United States Patent

Leffert

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[54] CLOSED CYCLE VAPOR ENGINE

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[73] Assignee: **General Motors Corporation,** Detroit, Mich.

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[52] **U.S. Cl.** **60/25,** 165/105

[51] **Int. Cl.** **F03g 7/06**

[58] **Field of Search** 60/27, 25; 165/105

[56] **References Cited**

UNITED STATES PATENTS

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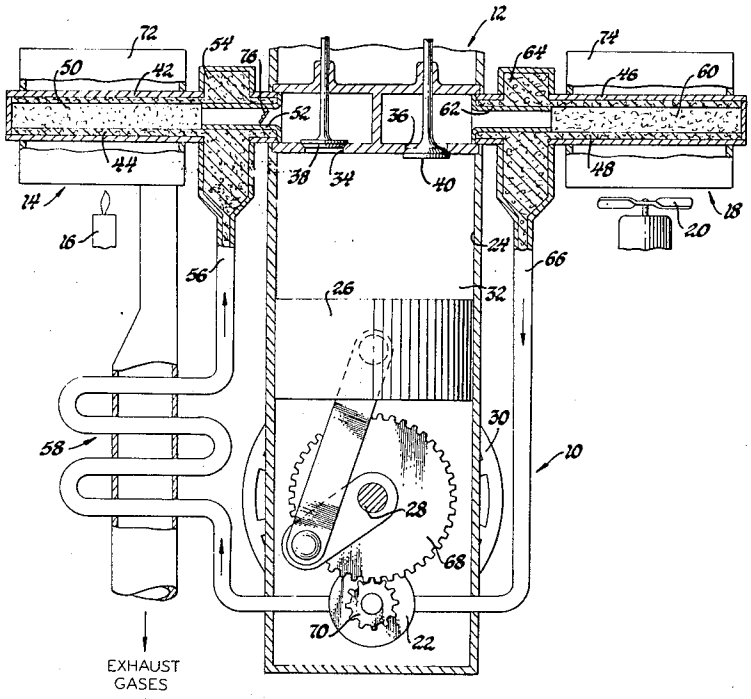
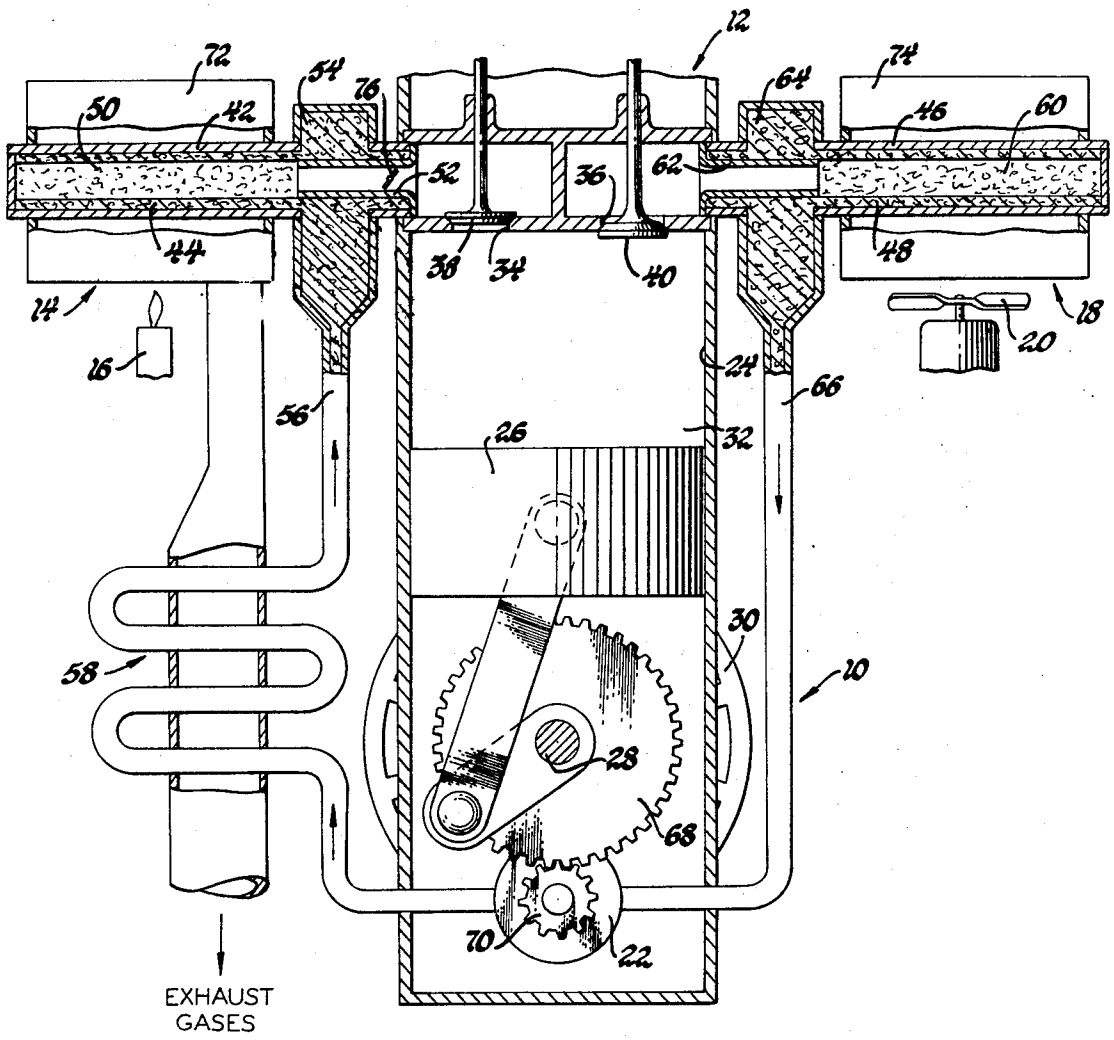
[57] **ABSTRACT**

