Study of Parameters Affecting the Thermal Performance of Heat Pipe-A Review

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***Abstract*— Heat pipes are the heat transfer devices that enhances larger amount of heat which performs on the principle of evaporation and condensation of a working fluid. The working fluids with their reliable properties are shortlisted. The data presented in this study will serve as a good database for the researchers. This paper gives detailed literature review about the main factors like thermal resistance, heat transfer capacity, heat transfer coefficients, heat pipe material/container, wick/capillary structure, working fluid, filling ratio and tilt angle affecting the thermal performance of heat pipe. There are wide applications of heat pipe in electronic cooling, aerospace, heat exchanger, machine and equipment cooling, temperature control and isothermolization etc.**

Keyword: Heat Pipe, Wick Materials, Working Fluids, Filling Ratios, Tilt Angle.

I. INTRODUCTION

Heat pipe is an evaporation-condensation device used for transferring heat in which the latent heat of vaporization is to be transported heat over long distances with a corresponding small temperature difference. 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 transferred to the condenser region where the vapors condense release the heat to the cooling media [1]. A heat-transfer device is made of a sealed metal tube with an inner lining of wick like capillary material and a small amount of fluid in a partial vacuum where heat is absorbed at one end by vaporization of the fluid and it get released at the other end by condensation of the vapour [2].

A Heat Pipe is also called as thermal superconductors because they are capable to transfer large amounts of heat over relatively large distances with small temperature differences between the heat source and heat sink. The amount of heat transferred by these devices is of variable magnitude and greater than pure conduction through a solid metal. Heat Pipe enhances their properties effectively and lower cost in much thermal management and heat recovery systems.

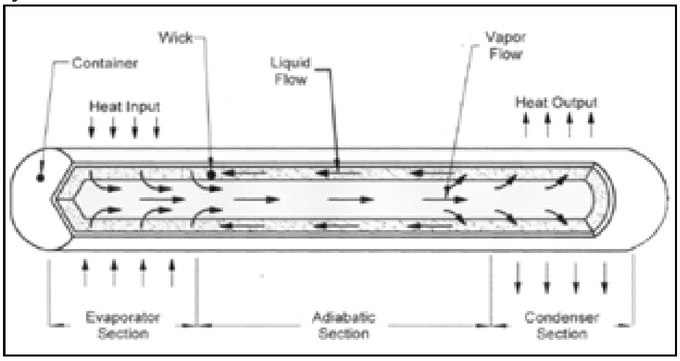

Figure 1: Standard Heat Pipe

These are used in various applications but not limited to passive ground/road anti-freezing, baking ovens, heat exchangers in waste heat recovery applications, water heaters and solar energy systems and they shows some perfection in high-performance electronics thermal management which are orientation specific [3].

II. LITARATURE REVIEW

Extensive research has been done in exploring the applications and usage of the heat pipe in coming years. Papers published are focusing on multiple orientations of heat pipe applications and its performances in electronic packaging industry. The literature review presented in this research paper covers the scope of steady state, transient state and studies on flat plate and circular heat pipes:

A. S.H. Noie, M.H. Kalaei and M. Khoshnoodi: The heat transfer characteristics of a two-phase closed thermosyphon were studied over a wide range of heat transfer rates, system pressure, aspect ratios and fill ratios. The experiments concentrated on the boiling-condensation heat transfer characteristics of a thermosyphon with a copper tube having inside diameters 25 mm and outside diameters 32 mm. Distilled water was used as the working fluid. The experimental boiling and condensation heat transfer coefficients inside the thermosyphon were compared with the existing correlations. A good agreement between the experimental results of condensation heat transfer of the thermosyphon and Nusselt's correlation was obtained. The optimal working fluid filling and the overall heat transfer coefficient was evaluated for practical operation. Finally, according to poor agreement between the experimental results of boiling heat transfer coefficient and existing correlations, the working conditions were analyzed and a new practical correlation was formulated [4].

