United States Patent

[11] 3,587,725

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Culver City, Calif.

[54] **HEAT PIPE HAVING A SUBSTANTIALLY UNIDIRECTIONAL THERMAL PATH**
5 Claims, 9 Drawing Figs.

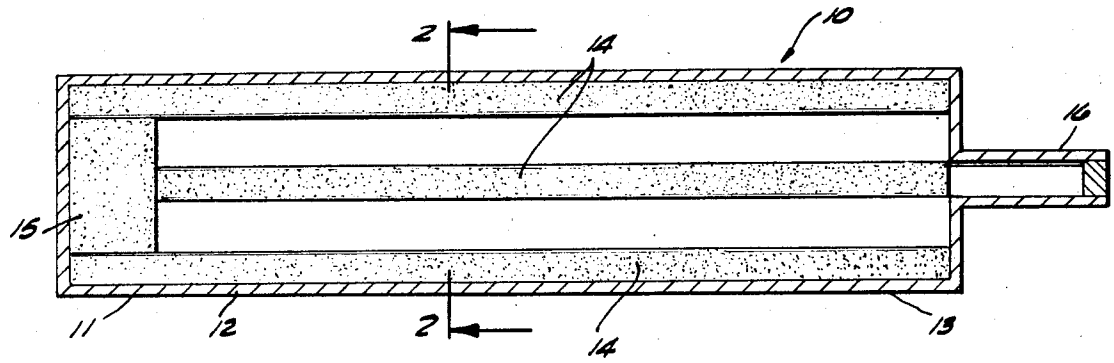
[52] **U.S. Cl.** **165/32,** 165/105
[51] **Int. Cl.** **G05d 23/00,** F28d 15/00
[50] **Field of Search** 165/32, 105

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Primary Examiner—Robert A. O'Leary
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ABSTRACT: The disclosed heat pipe includes a hermetically sealed chamber having first and second heat transfer regions. A fluid capturing wick located in the vicinity of the first region and a capillary wick containing a volatile working fluid are disposed within the chamber. The capillary wick extends from the first to the second region of the chamber. When heat is applied to the first region, the heat pipe acts as a thermal conductor, transferring heat from the first region to the second region by means of the evaporation and subsequent condensation of the working fluid. The condensed working fluid returns to the first region of the chamber by capillary action via the capillary wick. When heat is applied to the second region of the chamber, the heat pipe functions to prevent heat flow to the first region.



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SHEET 1 OF 2

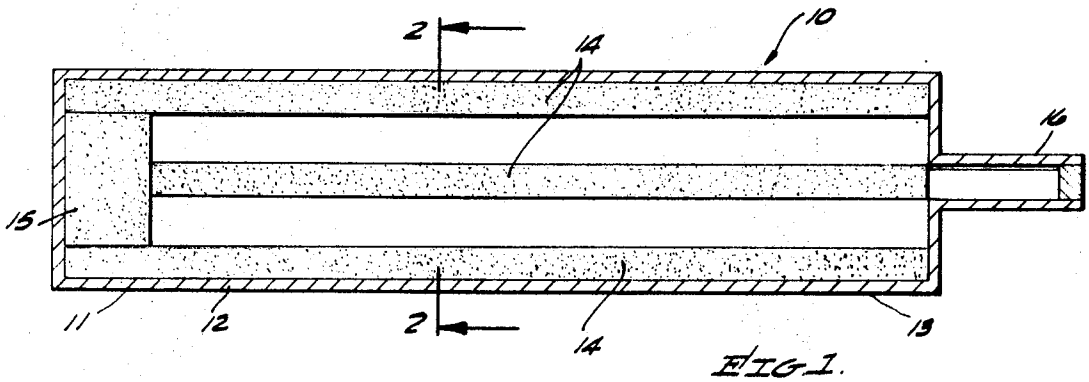


FIG. 1.

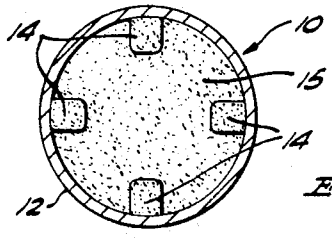


FIG. 2.