A closed cycle vapor engine has evaporator and condensor elements utilizing liquid carrying wick means arranged to provide surfaces for the evaporation and condensation of the engine working fluid and to transport said fluid in liquid form from the condensor to a condensate pump and from the condensate pump to the evaporator. Vapor passages connect the evaporator and condensor with the intake and exhaust openings of the expander, providing a closed system in which the evaporator and condensor operate essentially on the principle of a heat pipe.

13 Claims, 1 Drawing Figure





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CLOSED CYCLE VAPOR ENGINE

Field of the Invention

This invention relates to closed cycle vapor engines, for example of the external combustion type, having evaporator and condensor means for the working fluid, at least one of which includes wick means arranged to transport and evaporate or condense the engine working fluid utilizing the principle of a heat pipe.

Description of the Prior Art

It is known in the art relating to vapor engines to provide a closed cycle engine having the usual components of boiler, expander, condenser, and condensate pump and using as a working fluid a vaporizable substance, such as water. Such engines would include closed cycle steam engines, steam turbines and the like. Of course, the use of other working fluids than water is also known, in which case the more general term "vapor engine" is used. Notice, in particular, that vaporization occurs by "boiling" in conventional vapor engines.

In the art relating to heat transfer, there is also known a development more recent that that of the vapor engine and commonly called the "heat pipe." Such pipes in their most general form comprise a tubular member retaining any one of a number of vaporizable heat transfer fluids, including water, and having therein a wick extending the length of the tubular member to provide a flow path for the heat transfer fluid in its liquid state and an open passage coextensive with the wick to provide a flow path for the heat transfer fluid in its vapor

In such heat pipes one end is used as an evaporator to which heat is added, vaporizing (that is evaporating, not boiling) the fluid in the wick at that end and increasing the vapor pressure in the adjacent open passage. The other end of the tube acts as a condensor, from which heat is rejected, causing condensation of the vapor in the open passage and absorption of the resulting liquid into the wick. Thus, the flow of vapor in the open passage of the heat pipe is from the hot or evaporator end to the cold or condensor end, and the liquid flows in the opposite direction along the wick by capillary action.

