Oct. 26, 1971 J. B. COLEMAN ET AL 3,614,981

DUAL TUBE HEAT PIPE AND MEANS FOR CONTROL THEREOF

Filed Oct. 8, 1969 2 Sheets-Sheet 1

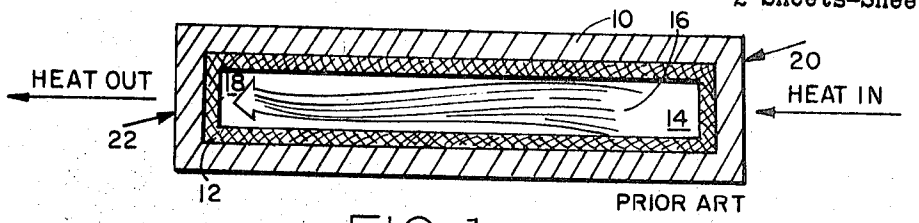


FIG. 1.

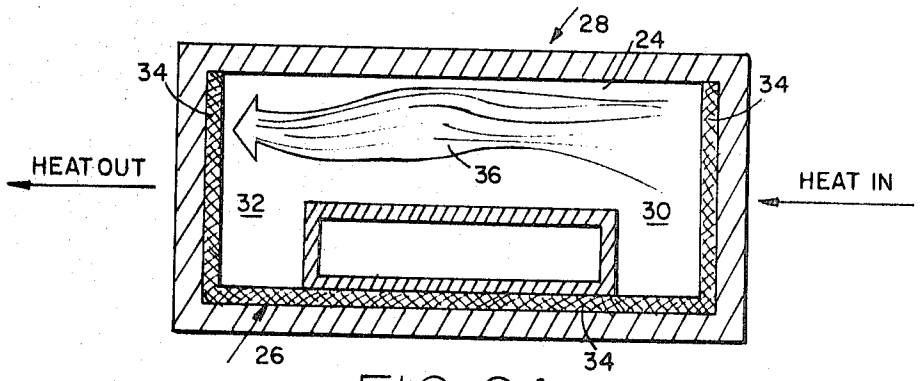


FIG. 2A.

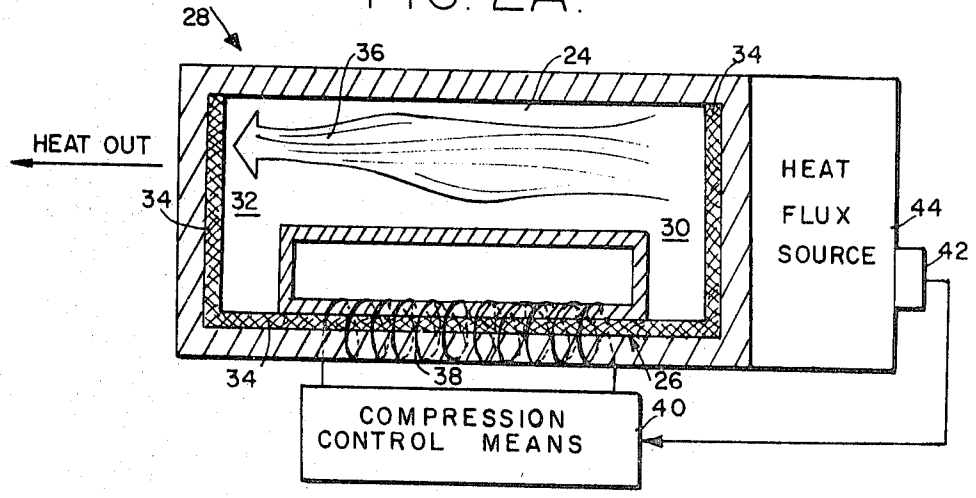


FIG. 3.

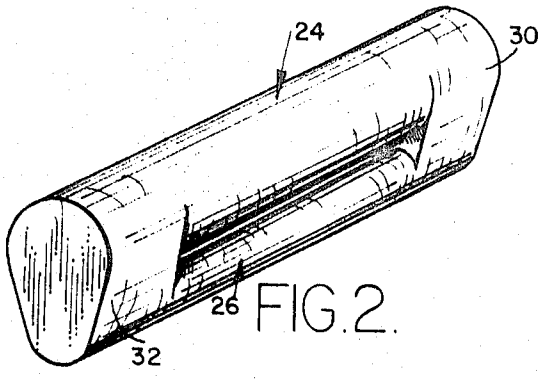


FIG. 2.