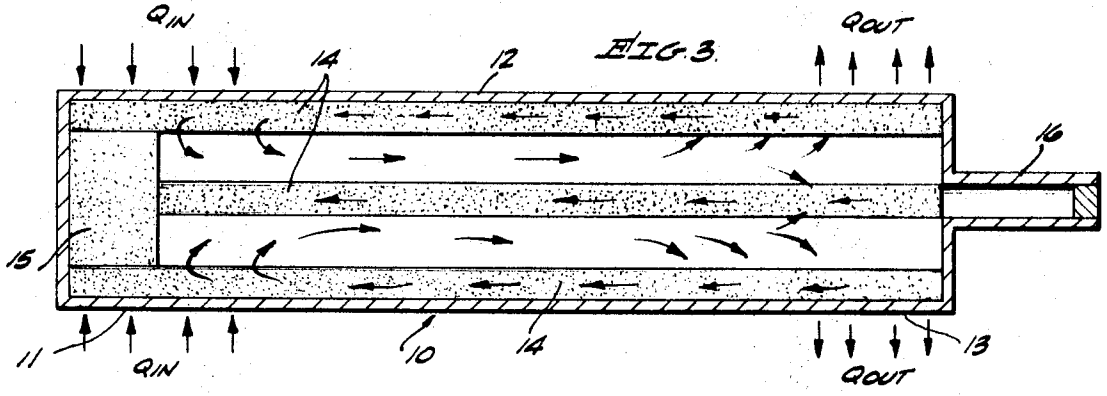


FIG. 3.

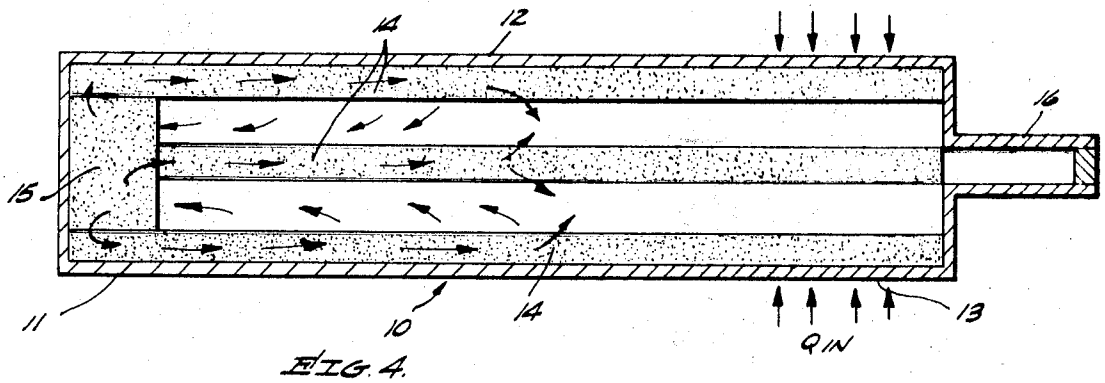


FIG. 4.

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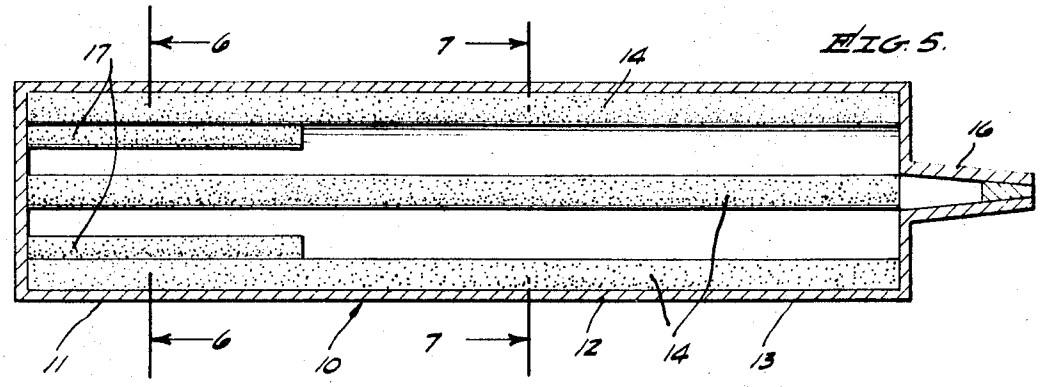


FIG. 5.