Among the examples of heat pipe devices known in the prior art may be included those shown in U.S. Pat. Nos. 2,350,348 Gaugler and 3,287,906 McCormick, both assigned to the assignee of the present invention. Some more general information on the subject may be obtained from an article by G. Yale Eastman titled, "The Heat Pipe" and published in the May 1968 issue of "The Scientific American." As indicated in this article, heat pipes have been shown to be capable of transporting large amounts of heat over substantial distances with very small temperature differentials.

SUMMARY OF THE INVENTION

From my own experiments relating to low-temperature heat pipes, I have found that through the use of the heat pipe principle (involving evaporation from a high thermal conductance wick into an adjacent body of vapor or condensation on such a wick from an adjacent body of vapor, as well as the inherent capillary flow of liquid within the wick) permits a substantial increase in the rate of vaporization (or condensation) per unit area. For example, I have evaporated water in a heat pipe at one atmosphere pressure at an input heat flux of about one million BTU per hour per square foot whereas the peak nucleate boiling flux at these conditions is only about 450,000 BTU per hour per square foot.

This invention takes advantage of this understanding by providing a new engine arrangement based upon concepts involving heat pipes and conventional vapor engines. This engine arrangement yields the advantages of a closed cycle vapor engine having combined therewith an evaporator and condensor, either or both of which may utilize the heat pipe principle for heat transfer and, accordingly, be of substantially reduced size. A specific embodiment of my invention provides a novel closed cycle vapor engine arrangement having an evaporator and condensor, each of which form, in effect, one

half of a conventional heat pipe, the two halves being separated by a mechanical expander and a condensate pump.

More specifically, the invention contemplates a mechanical expander which may be of the reciprocating piston, rotating piston, turbine or other suitable type, having inlet and outlet openings for the admission and exhaust of vaporized working fluid. An evaporator is connected with the inlet opening and is provided with an external combustion system or other suitable heat source so as to vaporize liquid supplied thereto and, in turn, deliver it to the expander inlet opening. A condenser is connected with the expander outlet opening to receive the vaporized working fluid exhausted therefrom. External cooling means of any suitable type may be provided for carrying heat away from the condensor so as to condense the vaporized working fluid therein to a liquid state. Either the evaporator or the condensor, and preferably both, are provided with wick means extending substantially the length thereof for the purpose of transporting the working fluid in the liquid phase through both the evaporator and condensor elements and providing surfaces for the evaporation and/or condensation of the working fluid in the manner of the conventional heat pipe and in accordance with what I have denominated "the heat pipe principle." The wick portions may extend into external connecting conduits which are joined through a condensate pump provided in order to raise the pressure of the condensate from the lower pressure existing in the condensor to the substantially higher pressure existing in the evaporator.

A further understanding of the invention and its advantages may be obtained from the following description of a preferred embodiment chosen for purpose of illustration and referring to the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE of the drawing is a schematic representation of a closed cycle vapor engine formed according to the principles of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT T

In the drawing, numeral **10** generally indicates a closed cycle vapor engine, including the basic elements of a mechanical expander **12** and evaporator **14** with a heat source **16**, a condenser **18** having heat rejection means **20** and a condensate pump **22**.

Expander **12** comprises at least one cylinder **24** having a piston **26** reciprocably disposed in the cylinder. Piston **26** is conventionally connected with a crankshaft **28** which drives a flywheel **30** and through which work delivered by the piston may be transmitted to an external load. The upper end of cylinder **24** is closed so as to define with piston **26** a variable volume working chamber **32**. Intake and exhaust openings **34** and **36**, respectively, are provided in the closed end of cylinder **24** and are provided with intake and exhaust valves **38** and **40**, respectively, which are actuated by suitable mechanism not shown to control the intake and exhaust of working fluid to and from the engine working chamber **32**.