INVENTORS

JOHN B. COLEMAN

JAMES P. WELSH

BY Robert Glen Epps

AGENT

Oct. 26, 1971 J. B. COLEMAN ET AL 3,614,981

DUAL TUBE HEAT PIPE AND MEANS FOR CONTROL THEREOF

Filed Oct. 8, 1969 2 Sheets-Sheet 2

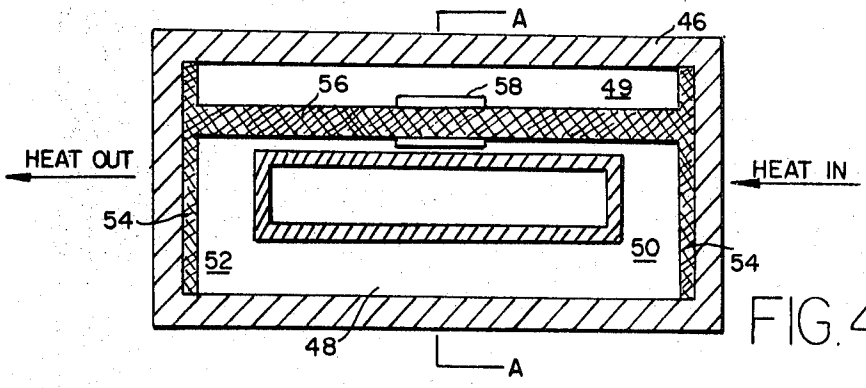


FIG. 4.

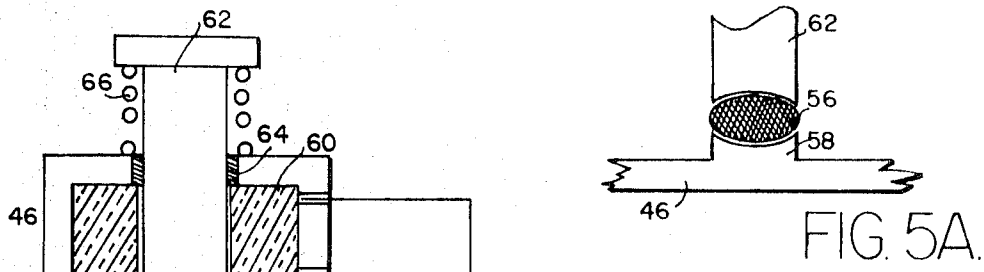


FIG. 5A.

FIG. 5.

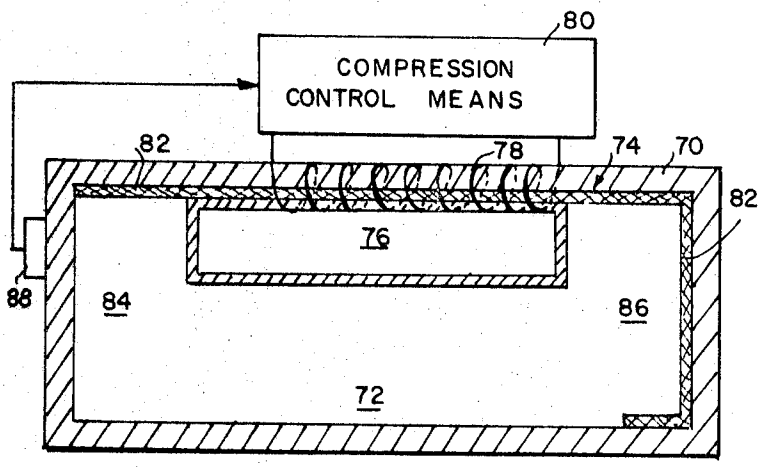


FIG. 6.

INVENTORS

JOHN B. COLEMAN
JAMES P. WELSH

BY Robert Schwartz

AGENT

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DUAL TUBE HEAT PIPE AND MEANS FOR CONTROL THEREOF

John B. Coleman, Buffalo, and James P. Welsh, Snyder, N.Y., assignors to Sanders Associates, Inc., Nashua, N.H.