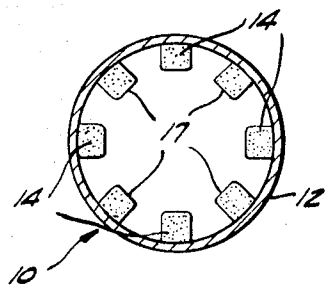


FIG. 6.

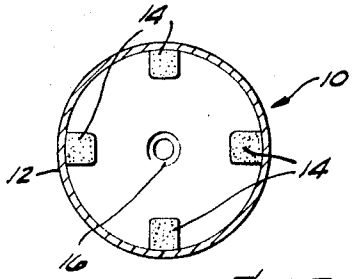


FIG. 7.

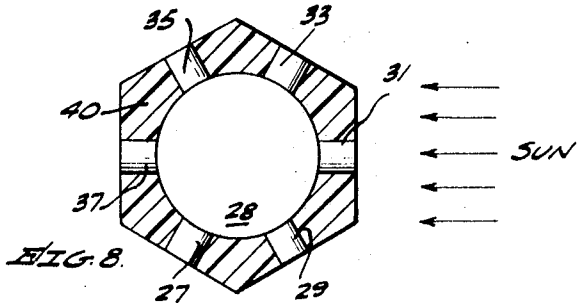


FIG. 8.

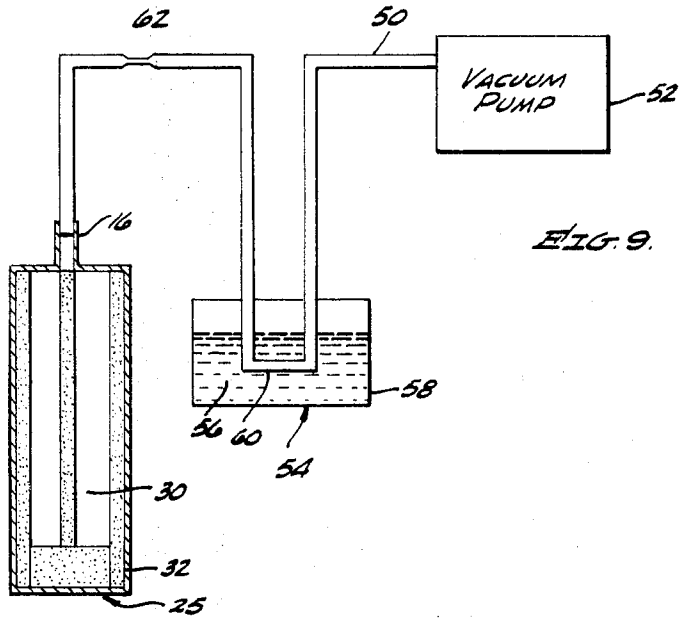


FIG. 9.

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HEAT PIPE HAVING A SUBSTANTIALLY UNIDIRECTIONAL THERMAL PATH

This invention relates to heat pipes, and more particularly, it relates to a heat pipe having a substantially unidirectional thermal path.

Heat pipes are used to conduct heat from one region to another region the propagation of heat being always from a region of higher energy to a region of lower energy. Prior art heat pipes have two heat transfer regions to which heat may be applied; if the region to which heat is applied is at a higher energy level than the other region heat will be transferred to the lower energy region.

Since a heat pipe of the foregoing type always transfers heat from the higher energy region to the lower energy region regardless of the physical location of the two regions, the heat pipe operates reciprocally and provides a bidirectional thermal path. However, for certain applications such as those contemplating a space environment, a unidirectional thermal diode that permits the transfer of heat in one direction but substantially blocks heat transfer in an opposite direction would be of great value to the art.

Accordingly, it is an object of the present invention to provide a heat pipe having a substantially unidirectional thermal path.

It is a further object of the present invention to provide a unidirectional heat pipe that is simple and economical to manufacture.

It is a still further object of the present invention to provide a thermally unidirectional heat pipe that is light in weight and reliable in operation.

