

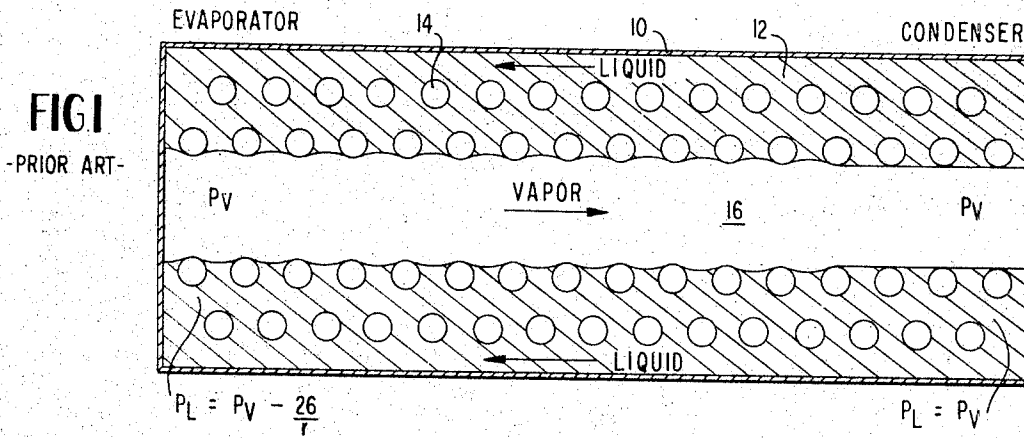
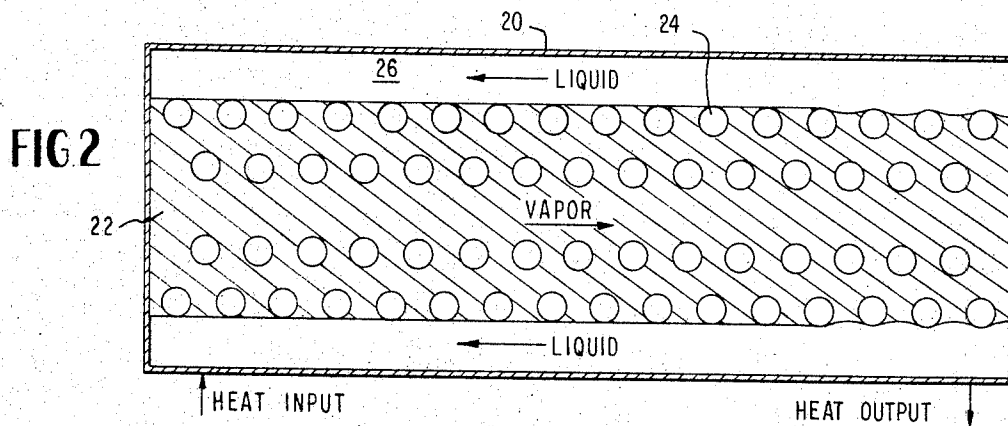
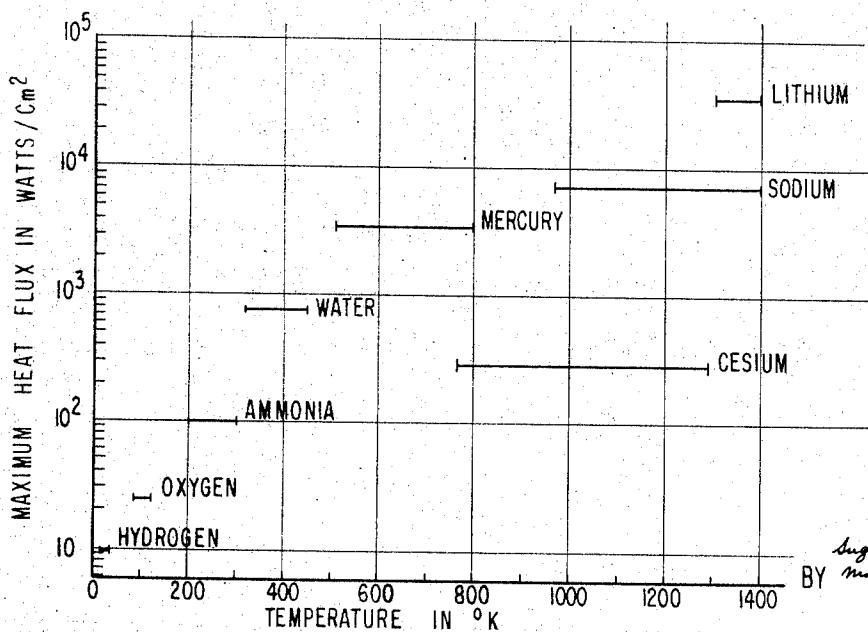
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HEAT PIPES FOR NON-WETTING FLUIDS

