Performance of Heat Pipe and its Application for Dehumidification and Air Conditioning

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Abstract—Heat pipes are heat transfer devices that enhances large amount of heat which works on the principle of evaporation and condensation of a working fluid. Inspite of wide application of heat pipe in microelectronics cooling system the trend of the chips performance and power utilization has been increased each year and a complete understanding of mechanism has not yet been completed even though it has the ability to operate against gravity and a greater maximum heat transport capability.

This article gives you a detailed literature review about the various parameters that affect the operational characteristics of circular heat pipe. Moreover the thermal resistance and heat transfer capability are affected by the choice of working fluid, the tilt angle, the fill ratio, thermal properties and heat input.

Keywords—heat pipe, condensation and evaporation

I. INTRODUCTION

The term heat pipe" as the name implies, device for transferring heat from a source to a sink by means of evaporation and condensation of a fluid in a sealed system.

The idea of heat pipes was originally invented by R.S. Gaugler of the General Motors Corporation in 1942 but it was not, however, until its independent invention by G.M. Grover in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place.

A heat pipe is a heat transfer mechanism that can transport large quantities of heat with a very small difference in temperature between the hot and cold interfaces. A heat pipe is an evaporation-condensation device for transferring heat in which the latent heat of vaporization is exploited to transport heat over long distances with a corresponding small temperature difference. The heat transport is realized by means of evaporating a liquid in the heat inlet region (called the evaporator) and subsequently condensing the vapor in a heat rejection region (called the condenser). Closed circulation of the working fluid is maintained by capillary action and /or bulk forces. [1]

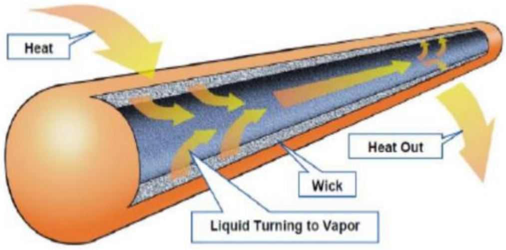

Fig.1 Heat pipe

II. DESIGN CONSIDERATIONS

The three basic components of heat pipe are:
•The Container
•The working fluid
•The wick or capillary structure

2.1 Container:

The function of the container is to isolate the working fluid from the outside environment. It has be therefore leak proof, maintain the pressure differential across its walls, and enable transfer of heat to take place from and into the working fluid. Selection of the container material depends upon many factors.

These are follows:

•Compatibility (both with working fluid and external environment)
•Strength to weight ratio.
•Thermal conductivity
•Ease of fabrication, including welding, machine ability and ductility
•Porosity
•Wettability

Most of the above are self-explanatory. A high strength to weight ratio is more important in spacecraft applications. The material should be non-porous to prevent the diffusion of vapour. A high thermal conductivity ensures minimum temperature drop between the heat source and the wick.

2.2 Working fluid

A first consideration in the identification of a suitable working fluid is the operating vapour temperature range.

Within the appropriate temperature band, several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered.

The prime requirements are:

- Compatibility with wick and wall materials.
- Good thermal stability.
- Wettability of wick and wall materials.
- Vapor pressure not to high or low over the operating temperature range.
- High latent heat.
- High thermal conductivity.
- Low liquid and vapor viscosities.
- High surface tension.
- Acceptable freezing or pour point.

The selection of working fluid must also be based on thermodynamics considerations which are concerned with the various limitations to heat flow occurring within the heat pipe like viscous, sonic, capillary, entrainment and nuclear boiling levels. In heat pipe designs, a high value of surface tension is desirable in order to unable the heat pipe to operate against the gravity and to generate high capillary driving force. In addition to high surface tension, it is necessary for working fluid to wet the wick and the container material i.e. contact angle should be zero or very small. The vapour pressure over the operating temperature range must be sufficiently grade to avoid high vapour velocity, which tends to setup large temp. gradient and cause floe instabilities.

