel and the heat exchanger. It can be seen that the average temperature of all the gas or fluid flowing in FIGURE 2 is the same in both cases. The only difference between

lines 19 and 21 is the profile of temperature across the combustion zone. The means by which this profile is obtained is by what I choose to call a profile fuel injection means to control the temperature at the zone periphery.

It will be apparent that a large variety of means can be devised which make this control of temperature profile possible. FIGURES 3–6 illustrate schematically some of these means.

The FIGURE 3 modification is similar to that shown in FIGURE 1 wherein the profile fuel injection means 18 is supplied adjacent the heat exchanger 15 and directs fuel for burning along the heat exchanger inner surface to control the temperature of the heat exchanger surface. Conveniently, as shown in FIGURE 3, the fuel may be directed substantially parallel to the surface and along the heat exchanger surface 15. The main fuel supply from injectors 17 is directed substantially centrally of the combustion zone 14. From this, it can be seen that line 21 of FIGURE 2, may be obtained by turning on injector 18 to raise the temperature of the heat exchanger surface. The control of the fuel and profile injector 18 is obtained by suitable valving 22. The flow of suitable liquid or vapor to injector 18 may come from the heat exchanger itself as shown in FIGURE 1 or from an independent external fuel source as indicated in FIGURE 3. The fuel is controlled by valve 22 so that the temperature near the wall 15 may be made high or low as required for proper operation of the fuel vaporizer. This showing in FIGURE 3 is representative of designs in which the temperature near the heat exchanger is controlled by a burner completely independent of the other parts of the combustion system.

FIGURE 4 illustrates a modification wherein two vapor burner injectors are positioned in the combustion zone 14 to provide the complete combustion system. All of the fuel for these burners is provided from the fuel vaporizer 15 controlled by suitable valve means 24 but the amount of fuel injected through part 18 of injector 23 near the heat exchanger 15 is controlled independently of the total fuel flow by means of valve 25. Thus the upper portion 18 of upper injector 23 may be separated as the profile control part of the injector to control the temperature of the wall of exchanger 15. The total fuel flow through the burner is controlled by valve 24 which may be regulated by the engine power setting in such a manner as to provide the total amount of fuel required to produce the required average temperature. This modification is representative of those in which the burner used to control temperature at the heat exchanger surface is physically connected to other parts of the main combustion system and is a part of the upper burner 23 using the same fuel but being operated independently of the main combustion system. A typical main burner of the type illustrated by 23 may be found in application Serial Number 850,329, filed November 2, 1959, and assigned to the same assignee as the instant invention.

A further modification is shown in FIGURE 5, wherein two vapor burner injectors 26 are schematically shown. The fuel flow to the injector near the heat exchanger wall 15 is controlled by valve means 27. The injector is of a form to direct fuel along the heat exchanger surface. Again the total fuel flow is under the control of valve 28. This figure represents a design in which the control of the temperature profile across the combustion zone is accomplished through the use of a major portion of the main combustion system by simply adding a valve 27 to elements normally found in such a combustion system.

Another modification is shown in FIGURE 6, which illustrates the use of more than one burner or injector near the heat exchanger wall. These injectors 29, which are the profile fuel injectors, are spaced axially along the heat exchanger inner surface. This arrangement may be required if a high temperature must be maintained for

a considerable length along the heat exchanger **15**. As the hot gas produced by the first injector is dissipated by mixing with cooler gas flowing further away from the wall **15**, the temperature near the heat exchanger may become too low for effective vaporization. Then, one or more auxiliary injectors **29** may be needed to maintain a high temperature near the surface **15**. The control of the temperature profile or the temperature of the heat exchanger surface may be effected in this case through control of the amount of fuel supplied to one or several of these injectors such as by valves **30** and **31**. It will be understood that the main burner **32** operates in the normal fashion.

Thus, it can be seen that many combinations are apparent utilizing fuel from the heat exchanger itself or an independent supply and such fuel may be either liquid or vapor. The use of the additional profile injectors to burn fuel along the surface of the heat exchanger raises the temperature of the exchanger to increase the vaporization of the fuel in it and, by regulating this additional fuel burning according to operating condition, it is possible to control the heat exchanger temperature so that the necessary heat available to the exchanger is the same as the heat required by the exchanger for complete vaporization under widely varying operating conditions.