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ABSTRACT OF THE DISCLOSURE

A dual tube heat pipe comprises a heat pipe wherein vapor flow from the evaporator to the condenser and the condensate return flow through a capillary structure are contained in separate and distinct tubes independent of one another. Means may also be provided for varying the condensate capillary flow rate by controlling the effective area of the capillary structure.

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates generally to the field of heat transfer systems and in particular to an improved heat pipe having a means for control of its thermal conductance.

Description of the prior art

The element heat pipe is a bilateral heat conductor of lower thermal resistance than alternative heat conduction paths of comparable dimensions. The heat pipe is a device wherein a working fluid is vaporized in an evaporator section and the vapors condense in a condenser section, the condensate returning via a wick to the evaporator to complete the cycle. In one frequently used operating condition the heat pipe will be fed by a specific heat flux and will be connected to a heat sink at a specific temperature. Other modes of operation may also be used including operation at a specific source temperature. The temperature of the heat source, condensate and vapor will be established by the heat flux and the operating parameters of the heat pipe. The performance of a heat pipe may be limited by a variety of factors including the pumping capacity of the capillary action in the wick. One of the undesirable characteristics of the heat pipe is that the operating temperature is an approximately linear function of the heat flow. Thus while the heat pipe may exhibit an extremely low thermal resistance, the temperature of the heat source or device being cooled will increase with increasing heat flux. Also in some instances it is necessary to introduce a finite thermal resistance at the condenser end of a heat pipe in order to achieve stable operation. These characteristics operate to the disadvantage of a heat pipe which must be used with a varying heat flux, and varying coolant or heat sink temperature.

OBJECTS AND SUMMARY OF THE INVENTION

It is therefore a primary object of the present invention to provide a new and novel controllable heat pipe.

It is another object of the present invention to provide apparatus of the above-described character which operates at a controlled temperature.

It is also an object of the present invention to provide apparatus of the above-described character having a variable thermal conductance.

It is a further object of the present invention to provide apparatus of the above-described character having unilateral heat transfer characteristics thereby operating as a thermal triode.

It is an additional object of the present invention to provide apparatus of the above-described character having a controlled liquid capillary flow rate.

The foregoing objectives are achieved by the present invention wherein a duel heat pipe provides separate paths for the vapor and condensate, each path thus being readily available for control. Means are provided for compressing or expanding the wicking material to thereby throttle the condensate flow. For any given heat flux transferred through the heat pipe, the hot-end or evaporator temperature may thus be increased or decreased and conversely for any given evaporator temperature the heat flux may be increased or decreased.

The foregoing as well as other objects, features and advantages of the present invention will become more apparent from the following detailed description taken in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic cross section illustration of a conventional heat pipe in accordance with the prior art.

FIG. 2 is an isometric view of a dual tube heat pipe fabricated in accordance with the principles of the present invention.

FIG. 2A is a schematic longitudinal cross section illustration of the dual tube heat pipe of FIG. 2.

FIG. 3 illustrates in schematic cross section a dual heat pipe with an electro-magnetic capillary flow throttle.

FIG. 4 schematically illustrates a longitudinal cross sectional top view of an alternative embodiment of the present invention.

FIG. 5 is a schematic transverse cross sectional view of the apparatus of FIG. 4.

FIG. 5A is a partial schematic cross sectional view of the apparatus of FIGS. 4 and 5 illustrating wick compression.

FIG. 6 schematically illustrates an embodiment of the present invention whereby heat is unilaterally and controllably transferred.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to FIG. 1 there is illustrated a conventional heat pipe in accordance with the principles of the prior art. In its essence the heat pipe is a bilateral heat conductor comprising an evacuated tube **10** lined with a capillary structure generally in the form of a wick **12**. When heat is applied to the evaporator section **14** of the heat pipe a working fluid (not shown) is evaporated and the vapors **16** move more under minute pressure differential to the condenser end **18** where they give up their latent heat of vaporization and condense. The condensate is then returned by capillary pumping action through the wick **12** to the evaporator. The heat passes into and out of the heat pipe through thermally conductive contact surfaces **20** and **22** respectively. In a conventional heat pipe heat transfer occurs between the vapors **16** and the cooler condensate flowing in the wick **12** and at high heat fluxes the temperature of the vapors **16** may become so high as to cause wick drying with the resulting failure of the heat pipe action.

