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Factors affecting the thermal performance of heat pipe –a review

R.Manimaran[1], K.Palaniradja[2], N.Alagumurthi[2] and J.Hussain[2]

[1]Pondicherry Engineering College, Puducherry, India

[2]Department of Mechanical Engineering, Pondicherry Engineering College, Puducherry, India.

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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 paper 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, angle of inclination and heat input.

Introduction

The electronic circuit used in electronic devices undergoes an increase in operating temperature due to increase in heat flux density through a miniaturization of components, the cooling problem becomes more and more challenging .Heat pipes are the one of the available technologies to deal with the high density electronic cooling problem due to their high thermal conductivity, reliability and low weight. Heat pipes are two-phase heat transfer devices with high effective thermal conductivity. Due to the high heat transport capacity, heat exchanger with heat pipes has become much smaller than traditional heat exchangers in handling high heat fluxes. With the working fluid in a heat pipe, heat can be absorbed on the evaporator region and transported to the condenser region where the vapour condenses releasing the heat to the cooling media [1].

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 vapour in a heat rejection region (called the condenser). Closed circulation of the working fluid is maintained by capillary action and /or bulk forces. The heat pipe was originally invented by Gaugler of the General Motors Corporation in 1942, but it was not, however, until its independent invention by Grover [3, 4] in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place. An advantage of a heat pipe over other conventional methods to transfer heat such a finned heat sink, is that a heat pipe can have an extremely high thermal conductance in steady state operation. Hence, a heat pipe can transfer a high amount of heat over a relatively long length with a comparatively small temperature differential [1, 2]. The increasing demand for energy efficiency in domestic appliances (such as a dishwasher, air conditioner, durable drier or fridge/freezer) and industrial systems and devices is the main drive for continuously introducing and/or improving heat recovery systems in these appliances, systems and devices. Heat transfer efficiency in such systems is the primary factor for efficient performance of the whole systems [5].

Fundamental Working Principles of Heat Pipes

Figure .1 shows that, a typical heat pipe consist of three main sections, which include an evaporator section, an adiabatic section, and a condenser section. Heat added at the evaporator section vaporises the working fluid, which is in equilibrium with its own vapour. This creates a pressure difference between evaporator section and condenser section, which drives the vapour through the adiabatic section. At the condenser section, heat is removed by condensation and is ultimately dissipated through an external heat sink. The capillary effect of the wick structure will force the flow of the liquid from condenser to evaporator section.

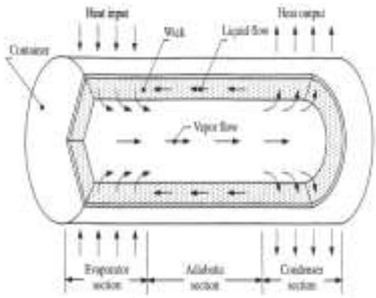

Fig .1 Heat pipe Construction and Operation

Heat pipe operates on a closed two-phase cycle and utilizes the latent heat of vaporization to transfer heat with a very small temperature gradient. Heat pipe consists of three main parts, which are the vessel, wick structure and working fluid. The vessel or a container is normally constructed from glass, ceramics or metal. Where else wick structure is constructed from woven fibreglass, sintered metal powders, screen, wire meshes, or grooves. Finally, typical working fluid used varies vary from nitrogen or helium for low temperature heat pipes to lithium,

Tele:
E-mail addresses: alagumurthi@pec.edu

potassium or sodium for high temperature. In order to fabricate a working heat pipes, all three parts are given important consideration to the material type, thermo physical properties and compatibility.

Heat pipe is capable of creating its own capillary pressure at the evaporator end. This would cause a continuous flow of liquid in the wick and replenish the liquid at the evaporator zone. Heat flows through evaporator section and condenser section assumed to be adiabatic. Due to this reason, the vapour experiences a negligible temperature drop. Generally heat pipes exhibit thermal characteristics that are even better than a solid conductor of the same dimension. As for wick structure, the working fluid travels from the condenser section to the evaporator section. The working fluid should be evenly distributed over the evaporator section. In order to provide a proper flow path with low flow resistance, an open porous structure with high permeability is desirable. This is to ensure that the working fluid returns from the condenser to the evaporator.