In accordance with the foregoing objects, a heat pipe according to the invention includes a hermetically sealed housing of low thermal conductivity having a first heat transfer region and a second heat transfer region. A fluid capturing wick is disposed in the vicinity of the first region, while a capillary wick extends from the first region into the second region. A volatile working fluid is contained within the housing to effectuate the transfer of heat from the first to the second region but not from the second to the first region.

Additional objects, advantages and characteristic features of the present invention will become readily apparent from the following detailed description of preferred embodiments of the invention when considered in conjunction with the accompanying drawings in which:

FIG. 1 is a longitudinal sectional view of a heat pipe according to one embodiment of the invention;

FIG. 2 is a cross-sectional view taken along line 2–2 of FIG. 1;

FIGS. 3 and 4 are views similar to FIG. 1 which schematically illustrate the operation of the heat pipe of FIGS. 1 and 2;

FIG. 5 is a longitudinal sectional view of a heat pipe according to another embodiment of the invention;

FIGS. 6 and 7 are cross-sectional views taken along lines 6–6 and 7–7, respectively, of FIG. 5;

FIG. 8 is a diagrammatic illustration of an application for a heat pipe according to the invention; and

FIG. 9 is a schematic diagram illustrating a method of manufacturing a heat pipe according to the invention.

Referring to FIGS. 1 and 2 with greater particularity, a thermally unidirectional heat pipe assembly 10 according to the invention includes an elongated tubular housing 12 of a material having a low thermal conductivity, such as stainless steel, for example, and a fluid capturing wick 15 contained within housing 12 adjacent one end thereof. Housing 12 may be essentially cylindrical in shape, for example, and may have a first heat transfer region 11 and a second heat transfer region 13. Wick 15 is disposed near the first region 11.

A capillary wick, which may consist of a plurality of wick strips 14, for example (four such strips being illustrated in FIGS. 1 and 2), extends longitudinally along the inner lateral surfaces of housing 12 throughout both the first and second heat transfer regions 11 and 13. Although wick 15 is shown to be in contact with wick strips 14 in the embodiment illustrated in FIGS. 1 and 2, wicks 15 and 14 may be separated from one another so that they are not touching. Capillary wick strips 14 are saturated with an appropriate volatile working fluid. At the end of housing 12 remote from wick 15 is a hermetically sealed vacuum stem 16, which when sealed off, allows assembly 10 to become a hermetically sealed enclosure.

The amount of working fluid contained within the heat pipe assembly 10 should be, as nearly as possible, equal to the void wick volume (i.e., the amount of fluid that the wick will hold when saturated) of the wicks 14. Too little fluid will prohibit efficient heat transfer within the heat pipe when it is conducting heat, while too much working fluid results in a low insulative capability when the heat pipe is functioning as a thermal insulator.

Referring to FIG. 3, in the operation of a heat pipe according to the invention, the heat pipe will conduct heat when heat is applied to region 11. Working fluid in the vicinity of region 11 is evaporated by the heat applied there. The evaporated working fluid then travels toward region 13, which is cooler than region 11. The working fluid vapor condenses in the vicinity of region 13 and releases heat through wicks 14 and housing 12 to the environment outside of assembly 10. The condensed fluid enters wicks 14 and, by capillary action, is returned to region 11 where once again the fluid evaporates. The thermal energy "captured" by the fluid at region 11 in the vaporization phase is "released" at region 13 in the condensing phase.

The operation of a heat pipe according to the invention in its thermally conducting condition may be further described by analogy to a closed loop steam system having a boiler, a condenser and a pump. Referring to FIG. 3, the boiler may be analogous to region 11 where heat is applied and where the working fluid is evaporated. The condenser may be analogous to region 13 where, by means of condensation, the heat is released through housing 12 (the extent and actual size of regions 11 and 13 may, of course, vary). The pump may be analogized to wicks 14 which, by means of capillary action, return condensed working fluid from region 13 to region 11.

