

April 13, 1965

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3,177,656

COOLING METHOD AND MEANS FOR ROCKET ENGINES

Filed Aug. 3, 1961

2 Sheets-Sheet 1

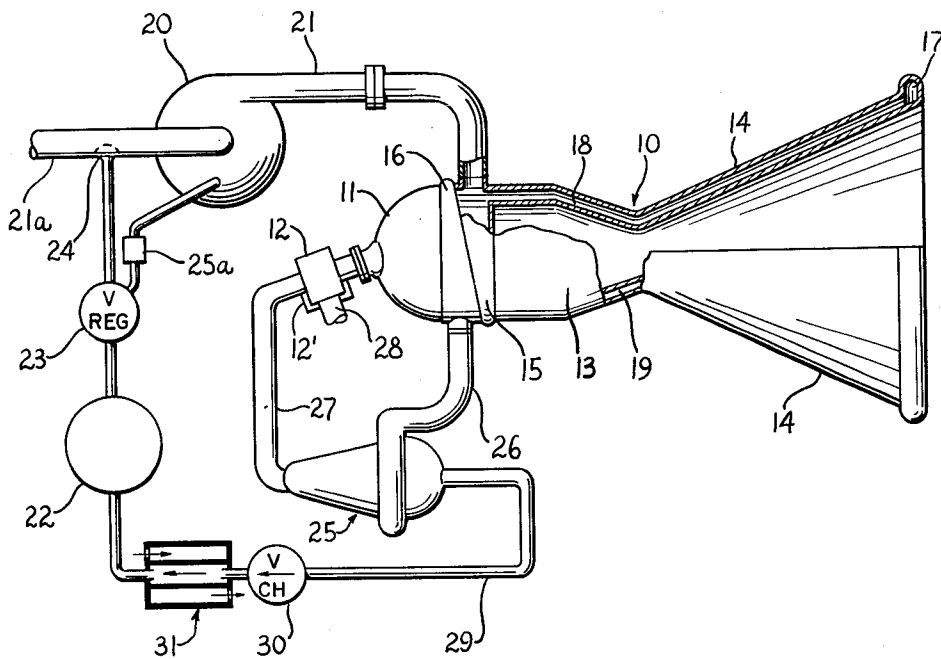


Fig. 1

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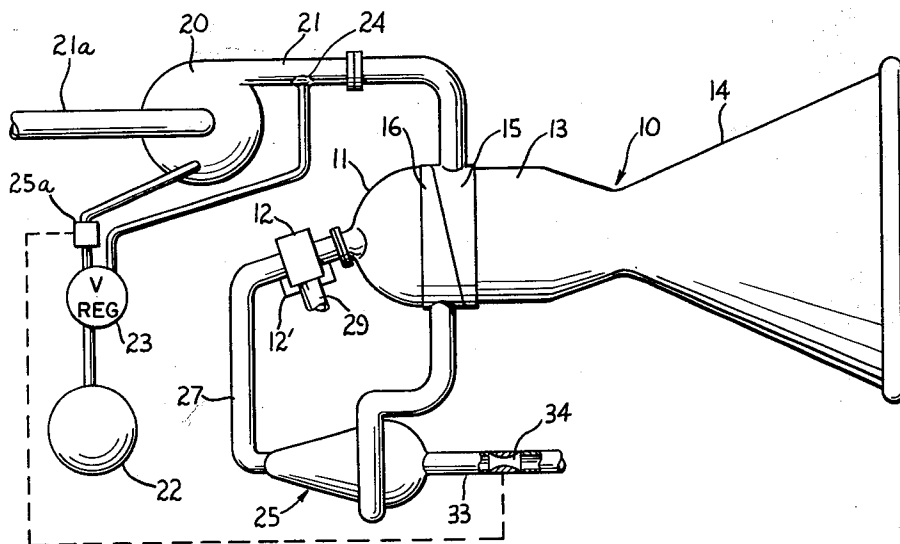