B. S.M. Peyghambarzadeh, S. Shahpouri, N. Aslanzadeh and M. Rahimnejad: In the paper the authors made heat transfer performance of a 40 cm length circular heat pipe having screen mesh wick is experimentally investigated. This heat pipe is made of copper with two diameters; larger in the evaporator and smaller in the adiabatic and condenser. Three different liquids including water, methanol, and ethanol are separately filled in the heat pipe. Low heat fluxes are applied (up to 2500 W/m^2) in the evaporator and constant temperature water bath is used at three levels including 15^{0}C, 25^{0}C, and 35^{0}C in the condenser.

Results illustrate that higher heat transfer coefficients are obtained for water and ethanol in comparison with methanol. Further increase in heat flux increases the evaporator heat transfer coefficient. For the case of methanol, some degradation in heat transfer coefficient is occurred at high heat fluxes due to the surface dry out effect. Increase in inclination angle decreases the heat pipe thermal resistance [5].

C. R. Manimaran, K. Palaniradja, N. Alagumurthi, J. Hussain: In spite of wide application of heat pipe in microelectronics cooling system the trend of the chips performance and power utilization is 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. 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 [6].

D. Indrajeet Bhoite, Avinash Rahane, Dinesh Sode, Chetan Sawant, Prof. Y. R. Ingole and Prof. P. D. Khaire: Experiment was performed out to study the working parameters of heat pipe. In this paper effect of optimum values of heat pipe working parameters namely heat input, flow rate of cooling water and angle of inclination with horizontal on thermal resistance and overall heat transfer coefficient is analyzed using taguchi method. The taguchi method is used to formulate the design of experiment, analyze the effect of working parameters and predict the optimal parameters of heat pipe. It is found that these parameters have a significant influence on performance of heat pipe. The analysis of the taguchi method reveals that, all the parameters mentioned equal contributions in the performance of heat pipe [7].

E. Mozumder1, A. F. Akon, M. S. H. Chowdhury and S. C. Banik: A miniature heat pipe with 5 mm diameter and 150 mm length with a thermal capacity of 10 W. Experiment was conducted with and without working fluid for different thermal loads to assess the performance of heat pipe. The working fluids chosen for the study were same as those commonly used namely, water, methanol and acetone. The temperature distribution across the heat pipe was measured and recorded using thermocouples. The performance of the heat pipe was quantified in terms 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 measured. Finally, optimum liquid fill ratio is identified in terms of lower temperature difference and thermal resistance and higher heat transfer coefficient. The data reported in this study will serve as a good database for the researchers in this field. Overall heat transfer coefficient of the Miniature heat pipe is found to be the maximum for the Acetone as working fluid [8].

F. R. Manimaran, K. Palaniradja, N. Alagumurthi, K. Velmurugan: The performance of the heat pipe is much depends on the filling ratio of the working fluid. An experimental set up was made from a copper tube having an inner diameter of 20.8 mm and outer diameter 22 mm. The Di-water is used as a working fluid. The temperatures at different places on the heat pipe were taken along with the temperature of inlet and outlet of the cooling water. The results represents that the variation of filling ratio, heat input and angle of inclination gives a significant effect on its performance [1].

III. COMPONENTS OF HEAT PIPE

A. Containers
B. Wick or Capillary Structure
C. Working Fluid
D. Fill Ratio
E. Tilt Angle

A. Containers

The function of container is to isolate with the working fluid from the outside environment. It has to therefore leak proof, maintain the pressure differential across its wall, and enable transfer of heat to takes place from and into the working fluid. Selection of material for container is depending on list of different factors. These factors are as follows-

- Compatibility with wick and wall material
- Compatibility (both with working fluid and external environment)
- Strength to weight ratio
- Thermal conductivity
- Ease of fabrication, including machine ability, ductility, welding
- Porosity
- Wet ability [3].

B. Wick or Capillary structure

The purpose of wick is to generate the capillary pressure to transport the working fluid from condenser section to evaporator section.

- It is porous wick structure which is made up of materials like steel, aluminum, nickel or copper.

- It must be able to disperse the liquid round the evaporator to any area where heat is likely to be received by heat pipe.
- Wicks are fabricated with metal foams and more particularly felt which is more frequently used. By changing the pressure on the felt during assembly, various pore sizes can be produced.
- Maximum capillary head can be generated by increasing wick with decreasing in pore size.
- The wick permeability increases with the increasing pore size.
- Another feature of the wick which must be optimized in thickness. The transport capability of heat pipe is increased by increasing wick thickness.
- Other properties of wick are capability with working fluid and wet ability.

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 to another end of the heat pipe via capillary action. Each wick structure has its associated advantages and disadvantages. Every wick structure composed of its own capillary limit. Groove heat pipe has the lowest capillary limit among the four but works best under gravity assisted conditions [3][6][10].

C. Working Fluid

A first consideration in the selection of a working fluid is its operating vapour temperature range from (50 ^{0}C to 150 ^{0}C) where several possible working fluids may exit. Within above temperature limits, several possible fluids may exist and a variety of characteristics must be examined in order to determine the most acceptable fluids for any applications. The primary requirements are:

- Compatibility with wick and wall material
- Good thermal stability
- Wet ability wick and wall material
- Vapor pressure not too high or low over the operating temperature range
- High latent heat
- High thermal conductivity
- Low vapor and liquid viscosities
- High surface tension
- Acceptable freezing or pour point [3] [6].

D. Fill Ratio

Fill ratio is the fraction (by volume) of the heat pipe which is initially filled with the liquid inside the heat pipe. Fill ratio means the percentage of the evaporator volume section that is filled by the working fluids [8]. There are two operational filled ratio limits. At 0% filled ratio, a heat pipe structure acts as a bare tubes having no working fluid where pure conduction mode of heat transfer with a very high undesirable thermal resistance is found. At 100% fully filled ratio, heat pipe is identical in operation to a single phase thermosyphon. The maximum thermosyphon action for a vertical heat pipe is found and stops for a horizontal heat pipe where axial conduction mode of heat transfer takes place. When the charge/fill ratio amount is small there is more space to accommodate vapor and make the pressure inside heat pipe become relatively low [6].

E. Tilt Angle

The orientation plays important role for the operation of a heat pipe. Depending on conditions a heat pipe can operate in horizontal or vertical or inclined position. For the horizontal position gravity has no effect. But in vertical position gravity can assist or oppose to the operation [6]. As the angle changes gravity plays important role. With change in angle the effect of gravity changes and this affects the thermal performance of heat pipe [10]. As the angle changes gravity may help or oppose the working of heat pipe. Depending on this, 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 type 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. In adverse tilt type, evaporator is positioned above condenser. Therefore, gravity opposes the flow of fluid from condenser section to evaporator section. This creates extra drag for capillary pumping pressure to overcome and hence the efficiency of heat pipe decreases. Hence, the heat pipe must be kept in favourable tilt angle for maximum efficiency [6] [10].

IV. APPLICATION OF HEAT PIPE

Heat pipe is very useful in number of field such as aerospace engineering, energy conversion devices, electronic cooling, biomedical engineering etc. Heat pipe of various shape such as flat shaped, disc shaped, rotating, reciprocating heat pipe is used due to its multidimensional nature of application. Carbon steel heat pipe technology is used for utilizing heat pipe as air pre heater and waste heat recovery boiler. Liquid high temperature heat pipe is used for high temperature air generator and heat tractor. Heat pipe is also used in chemical reactor including ammonia convertors [10]. Heat pipe is used in aerospace to cool the satellite solar array. Power industry use heat pipe as heat exchanger like air heaters on boilers. Heat pipe is applied for Machine/equipment cooling, air conditioning precoolers, electric motor, storage batteries, lathe cutting tool, drilling and die casting moulds, space suite temperature control etc. Heat pipe technology is used in black-body radiation cavities, Spacecraft structures, iso-thermalization, Isothermal mounting plates for electronics telescopes, optical equipment Surgical cryoprobe & dermatology, Infra-red detector cryogenic cooling, Laser mirror cooling [11].

V. ADVANTAGES

- High efficiency.
- Simple in construction.
- High heat recovery
- Compactness.
- No moving parts.
- Highly reliable.
- No external power requirement.
- Economical to manufacture.

VI. CONCLUSION

This review paper reveals the detailed analysis on heat pipe on different parameters such as container, wick/capillary structure, working fluid, tilt angle and fill ratios. In evaporator section, the working fluid is evaporated as it absorbs an amount of heat equivalent to the latent heat of vaporization, while in the condenser section the working fluid vapor will be condensed. Liquid is returned from the condenser to the evaporator section by the wick structure. Wick structure is used to generate the capillary pressure to transport the working fluid from condenser section to evaporator section Properties of working fluid affect the heat transfer parameter in case of wick material. Heat pipes are effective heat transfer device which are occurred in many applications in industry. Heat pipes that transport heat from a heat source (evaporator) to heat sink (condenser) over relatively long distance which are passive devices.

REFERENCES

[1] R. Manimaran, K. Palaniradjal, N. Alagumurthi and K. Velmurugan, "An Investigation of Thermal Performance of Heat Pipe Using Di-water", Science and Technology, India 2012.

[2] Per Wallin, "Heat Pipe, selection of working fluid", MVK 160 heat And Mass transfer, May 7, 2012, Lund, Sweden.

[3]C. R. Kamthane and P. M. Khanwalkar, "Development of Enhanced Cross Flow Heat Pipe Hydraulic Oil Cooler", IJPRET, Ahmadabad, Gujarat, India, 2014; Volume 2 (9): PP 218-228.

[4]S.H.Noie, M.H.Kalaei and M. Khoshnoodi, "Experimental Investigation of Boiling and Condensation Heat Transfer of a Two Phase Closed Thermosyphon", IJE Transactions A: Basics. Iran, Vol. 18, No. 1, February 2005 – 1-10.

[5] M.Peyghambarzadeh, S. Shahpouri, N. Aslanzadeh and M. Rahimnejad, "Thermal performance of different working fluids in a dual diameter circular heat pipe", Ain Shams Engineering Journal, Egypt (2013) 4, PP 855–861.

[6] R. Manimaran, K. Palaniradja, N. Alagumurthi and J. Hussain, "Factors Affecting The Thermal Performance Of Heat Pipe –A Review", JERS, New Delhi, India, Vol. III/ Issue II/April-June, 2012.

[7] Indrajeet Bhoite, Avinash Rahane, Dinesh Sode, Chetan Sawant, Prof. Y. R. Ingole and Prof. P. D. Khaire, "Thermal Analysis of Heat Pipe Using Taguchi Method", IJREAT , Volume 2, Issue 2, Apr-May, 2014.

[8] A.K.Mozumder, A.F.Akon, 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, December 2010 , Vol. ME 41, No. 2, PP 96-102.

[9] Navid Bozorgan and Nariman Bozorgan, "Effect of Nanofluids on Heat Pipe Thermal Performance: A Review of the Recent Literature" Analele Universitatii "Eftimie Murgu" Resita Anul XX, NR. 2, 2013, ISSN 1453 – 7397, PP 155-166.

[10] M.N.Khan, Utkarsh Gupta, Shubhansh Sinha, Shubhendu Prakash Singh and Sandeep Pathak, "Parametric Study of the Performance of Heat Pipe – A Review", IJMET, January-February (2013), Volume 4, Issue 1, PP. 173-184.

[11] "Heat Pipes" Prepared By Midwest Research Institute Kansas City, Mo. 64110 for Technology Utilization Office: N.A.S.A Washington, D. C., January 1975, PP 21-22.