Limitations on Heat Transport Capacity

Heat pipe performance and operation are strongly dependent on shape, working fluid and wick structure. Certain heat pipes can be designed to carry a few watts or several kilowatts, depending on the application. The effective thermal conductivity of the heat pipe will be significantly reduced if heat pipe is driven beyond its capacity. Therefore, it is important to assure that the heat pipe is designed to transport the required heat load safely. But during steady state operation, the maximum heat transport capability of a heat pipe is governed by several limitations, which must be clearly known when designing a heat pipe. There are five primary heat pipe transport limitations;

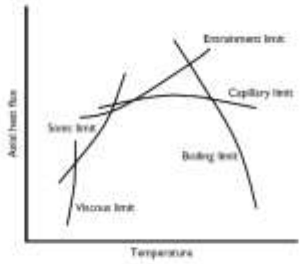

Fig .2 Limitations to heat transport in a heat pipe

Viscous limit

Viscous force will prevent vapour flow in the heat pipe. This causes the heat pipe to operate below the recommended operating temperature. The potential solution is to increase the heat pipe operating temperature or operate with an alternative working fluid.

Sonic limit

Vapour will reach sonic velocity when exiting the heat pipe evaporator resulting at a constant heat pipe transport power and large temperature gradient. The main reason is the power and the temperature combination. In other words, the heat pipe is due operating at low temperature with too much of power. This is a normal problem during a start-up. The potential solution for this limitation is to create large temperature gradient so that heat pipe system will carry adequate power as it warns up.

Entrainment limit

This is where high velocity vapour flow prevents condensate vapour from returning to evaporator. The main reason is due to low operating temperature or high power input that the heat pipe is operating. To overcome this, the vapour space diameter or the operating temperature is increased.

Capillary limit

It is the combination of gravitational, liquid and vapour flow and pressure drops exceeding the capillary pumping head of the heat pipe wick structure. The main cause is the heat pipe input power exceeds the design heat transport capacity of the heat pipe. The problem can be resolved by modifying the heat pipe wick structure design or reduce the power input.

Boiling limit

It is described as a film boiling in a heat pipe evaporator that typically initiates at 5-10 W/cm2 for screen wick and 20-30 W/cm2 for powder metal wicks. This is caused by high radial heat flux. It will lead towards film boiling resulting in heat pipe dry-out and large thermal resistances. The potential solution is to use a wick with a higher heat capacity or spread out the heat load.

Parametric Study

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 thermosyphon action is maximum for a vertical heat pipe and stops for a horizontal heat pipe and heat transfer takes place purely by axial conduction. When the charge amount was smaller, there was more space to accommodate vapor and make the pressure inside heat pipe become relatively lower. It helped nanofluid undergo vaporization and enhance its heat transfer performance [6].

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% [8].

The optimum filling ratio of charged fluid in the tested heat pipe was about 0.45 to 0.50 for both pure water and Al2O3-water based the nanofluid, respectively [9]. The experimental results indicate that the filling ratio and the heat input have the important effects on the heat transfer performance and the optimal performance of the HP was found when the filling ratio ranged between 50–75%, at 50o inclination angle, while the minimum performance was found when the filling ratio was 25% and 25o inclination angle [10]. In general, fill ratios of working fluid greater than 85% of volume of evaporator show better results in terms of increased heat transfer coefficient, decreased thermal resistance and reduced temperature difference across the evaporator and condenser [11].

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:

a) Groove
b) Wire mesh
c) Powder metal
d) 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.

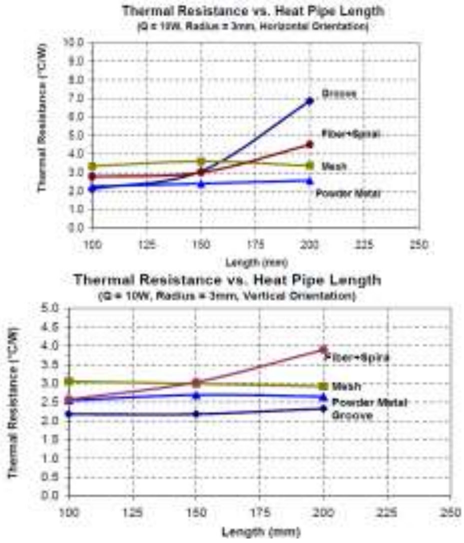

Fig.3.The actual test results of heat pipe with different wick structure at horizontal and vertical (gravity assisted orientations)

A traditional heat pipe consists of a vacuum tight enclosure, with the internal walls lined a capillary structure or wick and the vapour /liquid flow characteristics. The heat pipe is initially fully evacuated and then back filled with enough working fluid to saturate the wick. The pressure inside the heat pipe is equal to the saturation pressure associated with the heat pipe temperature. As heat enters the evaporator, equilibrium is perturbed generating at a slightly higher pressure and temperature, the higher pressure causes vapour to flow to condense and release its latent heat of vaporization, the condensed fluid is then pumped back to the evaporator by the capillary forces developed in the wick structure. This continuous cycle can transfer large amount of heat with very low thermal gradients[12].The temperature gradient associated with this vapour pressure gradient is typically in the order of a couple of degree Celsius [13].