Referring to FIG. 4, if heat is applied to region 13 of the heat pipe assembly 10, evaporated working fluid flows from region 13 to region 11 where the fluid condenses, saturating fluid capturing wick 15 with condensed fluid. Since the heat pipe assembly 10 contains only enough working fluid to saturate capillary wicks 14 (and as discussed above, it should contain no more), a substantial portion of working fluid is prevented from returning to region 13 via the capillary wicks 14, making region 13 substantially devoid of fluid. Heat transfer from region 13 to region 11 is thus impaired (wicks 14 and housing 12 have low thermal conductivity). Furthermore, the condensed fluid near region 11 produces a partial vacuum in the normally vaporizing space, thus further preventing vapor phase heat transfer. The temperature at region 11 remains below the temperature at region 13, thereby achieving a declining temperature gradient over the length of the heat pipe from region 13 to region 11. As a result, the heat pipe now functions as a thermal insulator.

The working fluid may be selected primarily with the desired temperature ranges of operation of the unidirectional heat pipe in mind. Desirable characteristics of a working fluid may include high latent heat of vaporization for greater heat transfer capacity, low viscosity for low internal fluid friction, and high surface tension and good wetting ability of the wick material for good capillary action. A nonexclusive list of possible working fluids with their appropriate temperature ranges is given below.

The above working fluids are readily available commercially and are manufacture by companies such as the Dow Chemical Company, Minnesota Mining and Manufacturing Co., E. I. du Pont de Nemours, and the Monsanto Co. It should be understood that the above list is only exemplary as to suitable working fluids and their approximate useful temperature ranges for a heat pipe according to the invention.

	Working fluid	Approximate Useful Temperature Range, ° C.
Group I	Silver	1,600–2,200
	Lithium	1,000–1,700
	Sodium	600–1,200
	Potassium	500–1,100
	Cesium	400–1,000
Group II	Mercury	200–500
	Dowtherm A	150–350
	Dowtherm E	120–250
	FC 43	120–220
	Dowcorning 200	100–200
	Water	75–150
	Freon 13	20–75
Group III	Silicon dioxide	−10–+40
	Freon 12	−28–+38
	Ammonia	−39–+22
	Propane	−50–+10

The five fluids included in Group 1 are ideal for high temperature operation. The four Group III fluids are useful for refrigeration applications. Group 11 comprises seven possible working fluids and covers the temperature ranges for which cooling is more often needed in the electronics milieu.

In order to minimize the temperature difference between the regions 11 and 13 when the heat pipe is conducting, the vapor pressure within the heat pipe should be above atmospheric pressure but below the critical pressure (above which pressure the working fluid may exist in its gaseous state only) of the working fluid. However, it is generally impractical to construct a heat pipe as a pressure vessel; therefore, for practical purposes, the operating pressure is generally substantially lower than the critical pressure (within 20 percent of atmospheric pressure, for example).

The structure and composition of the capillary wick is important since it determines, to a large extent, the efficiency of the unidirectional heat pipe. The capillary wick may take the form of a tubular lining on the inner surface of housing 12, or it may be a plurality of wick strips 14 such as illustrated in FIGS. 1—7. Any porous material such as nylon, paper, glass fiber, silicon dioxide, porous ceramics, ceramic-metal fiber components or combinations of the foregoing, for example, may be used as wick material. These materials may be in the form os screens, cloths, sintered structures or combinations thereof. Moreover, the wick material should have a low thermal conductivity since heat should flow via the vapor, not through the wick. The capillary wick may be force fit into housing 12, or it may be riveted, sintered or soldered thereto, for example.

Capillary wick thickness is an important design consideration. An excessively thick wick will impede the flow of the heat transversely through the wick; on the other hand, if the wick is too thin, the capillary (longitudinal) flow of the condensed fluid will be impeded. Furthermore, the length of the capillary wick should be minimized to reduce pressure drop in the condensed working fluid. For example, for a wick made of silicon dioxide and with Dowtherm A as the working fluid, when the working fluid is flowing in the wick against the force of gravity (i.e., the heat pipe is being operated in a vertical attitude) the wick length may be approximately 6 inches and the wick thickness approximately one eighth of an inch.

Fluid capturing wick 15 may be made of any suitable material having a high receptivity for the condensed working fluid; it is generally of the same material as the capillary wick 14.

