

[54] **METHOD AND APPARATUS FOR PROVIDING JET PROPELLED VEHICLES WITH A HEAT SINK**

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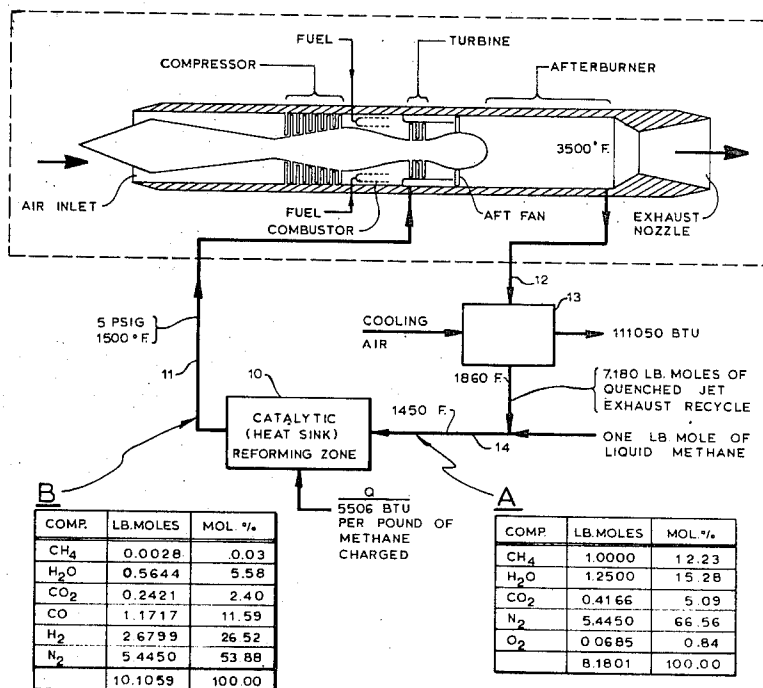
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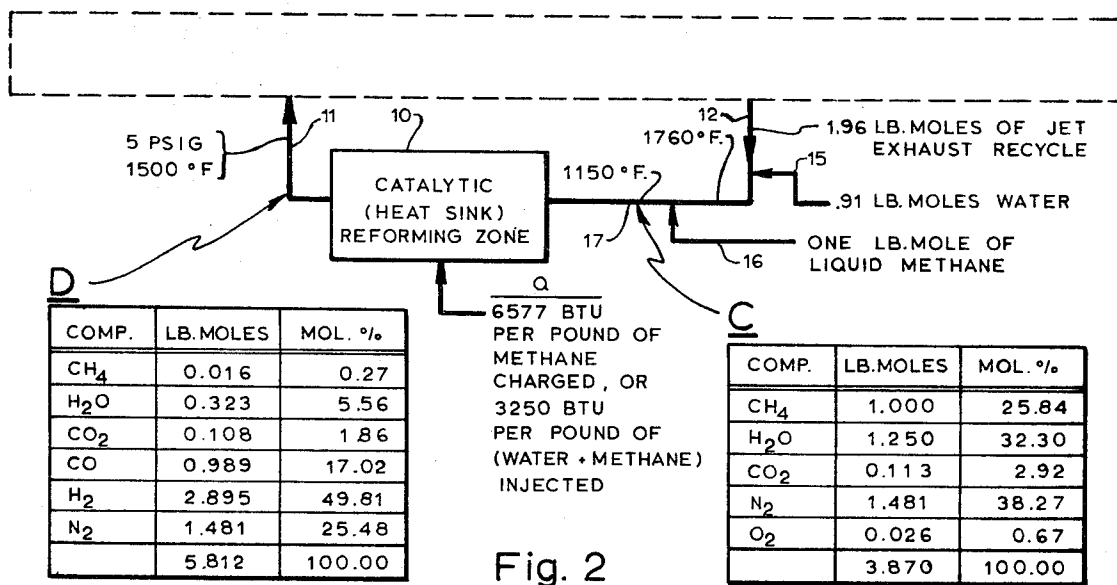
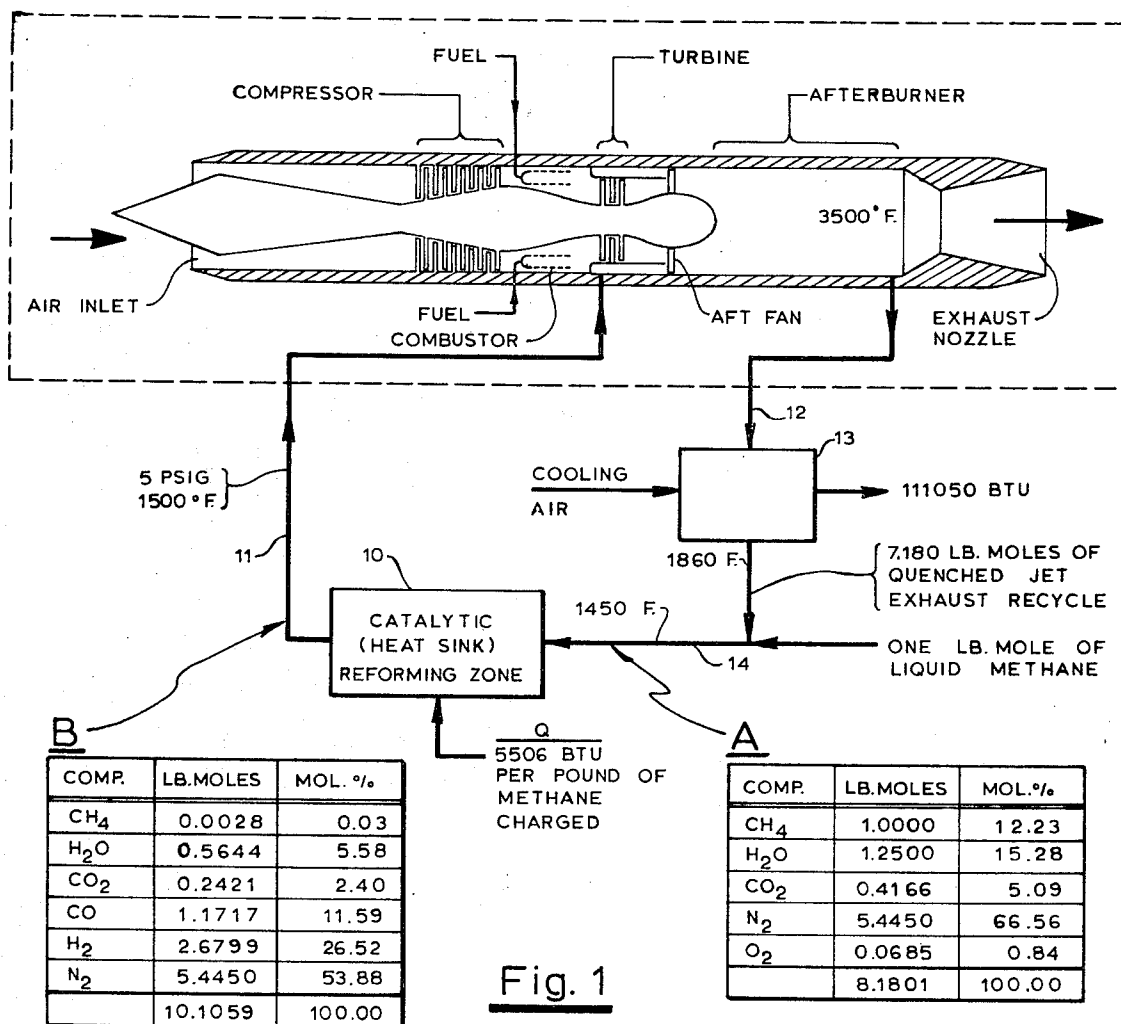
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[57] **ABSTRACT**

Use is made in a jet propelled vehicle of the catalytic reforming of a hydrocarbon with steam and carbon dioxide, as supplied by the exhaust from the afterburner of the jet engine, to generate heat sink capacities of the order of 6,000 BTU per pound of the fuel, e.g., methane, which is combined with the exhaust gases for passage to the reforming zone, or zones, which serve the desired heat sink function. In operation, a portion of the extremely hot exhaust gases from the engine afterburner, which contain steam and carbon dioxide but are as lean as practicable in oxygen, is first quenched by external or internal cooling and then admixed with the hydrocarbon fuel, which provides still further cooling. The resulting gaseous mixture is then passed over a catalyst in a reforming zone which operates endothermally. The gases from this zone are then passed to the aft fan of the engine which propels them into the afterburner for combustion and resulting thrust augmentation. The heat sink provided by the reforming zone can be utilized to take up heat from any desired points in the vehicle including the engine, wing surfaces, or the like, using direct or indirect methods of heat exchange.

8 Claims, 2 Drawing Figures





METHOD AND APPARATUS FOR PROVIDING JET PROPELLED VEHICLES WITH A HEAT SINK

BACKGROUND OF THE INVENTION

The use of hydrocarbon fuel for high speed flight requires enhancement of the sensible and latent cooling capability of the fuel. To this end, endothermic chemical reactions have been investigated and such reactions as thermal cracking, depolymerization, dehydrogenation and dehydrocyclization have been explored. Among the more promising methods proposed to date are the dehydrogenation of naphthenes or methylcyclohexane. Dehydrogenation of the latter compound, for example, over a platinum-on-alumina catalyst provides a heat sink having a capacity of the order of 2,000 BTU per pound of the fuel. Yet, with the trend to higher speed vehicles ever continuing, heat sink capacities which far exceed this level must be sought.

The invention disclosed herein is capable of substantially tripling the heat sink capacities hitherto available using hydrocarbon feeds. It does this by making use of the well known steam/CO₂ reforming of hydrocarbons over a reforming catalyst such, for example, as nickel-on-alumina. Thus, by using the present invention and employing methane as the feed, a heat sink capacity of about 6,000 BTU/lb of methane can be realized.

Most of the elements required for a practice of the invention are already on board a jet propelled vehicle. These include an afterburner-equipped jet engine which provides an exhaust containing the desired steam and carbon dioxide gases, as well as an aft fan which is normally used to blow by-pass air to the afterburner for combustion of added fuel, and which here can be used (either in lieu of the foregoing function or in addition thereto) to blow the gases from the reforming zone into the afterburner.

SUMMARY OF THE INVENTION

This invention relates to a method and apparatus for providing a jet propelled vehicle with a high capacity heat sink, said sink being adapted to take up excess heat generated at one or more points within the vehicle as it travels at supersonic or hypersonic speeds. This "heat sink," which term includes units incorporating either one or a plurality of such heat sinks in a single vehicle, takes the form of a catalytic reforming unit through which are passed afterburner exhaust gases (the useful elements of which are steam and carbon dioxide) along with an added hydrocarbon fuel. The resulting "reformate," or mixture of reformed gases, is returned as fuel to the afterburner of the engine where, on burning, it combines with much of the oxygen which is admitted to the afterburner from one source or another. This has the effect of augmenting the thrust of the engine, while at the same time providing an exhaust stream of reduced oxygen content. Oxygen, to the extent that it is present in the exhaust gas recycled to the reforming zone, reduces the heat sink capacity of said zone inasmuch as the combustion reaction supported by the oxygen is exothermic. Accordingly, in a practice of the present invention, the supply of fuel and air to the jet engine will be so regulated that the oxygen content of the exhaust gas from the afterburner is either low or is substantially eliminated altogether. The data presented with the figures of the drawings hereof, for example, assume an oxygen content in the exhaust of the order of one mole percent, or less.

Referring to the operation of a jet engine of the type wherein a hydrocarbon feed is burned in a forward combustion zone in the presence of excess oxygen (air), and wherein the resulting combustion gases are passed through a turbine section and an aft fan for discharge into an afterburner wherein additional fuel (and optionally air) is added and burned, the present invention can be described as the improvement comprising capturing a portion of the afterburner exhaust and quenching the same with external or internal cooling means, further cooling the quenched gas by admixing the same with a hydrocarbon, passing the resulting gaseous stream through a catalytic reforming zone, supplying heat to said zone to maintain the same at the desired reforming temperature, and passing the resulting reformed gases to the after burner as a source of fuel thereto. This combustion in the afterburner augments the thrust of the engine, while at the same time providing one way of controlling the content of oxygen in the exhaust stream leaving the afterburner to be in part recycled to the reforming zone, said oxygen content being kept at a low level. Rudimentary thermodynamic calculations will disclose the maximum oxygen content which the exhaust recycle stream may contain for a given system in order to maintain the desired heat sink capacity in the reforming zone where the strongly endothermic reforming reaction between the hydrocarbon fuel, the carbon dioxide and the steam is taking place. To further assist in keeping the oxygen at a low level in the afterburner exhaust, the supply of air and the main fuel to the engine (including that supplied to the afterburner, if any) can be adjusted so as to generally balance the supply of oxygen available in the afterburner with that required to combust the reformed gases from the reforming zone. This is the preferred method of practicing the present invention, at least during peak cooling demands on the part of the overly hot vehicle portions from which heat must be withdrawn for transfer to the reforming zone heat sink.

As noted above, the extremely hot exhaust gas to be recycled, which typically is at a temperature of 3,500°F as it leaves the afterburner, must be cooled (quenched) to avoid carbon formation as it is admixed with a hydrocarbon before being passed to the heat sink. Air cooling is an example of an external method which can effect such precooling, and this method is practical at lower altitudes using honeycombs, or the like, behind an exposed surface of the vehicle. In another method, adapted to higher altitude flights or the like, the desired temperature reduction can be effected by internal means such as injecting water into the hot gas stream. Alternatively, both external as well as internal cooling methods can be utilized. Methods such as these are adapted to bring the temperature of the exhaust gas recycle stream down into a range of from about 1,600° to 1,900°F. Thereafter the temperature is lowered still further as the cooler hydrocarbon is introduced into the stream and vaporized therein. Methane is the preferred hydrocarbon for injection into the reforming stream inasmuch as the reforming thereof is characterized by the highest endothermic heat requirement. Further, it is anticipated that future vehicles may employ methane as their principal fuel material, and it would be convenient to use the same fuel for both primary propulsion as well as for the fuel to the reformer. In lieu of methane, other light hydrocarbons can be used such, for example, as ethane or propane, these fuels being

used either alone or as admixed with one another or with methane.

The temperature to which the fuel-containing gaseous stream to the reforming unit is cooled before being passed over the reforming catalyst is capable of some variation. Thus, it should not be so hot as to induce cracking of the fuel, with resultant formation of carbon which would be deposited on the catalyst. On the other hand, the temperature of said stream should be hot enough so that it can be readily be brought to the reaction temperature to be maintained over the catalyst as heat is transferred thereto from some other portion of the vehicle which, in turn, is to be cooled.

The temperature to be maintained over the catalyst and that of the feed thereto are but two of the factors to be taken into account in determining whether or not there will be carbon deposition, with attendant rapid deactivation of the catalyst, as the gaseous feed passes through the reforming zone serving as the heat sink. Other factors which are involved in this determination are the relative concentration of the hydrocarbon in this feed stream, and the mole ratio of hydrocarbon to steam which prevails in the feed. The nature of these factors and their interrelationship, one to the other, are well known to those skilled in the art, for the reforming reaction which takes place in a practice of this invention is precisely the same as that which is carried out in other processes wherein carbon dioxide and steam are reacted with a hydrocarbon fuel over a reforming catalyst to form mixtures of hydrogen and carbon monoxide. For example, one reaction of this character is used to generate synthesis gas ($\text{CO} + \text{H}_2$) for conversion to alcohols. Accordingly, a detailed description of these various conditions to be observed in the reforming zone is not here made since such conditions form no part of the present invention. However, representative data are given below in connection with a description of the figures of the drawing for two different systems that the nature of the present invention may be the more clearly understood.

In carrying out the present invention, the reforming zone can be provided with any one of a variety of known catalysts used for reforming reactions of the type here encountered. A particular catalyst of good utility is made up of nickel deposited on a refractory material such as alumina, the catalyst being promoted, if desired, by the addition of an alkali or alkaline earth metal. Other catalytic materials which may be used comprise cobalt, platinum, palladium, iridium, rhenium and rubidium, among others, as deposited on a refractory support.

The reforming zone or zones used in a practice of this invention can take any one or more of a variety of physical shapes. Thus, the zone may be of the fixed bed or the fluidized bed types. Again, the reforming zone may be placed adjacent the portion of the vehicle to be cooled or at a distance therefrom. In the latter case heat can be transferred into the reforming zone using a secondary fluid cycle with the secondary fluid removing heat from critical portions of the vehicle by forced convection, transpiration or film cooling techniques. A given reforming zone can receive heat from one or a plurality of heat sources.

DESCRIPTION OF PREFERRED EMBODIMENTS

The nature of the present invention may be more clearly understood by reference to the appended drawing wherein:

FIG. 1 represents a schematic, diagrammatic view of a jet engine and shows an embodiment of the invention wherein a portion of the exhaust from the afterburner is withdrawn to be quenched by air, further cooled by admixture with methane and passed through a catalytic reforming zone operating endothermally to which heat is supplied from some other portion of the vehicle to maintain reforming temperatures. The reformed gases are returned to the afterburner, via the aft fan, for combustion; and

FIG. 2 is a view similar to that of FIG. 1, but with the engine being indicated by a dotted rectangle, and with the withdrawn afterburner exhaust portion here being quenched with a water stream, which forms added steam in the recycle gas, before then being further cooled by addition of methane.

Referring more particularly to the system of FIG. 1, there is shown within the dotted outline a jet engine with its forward air inlet, compressor and fuel injection and combustion zones, the resultant combustion gases, which contain excess oxygen, then passing through an aft fan for release into the afterburner. The afterburner receives added fuel as supplied from reforming zone 10 via line 11, the burning of said fuel serving to bring the oxygen content of the exhaust gases from the afterburner to a low level of less than 1 mole percent, as indicated by the data in box A after deducting the methane content. In the operation shown in this figure, a portion of the extremely hot ($3,500^\circ\text{F}$) combustion gases from the afterburner is withdrawn through line 12, the unit of withdrawal here being taken to be 7.18 pound moles. This gas is externally cooled as it passes through a cooling air zone 13 which serves to remove 111,050 BTU from the gas as its temperature is quenched to $1,860^\circ\text{F}$. The quenched gas in line 12 is now admixed with 1 pound mole of liquid methane, which has the effect of providing a gas stream in line 14 having a temperature of $1,450^\circ\text{F}$. The composition of the gas in line 14 is shown in data box A as being 12.23 mole percent methane, 15.28 mole percent steam, 5.09 mole percent carbon dioxide, 66.56 mole percent nitrogen and 0.84 mole percent oxygen, a typical "low" value. With the catalytic reforming zone 10 (which operates as a heat sink) being maintained at $1,500^\circ\text{F}$, thermodynamic equilibrium calculations show that the required heat input to said zone is 5,506 BTU per pound of methane charged. The composition of the reformed gases leaving zone 10 via line 11 for discharge through the aft fan and combustion in the jet afterburner, is shown in data box B. Thus, it will be seen that the reformat stream in line 11 is made up of 0.03 mole percent methane, 5.58 mole percent steam, 2.4 mole percent carbon dioxide, 11.59 mole percent carbon monoxide, 26.52 mole percent hydrogen and 53.88 mole percent nitrogen. The temperature of $1,500^\circ\text{F}$ shown for the reforming zone is typical for an alumina-supported nickel catalyst, among others.