2.3 Capillary or Wick Structure:

It is porous structure made of material like steel, aluminium, nickel or copper in various ranges of pore sizes. They are fabricated using metal foams, and more particularly felts, the latter being more frequently used. By varying the pressure on the felt during assembly, various pore sizes can be produced. By incorporating removable metal mandrels, an arterial structure can also be moulded in the field. Fibrous material like ceramics, have also been used widely. They generally have smaller pores. The main disadvantages of ceramic fibre are that they have little stiffness and usually require a continuous support by a metal mesh. Thus while the fibre itself may be chemically compatible with the working fluids, the supporting materials may causes problems. More recently, interest has turned to carbon fibre as wick material. Carbon fibre filaments have many fine longitudinal grooves on their surface, have a high capillary pressure and are chemically stable. A number of heat pipe that have been successfully constructed using carbon fibre wick seems to show a greater heat transport capability. [2]

To transport the working fluid from the condenser back to the evaporator, a wick structure is incorporated on the heat pipe’s top and bottom layer. As transport is based on capillary effects, the effective radius of the structure should be small. This causes a higher (capillary) pressure difference across the heat pipe. However, the radius should not be too small, as this causes a low permeability of the wick due to frictional effects. In addition to this geometric feature, the heat pipe orientation is also important. Body forces acting on the liquid can either increase or diminish its flow. To maximize heat pipe potential, in general, an open wick structure is preferred in a gravity-assisted orientation. When the liquid has to ascend against gravity, a more compact wick is required. The wick structure allows the liquid to travel from one end of the heat pipe to the other via capillary action. Each wick structure has its advantages and disadvantages.

There are four common wick structures

a) Rectangular microgrooves.
b) Supported foil channel.
c) Screen covered artery.
d) Wire and sintered metal.

III. FACTORS AFFECTING THE THERMAL PERFORMANCE OF HEAT PIPE

3.1. Effect of fluid charge

Filled ratio is the fraction (by volume) of the heat pipe which is initially filled with the liquid. There is two operational filled ratio limits. At 0% filled ratio, a heat pipe structure with only bare tubes and no working fluid, is pure conduction mode heat transfer device with a very high undesirable thermal resistance .A 100% fully filled heat pipe is identical in operation to a single phase thermosyphon.

The heat transfer performance of an OHP was apparently improved after the addition of alumina nanoparticles in the working fluid. Compared with the pure water, the maximal decrease of thermal resistance was 0.14 °C/W (or 32.5%) which occurred at 70% filling ratio and 0.9% mass fraction when the power input was 58.8 W [7]. In PHP, considerably high filled ratio will hinder the pulsation of the bubble and the efficiency of the heat transfer will not be favourable enough. The low filled ratio will get pulsation of the bubble easily, but it is extremely easy to dry out. So the most proper filled ratio is between 40% and 60%.

3.2. Effect of wick structure

A heat pipe is a vessel whose inner walls are lined up with the wick structure. There are four common wick structures:

- Groove

- Wire mesh
- Powder metal
- fiber/spring.

The wick structure allows the liquid to travel from one end of the heat pipe to the other via capillary action. Each wick structure has its advantages and disadvantages. Every wick structure has its own capillary limit. Fig. 1 depicts actual test performance of four commercially produced wicks. It can be seen that the groove heat pipe has the lowest capillary limit among the four but works best under gravity assisted Conditions.

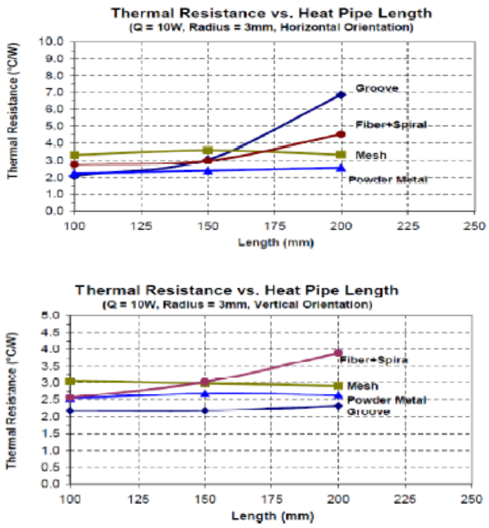

Fig.2 .The actual test results of heat pipe with different wick structure at horizontal and vertical.[2]

3.3. Effect of working fluid

A first consideration in the selection of a suitable working fluid is the operating vapour temperature range within the approximate temperature band (50 to 1500 C) several possible working fluids may exit .A variety of characteristic must be examined in order to determine the most acceptable of these fluids for the application considered the primary requirements are: compatibility with the heat pipe material (s),thermal stability, wettability, reasonable vapour pressure ,high latent heat and thermal conductivity, low liquid and vapour viscosities and acceptable freezing point. The heat transfer performance of an OHP was apparently improved after the addition of alumina nanoparticles in the working fluid. Compared with the pure water, the maximal decrease of thermal resistance was 0.14°C/W (or 32.5%).