Although the first wicked heat pipe was invented in 1963,it was in the early 1990's that the heat pipe started to be used in high volume consumer electronics .Today, heat pipes are an accepted thermal management tool used in many applications including workstations, mainframes ,power supplies and heat exchangers because of their performance and reliability. Almost every current notebook computer uses a heat pipe to transfer heat from the CPU to the EMI shield of the keyboard and then by natural convection and radiation to the surrounding. This type of passive design has been a very effective thermal management technique for low power CPUs [14].

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 increase in heat pipe wall temperature difference was smaller than that for a pure water filled heat pipe under various heat loads when silver nanoparticles dispersed in working fluid [15]. 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%) [7].

Comparing with the water thermosyphon heat pipe, remarkable increases of the heat pipe rate were observed in the case of the thermosyphon heat pipe with different concentration levels of iron oxide nanoparticles .For example the presence of 2% iron oxide nanoparticles in water results in an increase of the heat transfer rate with 19% [16].The enhancement heat transfer can be approved by changing the fluid transport properties and flow features with nanoparticles suspended. New experimental data on the thermal efficiency enhancement of heat pipe with nanofluids are presented. Effects of %nanoparticles volume concentrations on the heat pipe thermal efficiency are considered. For the heat pipe with 0.10% nanoparticles volume concentration, the thermal efficiency is 10.60% higher than that with the based working fluid [17]. 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. The higher viscosity makes the bubble difficult to produce and the force of friction causes obstruction of the liquid slug with tube wall becomes larger, so obstruction is relatively greater when the bubble is promoted and influences the whole efficiency of the heat transfer [18].

The maximum heat flux apparently increase with the increase of the mass concentration when the mass concentration is less than 1.0 wt.%. Then, they begin to decrease slowly after the mass concentration is over 1.0 wt.%. The mass concentration of 1.0 wt.% corresponds also to the best input power enhancement. The maximum input power of the heat pipe can enhance by 42% after substituting the nanofluid for deionized water [19]. The presence of nanoparticles in the working fluid leads to a reduction in the speed of the liquid, smaller temperature difference along the heat pipe and the possibility of reduction in size under the same operational conditions [20]. When the concentration of added nanoparticles was 3.0 wt.%, the thermal efficiency turned out to be lower than the concentration of 1.0 wt.%. In addition to the influence of the above mentioned absorbability between nanoparticles and water molecules, adding too many nanoparticles to fluid would make the property of working fluid at evaporator section tend to be in solid phase, and would make the convection performance of nanofluid at evaporator section reduced. This was disadvantageous to the thermal efficiency of heat pipe [21]. The thermal resistance of the heat pipes with nanoparticle solution is lower than that with DI water. As a result, the higher thermal performances of the new coolant have proved its potential as a substitute for conventional DI water in vertical circular meshed heat pipe [22].

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 [16]. 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 [23]. 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 [24].

Conclusion

The review reveals that the heat pipe operation is affected by the boiling and capillary limitations. The fluid charge has a direct impact on the void fraction if the evaporator core varies. Results indicate that heat pipe shows greater enhancement in heat transfer when the filling ratio is 40% to 85%. The wick structure has a dominant effect on the heat pipe performance which provides capillary pressure difference for the liquid–vapour flow between evaporator and condenser sections. The fluid selection mainly depends on the operating vapour temperature range; also the primary requirements such as compatibility of the fluid with the heat pipe material should be taken into account. Many articles reveal that nanofluids have greater potential for improving the thermal efficiency of the heat pipe. The orientation of the heat pipe is important for the practical applications: favourable tilt and adverse tilt.It is preferable to operate heat pipe in a favourable tilt position so that heat transfer capacity can be increased.

References:

[1] Firouzfar E., Attaran M., A review of heat pipe heat exchanger activity in Asia, Proceedings of world academy of science, engineering and technology. 2008; 30:1307-6884.

[2] Gaugler, R.S. US Patent 2350348. Appl. 21 Dec, 1942. Published 6 June 1944.

[3] Grover, G.M. US Patent 3229759. Filed 1963.