FIG. 2 is an isometric view of a dual tube heat pipe whereby vapors and condensate are provided with independent and separate flow paths **24** and **26** respectively between the evaporator **30** and condenser **32**. FIG. 2A is a longitudinal cross section view of the embodiment of FIG. 2 and illustrates an evacuated structure **28** comprising two tubes **24** and **26** united at each end by common evaporator and condenser chambers **30** and **32** respectively. The smaller tube **26** is filled with wicking material **34** and the ends of the chambers **30** and **32** are lined with a continuation of wick **34**. The larger tube **24** forms the vapor flow path which is independent and thermally isolated from the condensate flow path provided by the wick filled smaller

tube 26. In this manner the vapors 36 flowing from the evaporator 30 to the condenser 32 do not contact the wick 34 except within the evaporator and condenser chambers and are thereby isolated from the condensate flowing through the wick 34 and do not cause wick drying. The isolation of condensate and vapor also permits the control of the vapor and condensate flow within the heat pipe as will be more fully discussed hereinbelow.

For certain heat pipe applications the heat source temperature must be held substantially constant. FIG. 3 illustrates a dual tube heat pipe including an adaptive control system and wherein parts identical to those shown in FIG. 2 are identified with like numerals. One means of controlling heat flux and thus the temperatures in the heat pipe is through control of the liquid capillary flow rate which may be accomplished by changing the effective capillary area. To this end the capillary structure or wick 34 may be formed of a magnetically sensitive material which is compressed or expanded by a controllable magnetic field. A suitable magnetic structure may assume many forms but for illustrative purposes is shown as a coil 38 disposed about the condensate flow path 36 through which the condensate returns from the condenser 32 to the evaporator 30. The coil 38 is coupled to a wick compression control means 40 which in its simplest form would be a variable voltage supply. It will be apparent that the compression control means 40 may be coupled to and controlled by a temperature sensor 42 which monitors the temperature of the heat flux source 44. In this manner automatic adaptive control of the liquid capillary flow rate may be provided. As the source 44 temperature rises the compression of the wick 34 is relaxed permitting an increased capillary flow. Should the source temperature drop below its given design value the wick is compressed, throttling the capillary flow and reducing heat conductance of the heat pipe.

A variety of wick materials, either magnetic or paramagnetic, may be used in the embodiment of the present invention shown in FIG. 3. If a normally nonmagnetic wick material must be used, magnetic materials may be disposed such as by embedding within the nonmagnetic fibers. The magnetic structure may also be varied such as with linear or nonlinear windings thus providing corresponding magnetic flux distributions over the desired pipe length. The materials of which the evacuated heat pipe tubes are formed are generally nonmagnetic and do not significantly impede the magnetic flux, however, if the heat pipe material is magnetic or has high permeability, control may still be achieved with the appropriate magnetic structure at the expense of increased control power.

Turning now to FIGS. 4 and 5 there is illustrated an alternative embodiment of the present invention wherein the liquid capillary flow rate may be controlled. The dual tube evacuated heat pipe 46 is again provided wherein the vapor and condensate flow paths 48 and 49 are isolated from one another. Both the evaporator and condenser ends 50 and 52 respectively of the heat pipe are covered with wicking material 54 which is contiguous with a longitudinal wick 56 a part of which passes over the platen portion 58 of an electromagnetic press. The structure of the press is more clearly shown in the transverse cross sectional view of FIG. 5 which is taken along line A—A of FIG. 4. An actuating solenoid 60 is disposed through the condensate flow path tube of the heat pipe 46 such that the plunger 62 thereof when activated presses the wick 56 against the platen 58 as shown in FIG. 5A reducing the wick area and throttling the capillary flow. The plunger 62 may pass through the heat pipe tube 46 through a non magnetic bushing 64 and may be biased to the withdrawn position by spring 66. The wick 56 is compressed in proportion to the current through the solenoid coil 60 disposed within the heat pipe 46 and which is coupled to a compression control means 68. Again, although not shown in this embodiment a closed loop capillary flow control system may be provided by coupling the compression control means 68 to a temperature sensor affixed to the heat flux source as shown in FIG. 3. It will be readily apparent that alternative embodiments of the present invention may provide pneumatic, hydraulic or thermal expansion means for providing compression in response to an external signal rather than the electromagnetic means illustrated.