While I have hereinbefore described a preferred form of my invention, obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

I claim:

1. A vapor combustion system comprising, heat exchanger means surrounding and forming a combustion zone, means connected to and directing fuel through said exchanger to be vaporized therein, vapor injection means connected to said exchanger and directing the vaporized fuel into said zone for burning, and additional controlled profile fuel injection means directing fuel for burning along the heat exchanger surface to provide temperature control of said heat exchanger independently of the normal combustion in said zone and change the temperature profile across the combustion zone by changing the temperature at the periphery of said zone.

2. A vapor combustion system comprising, tubular heat exchanger means surrounding and forming a combustion zone, means to direct air through said zone, means connected to and directing fuel through said exchanger to be vaporized therein, vapor injection means connected to said exchanger and directing vaporized fuel into said zone for burning, and additional controlled profile fuel injection means disposed in said combustion zone and directing fuel for burning along the heat exchanger surface to provide temperature control of said heat exchanger independently of the normal combustion in said zone and change the temperature profile across the combustion zone by changing the temperature at the periphery of said zone.

3. A vapor combustion system comprising, a tubular heat exchanger forming an internal combustion zone, means to direct air through said zone, controlled means connected to and directing a main fuel supply through said exchanger to be vaporized therein, vapor injection means connected to said exchanger and directing vaporizer fuel into said zone substantially centrally thereof for burning therein, and additional controlled profile fuel injection means disposed in said combustion zone and directing fuel for burning along the heat exchanger inner tubular surface to provide temperature control of said heat exchanger independently of the normal combustion in said zone and change the temperature profile across the combustion zone by changing the temperature at the periphery of said zone.

4. Apparatus as described in claim 3 wherein said additional fuel injection means is connected to said heat exchanger to receive main vapor fuel therefrom, and valve control means is provided between said heat exchanger and said additional injection means.

5. Apparatus as described in claim 3 wherein said additional fuel injection means is connected to an external fuel source independent of said main fuel, and valve control means is provided between said fuel source and said additional injection means.

6. Apparatus as described in claim 3 wherein said additional fuel injection means is formed by part of said vapor injection means, and valve control means is provided to control fuel to said additional injection means.

7. Apparatus as described in claim 3 wherein said additional fuel injection means comprises a plurality of injectors spaced axially along said heat exchanger inner surface, and valve control means is provided to control fuel to said additional injection means.

8. A vapor combustion system in a jet engine augmentor comprising, an afterburner section having a nozzle downstream thereon, a tubular heat exchanger axially surrounding said afterburner section and forming an internal combustion zone, controlled means connected to and directing a main fuel supply through said exchanger to be vaporized therein, fuel vapor injection means disposed in said zone and connected to said exchanger to direct vaporized fuel substantially centrally of said zone for burning therein, means to increase the heat exchanger surface temperature including additional controlled profile fuel injection means disposed in said zone and directing fuel substantially parallel to and along said heat exchanger inner surface to provide temperature control of said heat exchanger independently of the normal combustion in said zone and change the temperature profile across the combustion zone by changing the temperature at the periphery of said zone.

9. Apparatus as described in claim 8 wherein said additional fuel injection means is connected to said heat exchanger to receive main vapor fuel therefrom, and valve control means is provided between said heat exchanger and said additional injection means.

10. Apparatus as described in claim 8 wherein said additional fuel injection means is connected to an external fuel source independent of said main fuel, and valve control means is provided between said fuel source and said additional injection means.

11. Apparatus as described in claim 8 wherein said additional fuel injection means is formed by part of said vapor injection means, and valve control means is provided to control fuel to said additional injection means.

12. Apparatus as described in claim 8 wherein said additional fuel injection means comprises a plurality of injectors spaced axially along said heat exchanger inner surface, and valve control means is provided to control fuel to said additional injector means.

13. The method of operating a combustion system of the type having a heat exchanger for vaporizing the fuel which comprises, injecting and burning vapor fuel in the combustion system, injecting and burning additional fuel along the surface of the heat exchanger to raise the temperature of the exchanger and increase the vaporization of the fuel therein, and regulating the additional fuel burning to control the heat exchanger temperature and make the necessary heat available to the exchanger to balance the heat required by the exchanger for complete vaporization under varying operating conditions.

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