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HEAT PIPES FOR NON-WETTING FLUIDS

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5 Claims

ABSTRACT OF THE DISCLOSURE

The concept of heat pipes is a fairly recent development and a heat pipe may be considered as a structure of high thermal conductivity. A mass flow of a liquid is achieved inside a closed container by means of capillary action and heat is transported from one point to the other in the form of latent heat of vaporization. The useful temperature range of a heat pipe depends upon the vapor pressure of the working fluid. The prior art devices in their simplest form consisted of a sealed containment vessel, a wick material in contact with the vessel walls, a working fluid that fills the wick, and a space containing the vapor of the working fluid. One end of the pipe may be considered the evaporator which is adapted to be placed adjacent a heat source while the other end of the pipe is considered a condenser. At the evaporator, the liquid absorbs heat while it is boiled out of the wick into the vapor space. The vapor then flows to the condenser end of the pipe where the heat is removed from the vapor by condensation on the wick which in turn transports the liquid back to the evaporator. The heat pipe is capable of transporting large heat fluxes with very small temperature gradients. Effective thermoconductivities several hundred times that of copper have been measured.

Pressure gradients required to circulate the liquid and vapor are generated by the forces of surface tension of the liquid in the wick. At the interface of the liquid and vapor, surface tension forces will support a pressure differential between the vapor and the liquid equal $2\sigma/R$, where σ is the surface tension and R is the radius of curvature of the liquid. This pressure differential has a maximum value of $2\sigma/R_w$, where R_w is the radius of the pores in the wick. (The minimum radius of curvature is equal to the radius of the pores.) In the condenser, the radius of curvature of the liquid is very large and the pressure and vapor are very nearly the same. As the liquid flows through the wick toward the evaporator, viscous forces cause its pressure to drop. Viscous forces also act in the vapor, causing the vapor pressure to be larger toward the evaporator. These two effects cause the pressure differential between the vapor and liquid to increase from nearly zero at the condenser to a maximum at the evaporator. The larger the amount of fluid to be transported, the larger this pressure differential will be. Therefore, the flow rate that corresponds to a pressure differential of $2\sigma/R_w$ is a theoretical maximum flow rate. This maximum flow rate times the heat of vaporization of the fluid gives a theoretical maximum heat flux that the heat pipe can transport.

The actual maximum may be decreased by effects such as incomplete wetting of the wick by the working fluid or non-uniform wicking material. These can be overcome by careful selection of working fluid and wick.

In prior art devices of the nature described above, the particular temperature range in which the heat pipe is to be used determines the choice of a suitable working fluid. When dealing in the temperature range between approximately 250 and 500° C. no suitable working fluid was

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found for use with the prior art device. However, this temperature range is of great interest for some applications, for example, for radioisotope powered thermoelectric generators, where heat is frequently rejected in this temperature range. Mercury is a fluid with properties suitable for use in a heat pipe in the temperature range between 250° and 500° C. But mercury cannot be used in prior art heat pipes, since it does not meet one important requirement of being able to completely wet the capillary structure of the wick material.

It is therefore the purpose of this invention to describe a heat pipe concept applicable to fluids which do not wet the wick material. While mercury and steel are examples of such combinations, the concept is of course not limited to these two materials. Therefore the present invention is directed to a heat pipe having the capillary wick structure located in the center of the tube with a non-wetting liquid (such as mercury in the case of a steel wick) contained in a small annulus between the wall of the tube and the wick. The liquid substantially fills this annulus with preferably a small excess of liquid inside the wick. Upon heating the evaporator end of the tube the liquid will evaporate into the wick and move to the condenser end of the tube. At the condensing end of the tube the vapor will be condensed and the circulation of the vapor within the wick and the mercury surrounding the wick will transfer large quantities of heat from the evaporator end of the tube to the condenser end of the tube.

Other objects of the invention will be pointed out in the following description and claims and illustrated in the accompanying drawings, which disclose by way of example, the principle of the invention and the best mode which has been contemplated of applying that principle.