Connecting with the extending outwardly from the intake opening **34** is an evaporator **42**, preferably formed as a tubular element and having suitable wick means **44**, such as wire mesh or the like, substantially covering the inner surfaces thereof to point adjacent intake opening **34**.

In like manner, there is connected with the exhaust opening and extending outwardly therefrom a condensor **46** which is preferably formed as a tubular member and also includes suitable wick means **48** extending over substantially all the internal surface thereof to a point adjacent the exhaust opening **36**.

The interior portion of the evaporator adjacent the surrounding wick **44** defines an open passage **50** through which vapor may flow from the evaporator to the intake opening **34**. The end of the wick **44** adjacent the intake opening may be protected by an inner covering **52** for a purpose to be subsequently described. The inner portion of the wick adjacent

the expander connects with an enlarged wick containing connector portion **54**, which in turn connects through a preferably wick-containing conduit **56** with the outlet side of the condensate pump **22**. Conduit **56** preferably has located therein a preheater device **58**.

In manner similar to the evaporator, the interior portion of the condensor which is surrounded by wick means **48**, defines an open passage **60** that connects with the exhaust opening **36** to receive vaporized fluid therefrom. The inner end of the wick **48** is protected by an inner covering **62** and, at this point, connects with a wick containing connector portion **64**, which in turn connects with a preferably wick-containing conduit **66** leading to and connecting with the inlet of the condensate pump **22**.

The condensate pump may be of any suitable type, such as a gear pump, and may be driven in any suitable manner. As shown here, the pump is driven through gears **68**, **70** connecting the pump with the expander crankshaft **28**.

The outer end of evaporator **14** is enclosed by a housing **72** to which heat is supplied by the external heat source **16**. The heat source may be of any suitable type including the external combustion means illustrated. In like manner, the outer portion of condensor **18** is surrounded by a housing **74** from which heat is drawn by heat rejection means **20**. The heat rejection means may also be of any suitable type, for example, a fan drawing air past cooling fins.

The internal working system of the engine is substantially filled with a working fluid, which is vaporizable within the temperature range intended for operation of the engine. While water might be a suitable fluid, it might also be desirable to use an azeotrope mixture, like alcohol and water, which would have the advantage of not freezing easily under ambient temperatures at various operating locations. The working fluid within the engine is sufficient to substantially fill all the wick portions with fluid in a liquid state, while leaving open the central passages **50** and **60** of the evaporator and condenser, respectively, as well as the engine working chamber **32** to be filled by the working fluid in its vapor state.

In operation, heat added to the evaporator from the heat source **16** vaporizes the liquid in wick **44** so as to form a pressurized body of vaporous working fluid in the open passage **50**. When intake valve **38** is opened, the pressurized fluid passes into the working chamber **32** of the engine and forces piston **26** downwardly with resultant work delivered to crankshaft **28**. Upon the upstroke of piston **26** the exhaust valve **36** is opened, permitting the vaporous working fluid to be delivered into the open passage **60** of condenser **18** at a pressure and temperature which are both substantially reduced from that existing in evaporator **14**. The cooling of the condensor by heat rejection means **20** condenses the vaporized working fluid into the wick **48**.

The liquid is then moved by capillary action along the wick **48** into connector portion **64** and through conduit **66** to the condensate pump, where its pressure is raised to equal or above that existing in the evaporator **14**. The fluid then moves by capillary action, or through the pressure created by the condensate pump, through conduit **56** where it passes into preheater **58**. In the preheater, exhaust heat from heat source **16** is utilized to preheat the fluid, after which it is delivered through connecting means **54** back to the wick **44** of the evaporator. Here it is distributed along the wick by capillary action and it is again ready to be evaporated for a repetition of the cycle.