[4] .Grover, G.M. Cotter, T.P. and Erickson, G.F. Structures of very high thermal conductance. J. App. Phys.1964; Vol. 35, P. 1990.

[5].Sauciue I., Akbarzade A., Johnson P., Chracteristics of two-phase closed thermosuphons for medium temperature heat recovery applications. heat Recovery Systems and CHP.1995; 15(7): P. 631-640.

[6]. Tun-Ping Tenga, How-Gao Hsua, Huai-En Mob, Chien-Chih Chenc Thermal efficiency of heat pipe with alumina nanofluid. Journal of Alloys and Compounds.2010 ; 504S: S380–S384.

[7]. Jian Qu, Hui-ying Wu , Ping Cheng, Thermal performance of an oscillating heat pipe with Al2O3–water nanofluids. International Communications in Heat and Mass Transfer.2010; 37:111–115.

[8].Yu-Hsing Lin , Shung-Wen Kang , Hui-Lun Chen, Effect of silver nano-fluid on pulsating heat pipe thermal performance. Applied Thermal Engineering .2008;28 :1312–1317.

[9].M. G. Mousa, Effect of Nanofluid Concentration on the Performance of Circular Heat Pipe. International Journal of Scientific & Engineering Research.2011; Volume 2, Issue 4.

[10]. Dr. Hussain H.Ahmad Raqeeb H. Rajab, An Experimental Study of Parameters Affecting a Heat Pipe. Al-Rafidain Engineering.2010; Vol.18 No.3.

[11]. A. K. Mozumder1, A. F. Akon1, M. S. H. Chowdhury and S. C. Banik, performance of heat pipe for different working fluids and fill ratios, Journal of Mechanical Engineering, Transaction of the Mech. Eng. Div., The Institution of Engineers, Bangladesh. 2010; Vol. ME 41, No. 2.

[12].Garner .S.D.,Heat Pipes for electronics cooling applications,Electronics cooling.1996; Vol 12,No.3.

[13]. Fashri, A., Washington D.C., Heat Pipe science and technology, Taylor and Francis: 1995.

[14].Ali,A,Dehoff, R,Grubb,K., Advanced heat pipe thermal solution for higher power note book computers,Pan Pacific Symposium Conference,2000.

[15]. Shung-Wen Kang , Wei-Chiang Wei, Sheng-Hong Tsai, Chia-Ching Huang, Experimental investigation of nanofluids on sintered heat pipe thermal performance,Applied Thermal Engineering. 2009; 973-979.

[16].Huminic G, Huminic A, Morjan I, Dumitrache F, Experimental study of the thermal performance of thermosyphon heat pipe using iron oxide nanoparticles.International Journal of Heat and Mass Transfer.2011; Vol.54, No.1-3, 656-661.

[17].Paisarn Naphon , Pichai Assadamongkol, Teerapong Borirak, Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency. International Communications in Heat and Mass Transfer.2008;35: 1316–1319.

[18].Yu-Hsing Lin , Shung-Wen Kang , Hui-Lun Chen, Effect of silver nano-fluid on pulsating heat pipe thermal performance. Applied Thermal Engineering.2008; 28: 1312–1317.

[19].ZhenHua Liu , QunZhi Zhu, Application of aqueous nanofluids in a horizontal mesh heat pipe. Energy Conversion and Management. 2011;52: 292–300.

[20].Maryam Shafahi , Vincenzo Bianco , Kambiz Vafai , Oronzio Manca, Thermal performance of flat-shaped heat pipes using nanofluids. International Journal of Heat and Mass Transfer.2010; 53: 1438–1445.

[21].Tun-Ping Tenga,, How-Gao Hsua, Huai-En Mob, Chien-Chih Chenc, Thermal efficiency of heat pipe with alumina nanofluid. Journal of Alloys and Compounds.2010; 504S: S380–S384.

[22].C.Y. Tsaia, H.T. Chiena, P.P. Dingb, B. Chanc, T.Y. Luhd, P.H. Chena, Effect of structural character of gold nanoparticles in nanofluid on heat pipe thermal performance. Materials Letters.2004; 58: 1461– 1465.

[23].Paisarn Naphon Pichai Assadamongkol, Teerapong Borirak, Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency. International Communications in Heat and Mass Transfer.2008; 35 : 1316–1319.

[24]. Senthilkumar R, Vaidyanathan S, Sivaraman B, Performance Analysis of Heat Pipe Using Copper Nanofluid with Aqueous Solution of n-Butanol. International Journal of Mechanical and Materials Engineering.2010; 1:4.