Another embodiment of a unidirectional heat pipe according to the invention is illustrated in FIG. 5. In this embodiment, a plurality of fluid capturing wicks 17 are provided in lieu of the wick 15. The wicks 17 are disposed on the inner lateral surface of heat pipe housing 12 approximately circumferentially midway between adjacent capillary wicks 14 and extend throughout only a portion of the length of the heat pipe. For example, the wicks 17 may extend only throughout the length of heat pipe region 11. The wicks 17, in a similar manner as wick 15 in the embodiment illustrated in FIG. 1, serve as a fluid capturing reservoir for the working fluid when the heat input is at region 13. The main advantage of using the wicks 17 as compared to using wick 15 is that more constant temperature gradient results along region 11 over the length of wicks 17 when the heat pipe is in its thermally insulative condition of operation.

Heat pipes described with respect to both FIGS. 1 and 5 may be used in both a gravitational or nongravitational environment, since the working fluid flow through the capillary wick is not dependent on gravity. Hence, the unidirectional heat pipe is particularly suitable for use in space environment.

Application of a heat pipe according to the invention to a space environment is schematically illustrated in FIG. 8. A plurality of heat pipes 27, 29, 31, 33, 35, and 37, constructed in accordance with the principles of the present invention, are attached to the outer surfaces of a spacecraft 28 and are surrounded by insulating material 40. The heat pipes 27—37 are oriented with their longitudinal axes disposed along respective spacecraft radii and with their ends containing wicks 15 or 17 nearest the interior of the spacecraft 28.

Heat pipes 27—37 are thus capable of transferring heat from the interior of the spacecraft 28 to the outside, but substantially block the flow of heat from the outside to the inside. Hence, on the side of the spacecraft 28 away from the sun, the heat pipes transfer heat from instrumentation within the spacecraft 28 to the spacecraft's outer surfaces. On the other hand, the heat pipes on the side of the spacecraft facing the sun substantially insulate the spacecraft 28 from the sun's heat. Therefore, efficient heat removal from the inside of the spacecraft into space may be achieved even though the spacecraft 28 rotates so as to change its surface facing the sun.

An array of unidirectional heat pipes similar to that shown in FIG. 8 may be used in other extreme climatic conditions. For example, in a desert environment, heat pipes according to the invention may be used in the construction of a roof of a building. Acting as an insulator, the heat pipes protect the inside of the building from the heat outside, while allowing heat inside of the building to travel to the outside of the building when the temperature inside of the building is greater than the temperature on the outside. In an extremely cold environment such as that of the arctic region, the function of the heat pipes would be reversed. A heat pipe according to the invention may, therefore, be used in any environment requiring a thermal diode; i.e., requiring heat insulation in one direction but heat conduction in the opposite direction.

Referring to FIG. 9, in order to manufacture a heat pipe according to the foregoing embodiments a heat pipe assembly 25 (which for purposes of explanation is illustrated as the heat pipe 10 of FIG. 1) must first be "baked out" in a manner similar to that used in processing a vacuum tube, since a heat pipe according to the invention operates at its maximum heat pipe housing contains essentially no fluids other than the working fluid. For this purpose a tube 50 is attached to heat pipe 25 by vacuum stem 16. The other end of tube 50 communicates with a vacuum pump 52. The entire heat pipe 25 is subjected to high temperature while the interior 30 of heat pipe assembly 25 is being evacuated by vacuum pump 52.

A volume of working fluid greater than the void wick volume of the capillary wick may then be placed within the heat pipe assembly 25 by condensation, for example.

A looped portion 60 of tube 50 is then immersed in a cold trap 54. Cold trap 54 comprises a cooling fluid 56, such as ice water for example, and a container 58 for the fluid 56. Cold trap 54 functions principally to condense any working fluid that may escape from assembly 25 during the manufacturing of the heat pipe.

Region 32 of the heat pipe assembly 25 (which corresponds approximately with heat input region 11 of the heat pipe of FIGS. 1 and 5) is then heated to the desired normal operating temperature of the heat pipe while the vacuum pump 52 is operating. The heating and vacuum pumping allows unwanted gases to escape from assembly 25 and tends to maintain the interior 30 of assembly 25 filled with the working fluid either in its vapor or liquid form.