For the heat pipe with 0.10% nanoparticles volume concentration, the thermal efficiency is 10.60% higher than that with the based working fluid. The better efficiency of the heat transfer is 100 ppm concentration of silver nanofluid water solution; the worse one is 450 ppm concentration of silver nanofluid water solution. Although the nanofluid has the higher heat conduction coefficient that dispels more heat theoretically. But the higher concentration will make the higher viscosity.

3.4. Effect of tilt angle

The orientation is important for the operation of a heat pipe. Depending on conditions, a heat pipe can operate in horizontal position or in vertical position. For the horizontal position of a heat pipe, gravity has no effect. But in vertical position gravity can assist or oppose to the operation of the heat pipe. The tilt of a heat pipe is classified into two types; favourable tilt and adverse tilt. Favourable tilt is the tilt position where gravity assists heat pipe operation. In favourable tilt, condenser is positioned above evaporator. By this way, liquid return from condenser to evaporator is assisted by gravity. Therefore, capillary pumping pressure can overcome more pressure losses and this increases the heat transfer capacity of the heat pipe, in terms of capillary limit. Other type is adverse tilt. In this tilt condition, evaporator is positioned above condenser. Therefore, the liquid in the condenser shall overcome gravity force to return to evaporator. This creates extra drag for capillary pumping pressure to overcome.

As a result, heat transfer capacity of the heat pipe decreases. Therefore, it is preferable for a heat pipe to operate in favourable tilt position, if possible. An increase of heat transfer rate of 39% is obtained for 2% iron oxide nanoparticles when the angle of inclination of heat pipe is 90o The heat pipe efficiency increases with increasing tilt angle because the gravitational force has a significant effect on the flowing of working fluid between evaporator section and condenser section. However, when the heat pipe tilt angle exceeds a value of 60° for de-ionic water and 45° for alcohol, the heat pipe thermal efficiency tends to decrease. The efficiency of heat pipe increases with increasing values of the tilt angle. However, when the heat pipe inclination angle exceeds 30° for de-ionic water and 45° for copper nanofluid and copper nanofluid with aqueous solution of n-Butanol, the heat pipe thermal efficiency tends to decrease.[3]

IV. HEAT PIPES FOR DEHUMIDIFCATION AND AIR CONDITIONING

In an air conditioning system, the colder the air as it passes over the cooling coil (evaporator), the more the moisture condense out. The heat pipe is designed to have one section in the warm incoming stream and the other in the cold outgoing stream. By transferring heat from the warm return air to the cold supply air, the heat pipes create the double effect of pre-cooling the air before it goes to the evaporator and then re-heating it immediately.

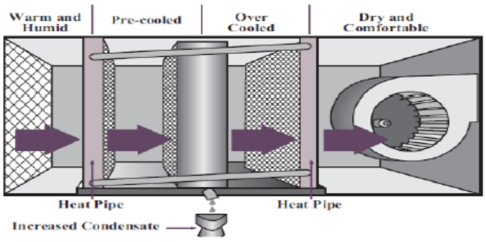

Fig.3 Working of heat pipe in Air Conditioner[2]

Activated by temperature difference and therefore consuming no energy, the heat pipe, due to its pre-cooling effect, allows the evaporator coil to operate at a lower temperature, increasing the moisture removal capability of the air conditioning system by 50-100%. With lower relative humidity, indoor comfort can be achieved at higher thermostat settings, which result in net energy saving. Generally, for each 1o F rise in thermostat setting, there is a 7% savings in electricity cost. In addition, the pre-cooling effect of the heat pipe allows the use of smaller compressor.