Obviously, the actions of evaporation and condensation, as well as the operation of the condensate pump, are continuous during operation of the engine. However, since the vapor is intermittently admitted and exhausted from the working chamber, wick coverings **52** and **62** assist in preventing undesired sweeping out of the liquid from the wicks at the inner portions thereof during the flow surges that take place there.

In order to control the engine output the flow of vaporized working fluid may be throttled in any convenient manner. One method would be to vary the opening period of the intake valve **38** or, alternatively, to vary the lift of this valve. Another method would be to provide a separate throttle valve **76** in the intake passage **50** to control the flow of vaporized fluid to inlet opening **34**.

While the invention has been disclosed by reference to a specific embodiment, it should be understood that numerous changes could be made within the scope of the inventive concepts disclosed.

I claim:

1. A closed cycle heat engine of the type adapted to utilize a vaporizable working fluid, said engine comprising

an expander having a fluid inlet, a fluid outlet and mechanical output means, said expander being capable of receiving through said inlet vaporized working fluid at elevated temperature and pressure, expanding said vaporized working fluid to a lower temperature and pressure with a resultant output of work to said output means and exhausting said working fluid through said fluid outlet,

an evaporator connected with said expander fluid inlet and arranged to receive working fluid in a liquid state, to vaporize said working fluid upon the application of heat thereto and to deliver said fluid at elevated temperature to said expander fluid inlet,

a condenser connected with said expander fluid outlet and arranged to receive therefrom working fluid in an at least partially vaporized state and to condense said working fluid to a liquid state by the removal of heat therefrom and

a condensate pump connected with said condenser and said evaporator and arranged to receive liquid working fluid from said condensor and to deliver it to said evaporator at an elevated pressure,

wherein one of said evaporator and condenser elements includes liquid carrying wick means arranged to form surfaces for the evaporation or condensation of liquid within said one element and to transport liquid between said surfaces and said condensate pump and a vapor carrying passage adjacent said wick means, said passage communicating with the appropriate one of said expander fluid inlet and outlet, whereby said one of the evaporator and condensor elements is adapted to operate on the heat pipe principle utilizing as a heat transfer fluid, the working fluid of said engine.

2. The engine of claim **1** wherein the other of said evaporator and condensor elements also includes liquid carrying wick means arranged to form surfaces for the evaporation or condensation of liquid within said other element and to transport liquid between said surfaces of said other element and said condensate pump and a vapor carrying passage adjacent said wick means, said passage communicating with the other one of said expander fluid inlet and outlet, whereby said other one of the evaporator and condensor elements is also adapted to operate on the heat pipe principle, utilizing as a heat transfer fluid the working fluid of said engine.

3. The engine of claim **2** and further comprising throttle means in the passage between said evaporator and the expander fluid inlet, said throttle means being operable to control the flow of vaporized working fluid into the expander to control the output of said engine.

4. The engine of claim **3** and further comprising preheater means arranged between said condensate pump and said evaporator and adapted to increase the temperature of the condensate passing therebetween before delivery into the evaporator.

5. The engine of claim **4** and further including external combustion means arranged to supply heat to said evaporator for evaporating the working fluid, said external combustion means having exhaust gas passage means in heat exchange relation with said preheater, whereby waste heat from said external combustion means is supplied to said preheater for heating the liquid condensate before its return to the evaporator.

6. A closed cycle heat engine of the type adapted to utilize a vaporizable working fluid, said engine comprising

an expander having at least one cylinder with a piston reciprocably disposed therein, said piston being connected with mechanical output means, said piston and cylinder cooperating to define a variable volume working chamber having a fluid inlet and a fluid outlet, said expander being capable of receiving through said inlet vaporized working fluid at elevated temperature and pressure, expanding said vaporized working fluid to a lower temperature and pressure with a resultant output of work to said output means and exhausting said working fluid through said fluid outlet,

an evaporator connected with said expander fluid inlet and arranged to receive working fluid in a liquid state, to vaporize said working fluid upon the application of heat thereto and to deliver said fluid at elevated temperature to said expander fluid inlet,