Fig. 2

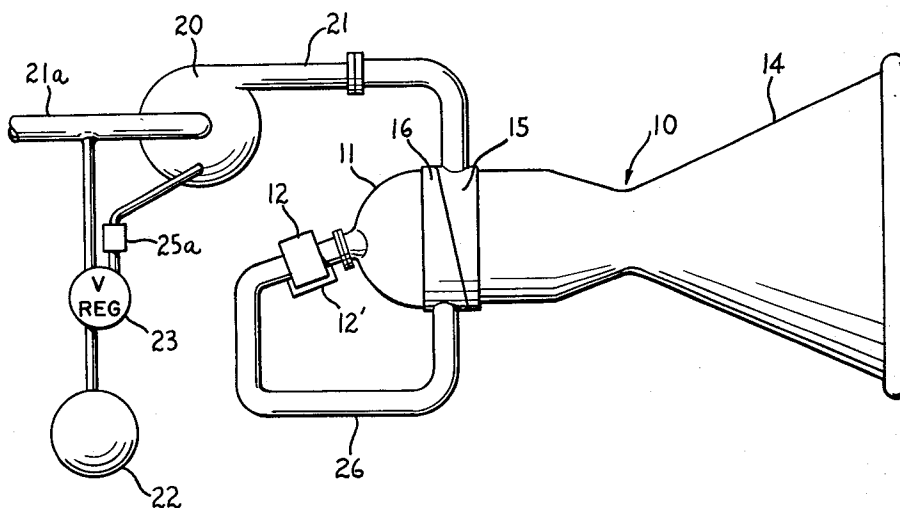


Fig. 3

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COOLING METHOD AND MEANS FOR ROCKET ENGINES

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Filed Aug. 3, 1961, Ser. No. 129,136
10 Claims. (Cl. 60—35.6)

This invention relates in general to liquid cooled thrust chambers for rocket engines and has particular reference to a proposed novel method and means for increasing the heat transfer capabilities of coolants in their circulation through the cooling jacket of such a chamber.

In rocket engine design, and in particular when the main concern in choice of propellants is restricted by performance and storability, it is more than likely that a fuel and oxidizer is chosen, such that neither will adequately cool the thrust chamber. This requires the use of uncooled motors which will drastically limit the firing duration.

Under normal steady flow conditons for a liquid coolant, three regions of heat transfer exist, namely convection, nucleate boiling and film boiling. Nucleate boiling occurs when the heat fluxes are high enough to cause the liquid side wall temperature to be above the liquid saturation temperature. For a flow geometry and particular values of temperatures, pressure and velocity, the coolant will have a maximum heat flux defined by the upper limit of nucleate boiling. If the combustion flux is greater than this limiting value, there will be a vapor blanket formed on the liquid surface causing high metal surface temperature and metal wall failure. If the velocity of the coolant flow were increased, the value of the upper limit of nucleate boiling would also increase until the nucleate boiling heat transfer becomes replaced by forced convection heat transfer.

With the primary object in view of increasing the velocity of flow of the coolant liquid in the cooling jacket of a thrust chamber above the normal rate, we have discovered that this may be accomplished by adding a compatible gas to the flowing coolant liquid before it passes through the jacket passages. The volume flow is increased and the velocity of the mixture therefor increases due to the large volume fraction occupied by the vapor. As the volume of gas is increased, the velocity of the mixture also increases as a function of average specific volume. This velocity increase will increase the upper limit of nucleate boiling of the mixture or, if the velocity were high enough (high vapor fractions) boiling would be suppressed and the mode of heat transfer would be forced convection. The ΔT across the wall will also increase. The introduction of a compatible gas to the liquid coolant can extend the cooling capabilities of the original coolant.

The advantages of our method of increasing the velocity of coolant flow are as follows:

- (1) Generally increased heat transfer capabilities.
- (2) Performance improvements, since injection of a gas (other than inert) such as hydrogen fuel is practicable and would give an increase in the performance of the thrust chamber.
- (3) Increased flexibility of coolant passage design. Thrust levels can be increased beyond single component cooled designs.