In the drawings:

FIGURE 1 is a cross-sectional view along the length of a prior art heat pipe;

FIGURE 2 is a sectional view along the length of a heat pipe constructed according to the present invention; and

FIGURE 3 is a graph showing the relationship of the various working fluids relative to the heat flux and temperature.

Turning now to FIGURE 1 which shows a prior art heat pipe comprising a closed container 10 having the wall thereof lined with a wick material 12 of a porous nature. The pores 14 have been illustrated on a greatly exaggerated scale for the purposes of explaining the operation of the heat pipe. A hollow core 16 extends the length of the wick material within the container. This type of heat pipe shown in FIGURE 1 is adapted to utilize a fluid which wets the wick and in actual operation the wick is saturated with the liquid. When heat is supplied to the evaporator end of the heat pipe the liquid starts to evaporate and the liquid vapor interface recedes into the wick to form a meniscus with a radius of curvature r_e equal to or greater than the largest pore radius. Due to the surface tension σ of the liquid the pressure of the liquid differs from that of the adjacent vapor by an amount $\Delta p_e = 2\sigma/r_e$. At the condensing end the vapor condenses on the surface of the wick and the interface between vapor and liquid has a radius of curvature r_c of the same order of magnitude as the dimensions of the container. The corresponding pressure difference Δp_c is equal to $2\sigma/r_c$. The net pressure difference $\Delta p = 2\sigma(1/r_e - 1/r_c)$ constitutes the "pumping power" for recirculating the working medium against the viscous forces in the wick and the vapor space.

In the case of non-wetting fluids the heat pipe concept illustrated in FIGURE 2 can be utilized. The capillary wick structure 22 is located in the center of the tube 20.

A non-wetting liquid such as mercury in the case of a steel wick is contained in a small annulus 26 between the wall and the wick. The liquid substantially fills this annulus with preferably a small excess of liquid inside the wick. Upon heating the evaporator end of the tube the liquid will evaporate and retreat from the wick to form a radius of curvature r_c' (order of magnitude of container dimensions). The pressure difference Δ_{pe}' between liquid and vapor is given $\Delta_{pe}' = -2\sigma/r_c'$. At the condensing end of the tube the vapor will condense inside the wick. The radius of curvature of the interface will be r_c' which is equal to or greater than the largest pore radius and the corresponding pressure difference

$$\Delta_{pc}' \text{ will be } \Delta_{pc}' = -2\sigma/r_c'$$

The net pressure difference $\Delta_p' = -2\sigma(1/r_c' - 1/r_c)$ constitutes the "pumping power" for recirculating the working fluid against the retarding affect of the viscous forces in the liquid and the vapor.

Referring to FIGURE 3 it is seen that suitable working fluids can be found over the entire temperature range interest and that the performance of heat pipes will generally be better at high temperatures. The operating temperature range of the heat pipe shown in FIGURE 2 which utilizes mercury as the working fluid and with the wick formed of steel, such as steel wool, is clearly shown in FIGURE 3 as being from about 500° K. to 800° K.

Heat pipes are structures of extremely high effective conductivity and do not require gravity for the operation. These features combined with their simplicity and inherent reliability make them well adapted for use in space. Experimental heat pipes have usually been made in tubular form for easy fabrication and instrumentation. The geometry of the heat pipe is by no means restricted to this configuration.

Heat pipes are ideal for controlling the temperatures of various components as for example the cabin temperature of a spacecraft. Some missions requiring an isothermal environment for sensitive instruments regardless of the orientation of the vehicle with respect to incident

sunlight may be provided with such an environment by surrounding the vehicle with an annulus-shaped heat pipe.

If the condenser and evaporator are different sizes, the heat pipe will act as a heat concentrator or diffuser.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore, to be understood, that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A heat pipe for non-wetting fluids comprising, casing means defining a closed chamber, capillary means so disposed in said chamber as to provide a space between said capillary means and said casing and a fluid which is non-wetting with respect to said capillary means being disposed in said space.

2. A heat pipe as claimed in claim 1 wherein said casing means is a cylindrical pipe closed at both ends.

3. A heat pipe as claimed in claim 1 wherein said capillary means is a wick comprised of a porous material.

4. A heat pipe as claimed in claim 2 wherein said capillary means is shaped as a cylinder and is disposed concentrically within said cylindrical casing and spaced therefrom.

5. A heat pipe as claimed in claim 1 wherein said capillary means is a wick comprised of steel wool and said non-wetting fluid is mercury.

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