With reference now to FIG. 6 there is schematically illustrated an embodiment of the present invention which may be termed a thermal triode; i.e. a heat pipe which has variable thermal conductance in one direction and substantially no thermal conductance in the opposite direction. Again in this embodiment the dual tube heat pipe 70 has distinct vapor and condensate flow paths 72 and 74 respectively which are thermally isolated from one another by open space 76. A wick compression means schematically illustrated as a coil 78 and associated power supply 80 are also provided. In this embodiment, however, the wick 82 is terminated short of the condenser section 84. This arrangement will conduct heat from the evaporator section 86 to the condenser section 84 efficiently and the thermal conductance of the heat pipe may be readily controlled through compression and expansion of the wick 82. Heat from a heat source disposed adjacent the condenser section 84 will not be transferred in the opposite direction, however, since without a fluid saturated wick in the condenser section any heat transfer must be through vapor which is a poor thermal conductor. Again a thermal sensor 88 may be coupled to the heat pipe 70 and have its output coupled to and operative to control the compression control means 80 to thereby provide a closed loop proportional control means.

Although the foregoing description is directed only to dual tube heat pipes it will be readily apparent to those skilled in the art that the present invention contemplates such apparatus having a plurality of tubes. For example a central vapor flow path may be provided and any number of condensate flow paths, one or more of which are controllable, may be disposed around the vapor path. It is only necessary that the vapor and condensate paths be separate and thermally isolated from one another.

It will thus be seen that the applicants have provided a new and novel heat pipe structure wherein the vapor and condensate flow paths are isolated from one another and in which means for capillary flow and thus thermal conductance control may be provided. For any given heat flux through the heat pipe the evaporator temperature may be controlled. Conversely for any given evaporator temperature the heat flux may be increased or decreased. The objectives set forth hereinabove are thereby efficiently met and since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the preceding description or shown in the appended drawings shall be interpreted as illustrative and not in a limiting sense.

Having described what is new and novel and desired to secure by Letters Patent, what is claimed is:

1. An improved heat pipe comprising

first and second hollow tubular members coupled at first ends thereof to a first evacuated evaporator chamber and at the other ends thereof to an evacuated condenser chamber,

a capillary structure formed of a magnetically sensitive wicking material disposed on the interior surfaces of said evaporator and condenser chambers and substantially filling the second of said hollow tubular member,

a quantity of volatile working fluid sufficient to saturate said capillary structure,

said first tubular member providing a vapor flow path from said evaporator to said condenser and said capillary filled second tubular member providing a

condensate flow path from said condenser to said evaporator, and

a magnetic structure disposed with respect to said second hollow tubular member such that the capillary structure disposed therein may be selectively compressed and expanded to thereby provide control of the condensate flow rate in said capillary structure.

2. Apparatus as recited in claim **1** wherein

said capillary structure is formed of a magnetic material.

3. Apparatus as recited in claim **1** wherein

said capillary structure is formed of a nonmagnetic fibrous material having magnetic particles imbedded therein,

4. Apparatus as recited in claim **1** wherein

said magnetic structure comprises a coil disposed about said second hollow tubular member, and a variable source of electric current coupled to said coil

whereby compression and expansion of said capillary structure is selected in accordance with the level of current flowing through said coil.

5. Apparatus as recited in claim **1** further including

a thermal sensor coupled to said heat pipe, producing an electrical output proportional to the temperature thereof, electrically coupled to said magnetic structure, and operative to control said magnetic structure

whereby automatic proportional control of said condensate flow rate is provided.

References Cited

UNITED STATES PATENTS

2,893,706	7/1959	Smith	165—106
3,305,005	2/1967	Grover et al.	165—105
3,414,050	12/1968	Anand	165—105 X
3,414,475	12/1968	Fiebelmann	165—105 X
3,429,122	2/1969	Pravda et al.	165—105 X
3,502,138	3/1970	Shlosinger	165—105 X
3,519,067	7/1970	Schmidt	165—105 X

ALBERT W. DAVIS, JR., Primary Examiner

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