An important object of the invention is to provide means to practice the fundamental method of the invention which is of simple construction and capable of being modified readily to adapt it to various modes of operation.

Still further objects, advantages and features of the invention will become apparent as the following specific

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description is read in connection with the accompanying drawings, in which:

FIGURE 1 is a diagrammatic side elevation of one embodiment of the invention designed for two-phase cooling with closed cycle in a throttleable engine;

FIGURE 2 is a similar view, showing an adaptation for cooling with open cycle; and

FIGURE 3 is a similar view showing an adaptation for cooling with a regenerative cycle.

Referring now in detail to the drawings, wherein like reference characters designate corresponding parts in the several views, three embodiments of the invention have been represented by way of example. Common to all embodiments is a thrust chamber 10, a propellant injector 11, and a pair of propellant valves 12-12' associated with said injector.

Each thrust chamber 10 is of conventional design to include a substantially cylindrical combustion chamber 13 and a convergent-divergent nozzle 14. Thrust chamber 10 is coolant-jacketed. The type of cooling jacket is optional but the illustrative example is of the multi-pass type wherein respective inlet and outlet manifolds 15 and 16 are located at the upstream end of the combustion chamber 13, an annulus 17 is located at the downstream end of nozzle 14, and respective sets of downpass and return passages 18 and 19 located in the longitudinal wall of thrust chamber 10 connect annulus 17 with inlet and outlet manifolds 15 and 16, respectively.

A coolant pump 20 of suitable design is located in the coolant inlet line 21-21a upstreamward from its junction with inlet manifold 15.

Also common to all three illustrative embodiments of the invention is a storage tank 22 for the gas which may be chosen for addition to the liquid coolant as the dispersed phase of the two-phase mixture, the liquid coolant being the continuous phase. Gas storage tank 22 is connected through a regulator 23 to an injector 24 which is constructed and arranged to admit the selected gas phase to the coolant inlet line 21a at the upstream, or low pressure, side of pump 20 (FIGURE 1) or on the downstream, or high pressure side of pump 20 to coolant inlet line 21.

With particular reference to the embodiment of the invention disclosed in FIGURE 1, the engine constituted by thrust chamber 10 and propellant injector 11 is controlled by throttle means, to be described later herein, which regulates the rate of injection of the propellant components in propellant valves 12 and 12' and the proportion of one to the other. It also regulates the rate of flow of gas into the coolant inlet lines 21 or 21a and the proportion, either directly or indirectly, through the medium of gas regulator 23, previously mentioned. Incidentally, the proportion of gas to liquid coolant may be limited by cavitation characteristics of pump 20, because gas injector 24 is located at the low pressure side of the pump.

A centrifugal separator 25 of any desired conventional construction is connected to coolant outlet 26 of manifold 16. Separator 25 serves to separate the dispersed phase gas from the continuous phase liquid coolant after passage of the mixture through the cooling jacket. The separated liquid coolant is conducted through pipe line 27 to the appropriate propellant valve 12 of injector 11 for combustion with the co-related propellant which is fed to the co-operative valve 12' through pipe line 28 from a source of supply (not shown). The separated gas is returned to storage tank 22 through a gas return pipe line 29 which includes a check valve 30 to maintain the pressurized condition of said tank.

It should be explained at this juncture that centrifugal pump 20 preferably serves as the throttle means of the

engine. Throttling is effected by controlling the speed of pump 20 or its power input. Pneumatic, hydraulic or electrical transmission means 25a may be used to operate gas injection regulator 23 and the variable area restrictor orifice 34 shown in FIGURE 2.

An intercooler 31 is associated with gas return line 29 between check valve 30 and storage tank 22 to cool the gas, which is heated in the cooling jacket of thrust chamber 10 to a temperature higher than desired for re-use. This intercooler 31 may be used to raise the temperature of one of the propellant components, such as the oxidizer. This may be accomplished by passing the cool propellant component through the heat transfer coil 32 of intercooler 31.