V. APPLICATIONS

Heat pipe has been, and is currently being, studied for variety of application, covering almost the entire spectrum of temperature encountered in heat transfer processes. Heat pipes are used in wide range of product like air-conditioners, refrigerators, heat exchangers, transistors, capacitor, etc. Heat pipes are also used in laptops to reduce the working temperature for better efficiency. Their application in the field of cryogenics is very significant, especially in the development of space technology. We shall now discuss a brief account of various application of heat pipe technology.

5.1 Space Technology

The use of heat pipe has been mainly limited to this field of science until recently, due to cost effectiveness and complex wick construction of heat pipes. There are several application of heat pipes in this field like

- Spacecraft temperature equalization
- Component cooling, temperature control and radiator design in satellites
- Other application includes moderator cooling, removal of heat from reactor at emitter temperature and elimination of troublesome thermal gradients along the emitter and collector in spacecraft.

5.2 Laptop Heat Pipe Solution

Heat pipe technology originally used for space applications has been applied to laptop computer cooling. It is an ideal, cost effective solution. Its light weight (generally less than 40 grams), small, compact profile, and its passive operation, allow it to meet the demanding requirements of laptops. For an 8 watt CPU with an environmental temperature no greater than 40o C it provides a 6.25o C/watt thermal resistance, allowing the processor to run at full speed under any environmental condition by keeping the case temperature at 90o C.

One end of the heat pipe is attached to the processor with a thin, clip- on mounting plate. The other is attached to the heat sink, in this case, a specially designed keyboard RF shield. This approach uses existing parts to minimize weight and complexity. The heat pipe could also be attached to other physical components suitable as a heat sink to dissipate heat (see photo of inside of laptop and computer).

Fig.4 Heat Pipe for Laptop Solution[3]

Fig.4 Heat pipes for laptop solutions because there are no moving parts, there is no maintenance and nothing to break. Some are concerned about the possibility of the fluid leaking from the heat pipe in to the electronics. The amount of fluid in a heat pipe of this diameter is less than 1cm. In a properly designed heat pipe, the water is totally contained within the capillary wick structure and is at less than 1atm pressure. If the integrity of heat pipe vessel were ever compromised, air would leak into the heat pipe instead of the water leaking out. Then the fluid would slowly vaporize as it reaches atmospheric boiling point. A heat pipe’s MTTF is estimated to be over 100,000 hours of use.

5.3 CPU Work Stations

The heat pipe solutions for thermal control at this level are a component and overall system requirement. Not only do the heat pipes take on a different configuration with multiple heat pipes and cooling fins, but also air flow becomes critical design factor. Heat pipes design to move 75 watts are usually flat with fin stacks from 3 to 6 inches, in many cases with fins mounted on each side of the CPU input pad. Input pads are standard using stand-offs, transition socket and bolster plates on the bottom of the PC board. This spring clips used on the fan/ heat sink combinations won’t work here. Air flow management is important in the overall efficiency of the heat pipe and should calculate along with the intended heat pipe design. This group uses two thermal products, heat pipes to transfer the CPU heat (100 to 300 watts) and a second internal or external cooling source. Input power is generated from multiple CPUs and components with single or multiple heat pipes. Cooling temperatures on the output range from 00 C to -400 C. This system requires thermal isolation because of dew point consideration.

5.4 Notebook and Mobile PCs Thermal control

Heat pipes have proven to be the expected means of providing thermal control in notebook and Mobil PCs systems. Heat pipes can move and dissipate CPU generate heat selectively throughout the system without affecting temperature sensitive components. Low wattage heat pipes (under 20 watts) have standardized input plates to the heat pipe. The connection to the heat exchanger via the heat pipe can have any number of configurations to accommodate component placement, multiple power ranges and fan operation. [4]

VI. CONCLUSIONS

1. The effect of various parameters such as filling ratio, capillary structure, working fluids and tilt angle have studied. All these parameters have some positive and some negative impact on the heat transfer capacity of the heat pipe.

2. Use of micro heat pipes in electronic equipment's such as notebook computers, communication equipment, video game machines etc.

3. The future has vast storehouse of equipment's to be used in every sphere of life where heat removal will play a major role and hence heat pipes would find vast applications.

4. Also, by applying the heat pipe assembly in the air conditioning unit we can considerably improve the dehumidification and air conditioning capacity.

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