a condenser connected with said expander fluid outlet and arranged to receive therefrom working fluid in an at least partially vaporized state and to condense said working fluid to a liquid state by the removal of heat therefrom and

a condensate pump connected with said condenser and said evaporator and arranged to receive liquid working fluid from said condensor and to deliver it to said evaporator at an elevated pressure,

wherein one of said evaporator and condenser elements includes liquid carrying wick means arranged to form surfaces for the evaporation or condensation of liquid within said one element and to transport said liquid between said surfaces and said condensate pump, and a vapor carrying passage adjacent said wick means, said passage communicating with the appropriate one of said expander fluid inlet and outlet, whereby said one of the evaporator and condensor elements is adapted to operate on the heat pipe principle, utilizing as a heating fluid, the working fluid of said engine.

7. A closed cycle heat engine of the type adapted to utilize a vaporizable working fluid, said engine comprising

an expander having at least one cylinder with a piston reciprocably disposed therein, said piston being connected with mechanical output means, said piston and cylinder cooperating to define a variable volume working chamber having a fluid inlet and a fluid outlet, said expander being capable of receiving through said inlet vaporized working fluid at elevated temperature and pressure, expanding said vaporized working fluid to a lower temperature and pressure with a resultant output of work to said output means and exhausting said working fluid through said fluid outlet,

an evaporator connected with said expander fluid inlet and arranged to receive working fluid in a liquid state, to vaporize said working fluid upon the application of heat thereto and to deliver said fluid at elevated temperature to said expander fluid inlet,

a condenser connected with said expander fluid outlet and arranged to receive therefrom working fluid in an at least partially vaporized state and to condense said working fluid to a liquid state by the removal of heat therefrom and

a condensate pump connected with said condenser and said evaporator and arranged to receive liquid working fluid from said condensor and to deliver it to said evaporator at an elevated pressure,

wherein said evaporator and condensor elements include liquid carrying wick means arranged to form surfaces for the evaporation or condensation of liquid within said elements and to transport said liquid between said surfaces and said condensate pump and vapor carrying passages adjacent said wick means, said passages communicating with said expander fluid inlet and outlet, whereby said evaporator and condensor elements are adapted to operate on the heat pipe principle, utilizing as a heat transfer fluid, the working fluid of said engine.

8. An engine according to claim **7** and further including a protective cover over said wick means adjacent at least one of said expander fluid inlet and outlet means so as to prevent the excessive disturbance of liquid in said wick means due to surges of vaporized working fluid through said one of said inlet and outlet means.

9. The engine of claim **7** and further comprising intake and exhaust valves disposed respectively in said expander fluid inlet and fluid outlet and operable in a predetermined manner to control the flow of working fluid into and out of said working chamber.

10. The engine of claim **9** wherein the opening of said intake valve is adjustable so as to vary the amount of vaporized working fluid admitted to the working chamber and thereby vary engine power.

11. The engine of claim **9** and further comprising a throttle valve movably disposed between said intake valve and said evaporator and adjustable to variably restrict the flow of working fluid from said evaporator to said working chamber so as to vary engine power.

12. The engine of claim **9** and further comprising external combustion means arranged to deliver heat to said evaporator for vaporizing said working fluid.

13. The engine of claim **12** and further comprising preheater means disposed between said condensate pump and said evaporator, such that return condensate is passed through said preheater, said preheater also being connected with said external combustion means to receive the waste exhaust gases therefrom and pass them in heat exchange relationship with said return condensate so as to preheat said condensate before its return to said evaporator.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,670,495 Dated June 20, 1972

Inventor(s) Charles B. Leffert

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 1, Line 30, "vapor" should read --vapor state.--.

Col. 2, Line 40, "EMBODIMENT T", should read --EMBODIMENT--; Line 58, "the", first occurrence, should read --and--.

Col. 5, Line 36, "heating" should read --heat transfer--.

Signed and sealed this 9th day of January 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents