Methods For Optimal Design And Enhancement of Preformance of Heat Pipe – A Review

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Abstract- *Heat pipes are heat transfer devices that enhances large amount of heat which workson the principle of evaporation and condensation of a working fluid. Heat Pipes are used in many applications all from cooling of the CPU in a computer, space application, energy storage for some solar thermal applications, air conditions etc. Various parameters like, length, inclination angle, working fluids, the filling ratio, wick type and material affect the performance of heat pipe. Hence the combination and selection of above parameters are important for the optimal design of heat pipe. This paper reviews in detail some important design considerations and facts to be considered while selecting the above parameters. Metrics such as thermal resistance, overall heat transfer co-efficient and thermal efficiency were related to the above parameters selections. Further, the scope for improvement of performance of heat pipe using nanofluids and insertion of fins to the heat pipe is also discussed.*

Keywords- Heat Pipe, Inclination angle, Filling ratio, Nanofluids, Thermal resistance and Heat transfer coefficient.

I. INTRODUCTION

To transfer large quantities of heat over large distances at constant temperature without any power input power, a heat pipe with no moving part is used. To manage the transfer of heat between two solid interfaces coherently, a heat transfer device that combines the principle of both thermal conductivity and phase transition. To deal with the high density electronic cooling problem heat pipes are used due to their high thermal conductivity, reliability and low weight. Heat pipes are two-phase heat transfer devices with high effective thermal conductivity. To handle the high heat fluxes heat exchanger with heat pipes are used because of high heat transport.Many researches has been carried out to improve the performance of heat pipe. Of the many factors that affect the performance of heat pipe, some important parameters are, length and diameter, inclination angle, working fluid, filling ratio of working fluid as a percentage of evaporator volume, wick structure. Further gravity assisted heat pipes are more advantage than anti-gravity heat pipes. Selection of working fluid is a fundamental parameter affecting heat pipe's performance. For normal applications, the working fluids must be easily available and economical. They should have a low boiling point and high latent heat for being an ideal one. Researchers [1] conducted experiments with commonly available and cheap working fluids such as acetone, ethanol, methanol and water. They showed water is the best candidate for high heat flux applications. Being more cheap and large availability water can be the first choice ofpreference. In the next step, to enhance the heat transfer performance, use of nanoparticles in the working fluids is another major segment. Researchers [4], [5], [6] studied the influence of titanium, copper and silver nanofluids on the performance. It was found that the use of nanofluids increased the thermal efficiency and reduced thermal resistance significantly when compared to bare working fluids. On average, a thermal efficiency of 60-65% can be achieved. Further the influence of hybrid nanofluids was investigated by [7], and they were able to reduce the thermal resistance by 59% and the capacity of heat pipe was increased beyond 250W.

In a new approach to improve heat pipe performance, [10] studied the effect of finned structures on heat pipes. It was found that overall thermal performance enhanced significantly compared to non-finned heat pipes. This review recommends that the combined integrated performance of heat pipe with nanofluids and finned structures would result in ultimate maximum performance of heat pipe.

II. HEAT PIPE WORKING PRINCIPLE

Figure .1 shows that, e an evaporator section, an adiabatic section, and a condenser section are the three man parts of typical heat pipes. 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 that drives the vapour with the help of adiabatic section. Heat is removed through the condenser section by condensation and is finally 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.

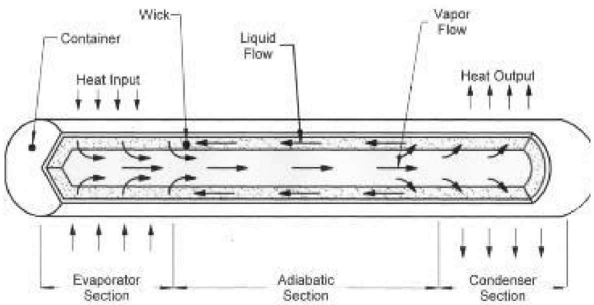

Figure-1NHeat pipe construction and working

Heat pipe works on a closed two-phase cycle and employ the latent heat of vaporization to transfer heat with a very small temperature gradient. Vessel, wick structure and working fluid are the three major component of the system. The material used for the construction of vessel or a container are glass, ceramics or metal. Where else wick structure is constructed from woven fibreglass, sintered metal powder, screen, wire meshes, or grooves. Finally, typical working fluid uses nitrogen or helium for low temperature heat pipes to lithium, potassium or sodium for high temperature. For the construction of 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 reveal thermal characteristics that are even better than a solid conductor for the same dimension. As for wick structure, the working fluid travels from the condenser section to the evaporator section. The working fluid must be distributed evenlyover the evaporator section. In order to provide a proper flow path with low flow resistance, an open porous structure with high permeability is prudent. This is to ensure that the working fluid returns from the condenser to the evaporator.

III. AIM AND OBJECTIVE

The aim of this review is to compile the notable findings of researchers in the field of heat pipe design and serve guidelines and thumb rules to be considered in the design of heat pipes.

The objectives of this review is,

1) To filter the best candidate among the working fluids for common applications of heat pipes, so as to produce a cost effective design.

2) To analyse the performance of heat pipes with nanofluids and compare with bare working fuids.

3) To emphasize the scope for combined performance of nanofluids and finned structures in heat pipe.

IV. LITERATURE REVIEW

Annamalai [1], Presented a paper on"Experimental Studies On Porous Wick Flat Plate Heat Pipe". In this study, the experimental analysis of the thermal performance of flat plate heat pipe of dimensions 133 X 133 X 35 mm was carried out for various heat input rates with different working fluids. Quantity of working fluid charged into the heat pipe is varied and its influence on performance was obtained. Different working fluids have been tested with heat pipe and their performance has been compared. At lower heat flux (1.38-2.73 W/m^2) the fluids such as acetone, ethanol, and methanol are better than water, whereas at higher heat flux (6.38 W/m^2) water is best candidature among these fluids considered. Water being more economical and easy availability will be a suitable choice of working fluid for high heat flux applications.

K. Mozumder [2], Presented a paper on“Performance of Heat Pipe for Different Working Fluids and Fill Ratios”. An attempt is made to design, fabricate and test a miniature heat pipe with 5 mm diameter and 150mm length with a thermal capacity of 10 W. Working fluids such as water, methanol and acetone were studied and compared. The performance of the heat pipe was determined by measure of thermal resistance and overall heat transfer coefficient. The amount of liquid filled was varied and the variation of the performance parameters for varying liquid inventory is observed. Acetone with 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser. In case of water the result showed that it is maximum value of heat transfer co-efficient and minimum of thermal resistance at 85% fill ratio.

R.A. Hossain [3], Presented the works onthe Design, Fabrication and Experimental Study of Heat Transfer Characteristics of a Micro Heat Pipe. In this study the heat transfer characteristics, a micro heat pipe (MHP) of circular geometry having inner diameter 1.8mm and length 150 mm is designed and fabricated. An experimental investigation is carried out also to investigate the performance of the MHP with different experimental parameters like inclination angle, coolant flow rate, working fluid and heat input. Three different types of working fluids are used, such as acetone, ethanol and methanol. The heat transfer characteristics are determined experimentally for different inclination angle and different coolant flow rate at different heat input. Acetone is proved to be better as working fluid.

PaisarnNaphon[4],Presented work on “Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency” In the study the enhancement of heat pipe thermal efficiency with nanofluids with titanium particles was presented. The heat pipe is fabricated from the straight copper tube with the outer diameter and length of 15mm and 600 mm, respectively. The heat pipe with the de-ionic water, alcohol, and nanofluids (alcohol and nanoparticles) are tested. The mixtures of the pure alcohol and nanoparticles with the concentration of 0.01, 0.05, 0.10, 0.50 and 1.0% by volume are prepared using an ultrasonic homogenizer. The titanium nanoparticles with diameter of 21 nm are used in the present study which the mixtures of alcohol and nanoparticles are prepared using an ultrasonic homogenizer. Thermal efficiency of heat increases and reaches maximum upto a tilt angle of 60° for de-ionic water and 45° for alcohol. For de-ionic water thermal efficiency as a function of heat flux increases and reaches maximum when the percentage charge of water is 66%. For mixture of alchol and titanium nano particles the optimal concentration of nanoparticles was 0.10 % for maximum efficiency. The maximum efficiency ranges from 65-70%.

R. Senthilkumar [5] Presented paper on“Experimental analysis of cylindrical heatpipe using Copper nanofluid with an aqueous solution of N-hexanol”. This study investigates the thermal performance of heat pipe using copper nanofluid in N-Hexanol. The cylindrical heat pipe is filled with de-ionized water, copper nanofluid, an aqueous solution of N-Hexanol and copper nanoparticle in an aqueous solution of n-Hexanol separately and tested for its performance. The heat pipe body is made up of copper, with a length of 600 mm outside and inside diameter of 20 mm and 17.6 mm respectively. The use of n-Hexanol in de-ionized water and copper nanofluid enhances the performance of heat pipe. The variation of thermal efficiency with heat flux increases and reaches maximum upto a tilt angle of 45° for allworking fluids. And for the same angle, the maximum efficiency is obtained in copper nanofluid – n-Hexanolmixture. Upto 65% efficiency is obtained. The thermalresistance of copper nanofluid in aqueous solution of n-Hexanol is nearly 80 to 90% less than the DI water.

Shung-Wen Kang [6], Presented paperon “Experimental investigation of silver nano-fluid on heat pipe thermal performance”. The outer diameter and length of the heat pipes used in these experiments were 6 mm and 200 mm, respectively. The heat pipe contained 211 μm wide 217 μm deep grooves. The nanofluid used in this study is an aqueous solution of 35 nm diameter silver nano-particles. The experiment was executed to measure the temperature distribution and to balance the heat pipe thermal resistance using nano-fluid and DI-water. The tested nano-particle concentrations ranged from 1 mg/l to 100 mg/l. At a same charge volume, the measured nano-fluid filled heat pipe temperature distribution demonstrated that the thermal resistance decreased 10–80% compared to DI-water at an input power of 30–60 W. DI-water diluted with 10 nm and 35 nm silver particles were used as working fluids and performance were evaluated. Analogize two nano-particle sizes which uses the thermal resistance value using DI-water, the maximum reduction was 50% (10 nm) and 80% (35 nm), respectively.

Ramachandran.R [7], Presented paperon “The role of hybrid nanofluids in improvingthe thermal characteristics of screen mesh cylindrical heat pipes”.The thermal performance of meshed wick heat pipe by varying the working fluid and heat input by conducting experiments. The heat pipes were fabricated with commercially available straight copper tubes with outer diameter of 12.5 mm, inner diameter 11.5mm with a length 300mm. In this work four screen mesh wicked heat pipes were fabricated and tested. All the heat pipes were tested for heat input from 50W to 250W each with an increment of 50W in each step. The thermal resistance of all the heat pipes charged with different working fluids such as DI water, Al2O3/DI water nanofluid of volume concentration 0.1 % and hybrid nanofluid volume concentration 0.1%(with two different combinations of (Al2O3 50%- CuO 50%)/DI water and (Al2O3 25%- CuO 75%)/DI water)was determined. The maximum percentage reduction was found to be 58.87% for the hybrid nanofluid of (Al2O3 25%- CuO 75%)/DI water compared to base fluid. An important observation from the study is that, use of hybrid nanofluid can raise the operating range of the heat pipe beyond 250W which makes hybrid nanofluid as a potential substitute for the conventional working fluid.

Jung-Shun Chen [8], Presented paper on “The length and bending angle effects on the cooling performance of flat plate heat pipes”. The effects of length and bending angle on the cooling performance of flat plate heat pipes (FPHPs) were examined experimentally in this study. All FPHPs had the same cross sectional area of 50 mm (width) by 2.5 mm (thickness). Experimental results reveals, by increasing the length from 80 to 150 mm, to 200 mm,and to 300 mm, the minimum thermal resistance, Rth(min), increased by the factors of 2.4, 6.0, and 17.9,respectively from that of 0.103 K/W of the 80 mm FPHP. Rise in Rth(min) was observed around the length of 150 mm. For the FPHPs with smaller length than 150 mm, Rth(min) could be smaller than 0.252 K/W. The decrease in maximum heat transport capability Qmax was observed from 109.5 to 49.6W(a factor of about 0.452) when the length was increased from 80 to 150 mm, and then slowly decreased to the minimum value of 35W (a factor of about 0.318) for the length of 300 mm. In contrast, the results of bending angles showed that by increasing the bending angle, the thermal resistance decreased; Rth(min) reduced by a factor of about 3.3from 0.6207 K/W of 0° bending to 0.1885 K/W of 90° bending. The corresponding maximum effective thermal conductivity, Keff(max), increased from 1933.4 to 6365.6 W/m K and Qmax increased from 45 to 85 W. This showed, a short FPHP preformed better than those of longer ones,and the thermal performance of FPHPs could be enhanced by proper bending.

Hamid Reza Goshayeshi [9, Presentedpaper on "Experimental study on the effect of inclination angle on heat transfer enhancement of a ferro fluid in a closed loop oscillating heat pipe using magnetic field". The study utilizes a oscillating heat pipe of length 380mm, inner diameter 1.75mm and outer diameter 3mm. This paper elaborates on the findings of study on the effect of Fe_2O_3 or Kerosene nanofluid to the copper closed-loop oscillating heat pipe under the magnetic field for inclination angles ranging from 0° to 90°, under different heat inputs (10–90 W). The heat pipe's heat transfer coefficient was evaluated without and with the magnetic field. It was shown that Fe_2O_3 nanoparticles could improve the thermal resistance and after which thermal performance and also pipe's heat transfer coefficient, especially under the magnetic field. The critical angle was 75° as the heat transfer coefficient increased due to higher inclination angle.

SalehAlmsater [10], Presented paper on "Performance enhancement of high temperature latent heat thermal storage systems using heat pipes with and without fins for concentrating solar thermal power plants". This paper investigates an approach for reducing the thermal resistance by utilising axially finned heat pipes. A numerical model simulating the phase change material melting and solidification processes has been developed. The results show that by adding four axial fins and including the evaporation and condensation, the overall thermal performance of the storage system is enhanced significantly compared to having bare heat pipes. After 3 h a total of 106% increase in energy storage is obtained during the charging process. The results proves that the combined effect of incorporating the evaporation/condensation process and adding the fins leads to athreefold increase in the heat storage during the first 3 h. During the discharge process, there was a 79% increase in energy discharged and also the combined effect of incorporating the evaporation/condensation as well as adding the fins results in an almost four fold increase in the heat extracted within the first 3h.

Table-1. Comparison of dimensions, working fluid and result

S.No	Author	Dimensions	Working fluid	Results
1.	Annamalai	Length – 133mm Width – 133mm Height – 35mm Flat heat Pipe	Acetone, ethanol, methanol and water.	At lower heat flux (1.38-2.73W/m^2) the fluids such as acetone, ethanol, and methanol are better than water, whereas at higher heat flux (6.38 W/m^2) water is best candidate.
2.	K. Mozumder	Diameter – 5mm Length – 150mm	Water, methanol and acetone.	Optimal filling ratio for best performance for acetone and water are 100% and 85% respectively.
3.	R.A. Hossain	Diameter – 1.8mm Length – 150mm	Acetone, ethanol, and methanol.	Acetone was the better working fluid.
4.	Paisarn Naphon	Outer Dia – 15mm Length – 600mm	De-ionic water, alcohol and nanofluids (alcohol + titanium nanoparticles)	Thermal efficiency of heat increases and reaches maximum upto a tilt angle of 60° for de-ionic water and 45° for alcohol. For mixture of alcohol and titanium nano particles the optimal concentration of nanoparticles was 0.10 % for maximum efficiency. The maximum efficiency ranges from 65-70%.
5.	R.Senthilkumar	Outer Dia – 20mm Inner Dia -17.6mm Length – 600mm	De-ionized water, copper nanofluid, aqueous solution of n-Hexanol and copper nanoparticle in an aqueous solution of n-Hexanol.	The use of n-Hexanol in de-ionized water and copper nanofluid enhances the performance of heat pipe.
6.	Shung-Wen Kang	Outer Dia – 6mm Length – 200mm	Silver nano-fluid (aqueous solution) and DI water.	Upto 80% reduction in thermal resistance obtained using silver nano fluids when compared to DI water.
7.	Ramachandran.R	Outer Dia -12.5mm Inner Dia -11.5mm Length – 300mm	DI water, Al2O3 nanoparticle aqueous solution and hybrid	Hybrid nanofluid gives the maximum performance. They even extend the heat pipe capacity beyond 250W.

V. CONCLUSION

In this paper effort has been made to review various work carried out by researchers in the the field of heat pipe technology. Focus is made especially on factors influencing the performance of heat pipe. How factors such as inclination angle, working fluid and dimensions affect the heat transfer and thermal resistance and their optimal values are reviewed. This work could serve as a standard reference and gives important thumb rules to be used while designing heat pipe. Further the impact of nanofluids and hybrid nanofluids on the performance is also dealt in detail. Further, this promises for a new scope where combined effect of nanofluids and finned structures would result in ultimate maximum performance of heat pipe.

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