In the operation shown in FIG. 2, the quantity of hot ($3,500^\circ\text{F}$) exhaust gas from the jet afterburner which is withdrawn through line 12 is 1.96 pound moles. It is quenched to a temperature of $1,760^\circ\text{F}$ by internal means as it is admixed with 0.91 pound mole of water

added through line 15. The further addition through line 16 of 1 pound mole of methane further cools the temperature of the gas stream in line 17 to 1,150°F. As shown by the data in box C, the gas in line 17 which is fed to reforming zone 10 is 25.84 mole percent methane, 32.3 mole percent steam, 2.92 mole percent carbon dioxide, 38.27 mole percent nitrogen and 0.67 mole percent oxygen. Calculated thermodynamic equilibrium data show that maintenance of zone 10 at an exit temp. of 1,500°F requires a heat input to the said zone of 6,577 BTU per pound of methane charged, or 3,250 BTU per pound of water + methane injected. The makeup of the reformat gas in line 11, which is returned to the engine for combustion in the afterburner, is shown in data box D as being 0.27 mole percent methane, 1.86 mole percent carbon dioxide, 17.02 mole percent carbon monoxide, 48.81 mole percent hydrogen, 29.48 mole percent nitrogen and 5.56 mole percent steam.

It will be seen from the data presented above that the present invention provides one or more zones within the vehicle which represent heat sinks of great capacity.

It will be appreciated that the present invention is not to be limited by the terms of description or details of illustrations inasmuch as various modifications and alterations thereof coming within the scope of the invention, as defined in the claims, will suggest themselves to those skilled in the art. For example, while water is disclosed above as a representative internal cooling fluid for quenching the hot exhaust gases, other fluids (e.g., liquid hydrogen) could be used. Similarly, while only reformed gases are shown as being supplied as fuel to the afterburner, other fuels could be added, as is conventionally the case with present afterburner-equipped jet engines.

I claim:

1. A method of operating a jet propelled vehicle equipped with a jet engine incorporating an afterburner whereby heat may be removed from critical vehicle portions requiring cooling, said method comprising capturing a portion of the exhaust gases from the afterburner, quenching said captured gases by the practice of cooling means, further cooling the quenched gases by admixing the same with a hydrocarbon, passing the

resulting gaseous stream through a catalytic reforming zone, supplying heat to said zone as recovered from the aforesaid critical vehicle portions to be cooled, thereby maintaining said zone at the desired reforming temperature, and passing the resulting reformed gases to the afterburner as a source of fuel for combustion therein.

2. The method as recited in claim 1 wherein the exhaust gases are quenched by heat exchange with an air stream.

3. The method as recited in claim 1 wherein the exhaust gases are quenched by injection of a liquid water stream.

4. The method as recited in claim 1 wherein the hydrocarbon admixed with the quenched exhaust gases is methane.

5. The method of operation recited in claim 1 wherein the jet engine is equipped with an aft fan and wherein the reformed gases are passed to said fan for discharge into the afterburner of the engine.

6. The method as recited in claim 1 wherein the operation of the jet engine is such that the oxygen content of the exhaust gases from the afterburner is low.

7. The method as recited in claim 6 wherein combustion of the reformed gases in the afterburner consumes substantially all of the available oxygen admitted thereto.

8. A jet propelled vehicle having a jet engine of the type incorporating an aft fan and an afterburner, in combination with a conduit communicating with the afterburner for collecting a portion of the exhaust gases generated in the afterburner, means for quenching the collected exhaust gases, means for injecting a hydrocarbon fuel into the quenched gases, a catalyst-containing reforming unit adapted to receive the resulting fuel-containing gases and to subject the same to an endothermic reforming reaction, heat transfer means for conducting to the reforming unit, from some portion of the vehicle to be cooled, the heat necessary to maintain the reforming unit at the desired reforming temperatures, and means communicating with the reforming unit for receiving the reformed gases and for passing the same to the aft fan for discharge into the afterburner of the engine.

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