Concerning the gas to be employed as the dispersed phase of the coolant mixture, there are conditions which must be met. The gas must be readily separable from the continuous phase liquid coolant and must be compatible with the latter. Possibly an inert gas (helium, nitrogen or argon) or hydrogen may be used. The continuous phase liquid coolant is a propellant component, such as anhydrous liquid ammonia, hydrazine, or nitric acid.

The operation of the engine embodiment shown in FIGURE 1 will now be described. This is a closed-cycle operation. Throttle-regulated introduction of the selected gas to the liquid coolant inlet line 21 through injector 24 produces a mixture of the desired proportions of dispersed phase to continuous phase components. When this mixture is forced through the cooling jacket of thrust chamber 10 by pump 20, the resulting increase in velocity of the coolant mixture over that obtained when the coolant is liquid alone will in turn increase the value of the upper limit of nucleate boiling until the nucleate boiling heat transfer region is replaced by the forced convection region.

The embodiment of the invention disclosed in FIGURE 2 differs from that shown in FIGURE 1 in only a few respects. For instance, the gas outlet 33 of centrifugal separator 25 is open to the atmosphere for the purpose of releasing the dispersed phase gas coolant component to the atmosphere following separation from the continuous phase liquid component of the coolant mixture instead of returning the gas component to storage tank 22. This embodiment represents a compromise arrangement adapted to short periods of operation, i.e. until the pressurized supply of gas in tank 22 has become exhausted. Outlet 33 has a variable area restrictor orifice 34 which limits the discharge so that the pressure in the liquid injector line will be maintained at a proper and appropriate level.

Another feature of the FIGURE 2 embodiment is the location of gas injector 24 in communication with the high pressure side of pump 20, with the advantage that the maximum quantity of the gas is not limited by the cavitation characteristics of the pump. If there were no pumps, as in a pressurized feed system rocket engine, this would be the method of injection of gas employed.

FIGURE 3 discloses a further embodiment of the invention which is of the regenerative cooling type and utilizes one of the liquid propellants as the continuous phase coolant component. In this embodiment, the dispersed phase gas component is not removed after passing through the cooling jacket but is injected along with the coolant propellant into the combustion chamber. For example, with a liquid fuel coolant, hydrogen gas would be the chosen gaseous component, thus adding energy to the system and improving specific impulse performance by lowering the average molecular weight of the combustion products as is known, in accordance with the relationship

$$I_{sp} \propto \sqrt{T/M}$$

when

I_{sp} = specific impulse
 T = combustion temperature
 M = molecular weight

If the coolant propellant is liquid anhydrous ammonia or hydrazine, the oxidizer may be liquid oxygen, nitric acid, or nitrogen tetroxide. Conversely, if an oxidizer type of propellant is used as the coolant liquid in the jacket, gaseous oxygen would be injected as the dispersed phase component.

It will be observed in FIGURE 3 that the centrifugal separator of the previously described embodiments has been omitted. The outlet pipe 26 of outlet manifold 16 leads directly to the appropriate propellant valve 12 or 12'. Also, as in the FIGURE 2 embodiment, gas storage tank 22 is internally pressurized to deliver a single charge of dispersed phase gaseous coolant through throttle-controlled regulator 23 to injector 24, which in this instance, as in the FIGURE 1 embodiment, is connected to liquid coolant inlet line 21a at the low pressure side of pump 20.

While there have been shown and described and pointed out the fundamental novel features of this invention as applied to a few structural embodiments, it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art without departing from the spirit of the invention. It is the intention, therefore, to be limited only as indicated by the scope of the following claims.