Some of the working fluid, especially when in the vapor form, may be unintentionally drawn out of assembly **25** by the vacuum pump **52** or other means through stem **16**. In order to prevent this, a restriction **62** (which may be in the form of a venturi orifice) in the tube **50** is maintained at a temperature much higher than the temperature applied at region **32** of assembly **25**. If any of the working fluid escapes through restriction **62**, cold trap **54** condenses this fluid so that the amount of fluid escaping may be exactly determined (this may be done by weighing the cold trap **54**, for example). The amount of working fluid that escapes should be determined prior to the final evacuation of the heat pipe so that the fluid remaining in assembly **25** is substantially equal to the void wick volume of the capillary wick (as discussed previously).

An indication that most of the unwanted matter has been removed from interior **30** of assembly **25** and that the heat pipe is transferring heat effectively is provided when the temperature near the open end (stem **16**) of heat pipe assembly **25** is substantially equal (less than 1° C. difference, for example) to the temperature at region **32**.

Assembly **25** may than be hermetically sealed by "pinching off" stem **16**.

Although the present invention has been shown and described with reference to particular embodiments, nevertheless, various changes and modifications obvious to a person skilled in the art to which the invention pertains are deemed to lie within the spirit, scope and contemplation of the invention.

I claim:

1. A heat pipe having a substantially unidirectional thermal path comprising: a hermetically sealed housing of low thermal conductivity having a first heat transfer region and a second heat transfer region, fluid capturing wick means disposed in the vicinity of said first region, capillary wick means extending from said first region into said second region, the amount of said fluid being substantially equal to the void wick volume of said capillary wick means and a volatile working fluid contained within said housing for effectuating the transfer of heat from said first to said second region.

2. A heat pipe having a substantially unidirectional thermal path comprising: a hermetically sealed housing of low thermal conductivity having a first heat transfer region and a second heat transfer region, fluid capturing wick means disposed adjacent said first region, capillary wick means extending from said first region into said second region, and a volatile working fluid contained within said housing, the amount of said fluid being substantially equal to the void wick volume of said capillary wick means, whereby said heat pipe is capable of conducting heat from said first to said second region but is substantially incapable of conducting heat from said second to said first region.

3. A heat pipe according to claim **2** wherein said working fluid is selected from the group consisting of silver, lithium, sodium, potassium, cesium, mercury, Dowtherm A, Dowtherm E, FC 43, Dowcorning 200, water, Freon 13, silicon dioxide, Freon 12, ammonia and propane.

4. A heat pipe having a substantially unidirectional thermal path comprising: an elongated tubular hermetically sealed housing having low thermal conductivity and defining a vapor cavity, said cavity having first and second heat transfer regions in different longitudinal locations therealong, a fluid capturing wick disposed within said first heat transfer region, a plurality of capillary wick strips longitudinally disposed along the periphery of said vapor cavity and extending substantially throughout both said first and said second regions and a volatile working fluid disposed within said vapor cavity, the amount of said fluid being substantially equal to the void wick volume of said capillary wick strips.

5. A heat pipe having a substantially unidirectional thermal path comprising: an elongated tubular hermetically sealed housing having low thermal conductivity and defining a vapor cavity, said cavity having first and second heat transfer regions in different longitudinal locations therealong, a plurality of fluid capturing wick strips longitudinally disposed along the periphery of said vapor cavity and extending substantially throughout said first heat transfer region, a plurality of capillary wick strips longitudinally disposed along the periphery of said vapor cavity and extending substantially throughout both said first and said second heat transfer regions, said capillary wick strips being circumferentially interspersed with said fluid capturing wick strips along the periphery of said vapor cavity, and a volatile working fluid disposed in said cavity, the amount of said fluid being substantially equal to the void wick volume of said capillary wick strips.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,587,725 Dated June 28, 1971

Inventor(s) Algerd Basiulis

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

Col. 2, line 70, "manufacture" should be --manufactured--.
Col. 3, line 42, "os" should be --of--.
Col. 4, line 10, after "in" insert --a--;
Col. 4, line 52, after "heat" insert --transfer capability only when the space 30 enclosed by the heat--
Col. 5, line 36, after the comma (,), insert --and a volatile working fluid contained within said housing for effectuating the transfer of heat from said first to said second region,--;
line 38, delete "and a volatile working fluid contained within said housing for effectuating the transfer of heat from said first to said second region"

Signed and sealed this 11th day of January 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Patents