What is claimed is:

1. The method of operating a rocket engine for increasing the heat transfer capabilities of the liquid coolant in a rocket engine of which a given volume is circulated in a given time under pressure, which engine includes a thrust chamber having a cooling jacket for the passage of the liquid coolant therethrough under pressure, an inlet line for liquid coolant communicating with said jacket, and fuel injection means for said chamber; which method consists in adding a compatible gaseous dispersed phase to the coolant liquid as the continuous phase in the inlet line to increase the volume thereof, then circulating the increased volume mixture thus produced through the cooling jacket in said given time whereby the flow velocity of the circulating mixture is increased, separating the gaseous dispersed phase coolant from the liquid continuous phase coolant after circulation through the cooling jacket, and admitting the separated liquid coolant to the injector of the thrust chamber.

2. The method defined in claim 1, to which is added the step of reintroducing the separated gaseous coolant to the inlet line for addition to the fresh supply of liquid coolant.

3. The method defined in claim 2, to which is added the step of cooling the separated gaseous coolant before readmission to the liquid coolant inlet line to dissipate the heat increase resulting from heat transfer in the cooling jacket of the thrust chamber.

4. The method of operating a rocket engine for increasing the heat transfer capabilities of the liquid coolant in a rocket engine of which a given volume is circulated in a given time under pressure, which engine includes a thrust chamber having a cooling jacket for the passage of the liquid coolant therethrough under pressure, an inlet line for liquid coolant communicating with said jacket, and fuel injection means for said chamber; which method consists in adding a compatible gaseous dispersed phase to the coolant liquid as the continuous phase in the inlet line to increase the volume thereof, then circulating the increased volume mixture thus produced through the cooling jacket in said given time whereby the flow velocity of the circulating mixture is increased, separating the gaseous dispersed phase coolant from the liquid continuous phase coolant after circulation through the cooling jacket and releasing the said gaseous coolant to the at-

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mosphere, and admitting the separated liquid coolant to the injector of the thrust chamber.

5. The method defined in claim 4 wherein the separated gaseous coolant is released to the atmosphere through a restrictor orifice which limits the discharge so that the pressure in the liquid injection line to the injector of the thrust chamber will be maintained at a proper level.

6. In a rocket engine, the combination of a thrust chamber having a coolant jacket for the passage of a given amount of liquid coolant under a given pressure, a propellant injector for the thrust chamber, liquid coolant inlet and outlet lines communicating with the cooling jacket, a storage tank for a gaseous coolant, means to force said given amount of liquid coolant in a given time through the coolant inlet line and the cooling jacket of the thrust chamber and the coolant outlet line, means to inject gaseous coolant from the storage tank into the liquid coolant inlet line for mixture with the liquid coolant to increase its volume and resultant rate of flow of circulation through the cooling jacket, a centrifugal separator connected to the coolant outlet line of the cooling jacket of the thrust chamber, and an injection line to conduct separated liquid coolant from the said separator to the propellant injector of the thrust chamber.

7. The invention defined in claim 6, to which is added means to release the separated gaseous coolant from the separator to the atmosphere.

8. The invention defined in claim 7, wherein the gaseous coolant release means has an orifice of variable cross-sectional area to limit the discharge so that the pressure in the liquid injection line will be maintained at an appropriate level.

9. In a rocket engine, the combination of a thrust

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chamber having a coolant jacket for the passage of a given amount of liquid coolant under a given pressure, a propellant injector for the thrust chamber, liquid coolant inlet and outlet lines communicating with the cooling jacket, a storage tank for a gaseous coolant, means to force said given amount of liquid coolant in a given time through the coolant inlet line and the cooling jacket of the thrust chamber and the coolant outlet line, means to inject gaseous coolant from the storage tank into the liquid coolant inlet line for mixture with the liquid coolant to increase its volume and resultant rate of flow of circulation through the cooling jacket, a centrifugal separator connected to the coolant outlet line of the cooling jacket of the thrust chamber, an injection line to conduct separated liquid coolant from the separator to the propellant injector of the thrust chamber, and a return line to return the separated gaseous coolant from the centrifugal separator to the gas storage tank.

10. The invention defined in claim 9, to which is added means associated with the return line to cool the separated gaseous coolant before readmission to the gas storage tank to dissipate the heat increase resulting from heat transfer in the cooling jacket of the thrust chamber.

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