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OPTIMUM ANALYSIS OF FLUID FILL RATIO FOR HEAT PIPE

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ABSTRACT

In this paper the effort can be made for experimental investigation on the copper heat pipe. The copper heat pipe is efficient for achieving the maximum heat transfer. The copper heat pipe of suitable dimension is taken into the consideration, in which the working fluid like iron oxide mixed with DI water is used. The performance of copper heat pipe is tested and compared with different two working fluid; also the heat pipe is tested with different filling ratios. Overall the approached is made for improving the performance of heat pipe.

INTRODUCTION

The heat pipe is partially filled with a working fluid and then sealed. The working fluid mass is chosen so that the heat pipe contains both vapor and liquid over the operating temperature range. Below the operating temperature, the liquid is too cold and cannot vaporize into a gas. Above the operating temperature, all the liquid has turned to gas, and the environmental temperature is too high for any of the gas to condense. Whether too high or too low, thermal conduction is still possible through the walls of the heat pipe, but at a greatly reduced rate of thermal transfer. For the heat pipe to transfer heat, it must contain saturated liquid and its vapor (gas phase). The saturated liquid vaporizes and travels to the condenser, where it is cooled and turned back to a saturated liquid. In a standard heat pipe, the condensed liquid is returned to the evaporator using a wick structure exerting a capillary action on the liquid phase of the working fluid. Wick structures used in heat pipes include sintered metal powder, screen, and grooved wicks, which have a series of grooves parallel to the pipe axis. When the condenser is located above the evaporator in a gravitational field, gravity can return the liquid. In this case, the heat pipe is a thermosyphons. The heat pipe is a device that utilizes the evaporation heat transfer in the evaporator and condensation heat transfer in the condenser, in which the vapor flow from the evaporator to the condenser is caused by the vapor pressure difference and the liquid flow from the condenser to the evaporator is produced by the capillary force, gravitational force, electrostatic force, or other forces directly acting on it. The first heat-pipe concept can be traced to the Perkins tube.1,2 Based on the structure, a heat pipe typically consists of a sealed container charged with a working fluid. Heat pipes operate on a closed two-phase cycle and only pure liquid and vapor are present in the cycle. The working fluid remains at saturation conditions as long as the operating temperature is between the triple point and the critical state. a typical heat pipe consists of three sections: an evaporator or heat addition section, an adiabatic section, and a condenser or heat rejection section. When heat is added to the evaporator section of the heat pipe, the heat is transferred through the shell and reaches the liquid. When the liquid in the evaporator section receives enough thermal energy, the liquid vaporizes. The vapor carries the thermal energy through the adiabatic section to the condenser section, where the vapor is condensed into the liquid and releases the latent heat of vaporization. The condensate is pumped back from the condenser to the evaporator by the driving force acting on the liquid. For a heat pipe to be functional, the liquid in the evaporator must be sufficient to be vaporized. There are a number of limitations to affect the return of the working fluid.[14]

DIFFERENT TYPES OF HEAT PIPES

In addition to standard, Constant Conductance Heat Pipes (CCHPs), there are a number of other types of heat pipes,[8] including:

Vapor Chambers (flat heat pipes), which are used for heat flux transformation, and isothermalization of surfaces

Variable Conductance Heat Pipes (VCHPs), which use a Non-Condensable Gas (NCG) to change the heat pipe effective thermal conductivity as power or the heat sink conditions change Pressure Controlled Heat Pipes (PCHPs), which are a VCHP where the volume of the reservoir, or the NCG mass can be changed, to give more precise temperature control Diode Heat Pipes, which have a high thermal conductivity in the forward direction, and a low thermal conductivity in the reverse direction Thermosyphons, which are heat pipes where the liquid is returned to the evaporator by gravitational/accelerational forces, Rotating heat pipes, where the liquid is returned to the evaporator by centrifugal forces.

WORKING PRINCIPAL HEAT PIPE

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 vaporizes 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.

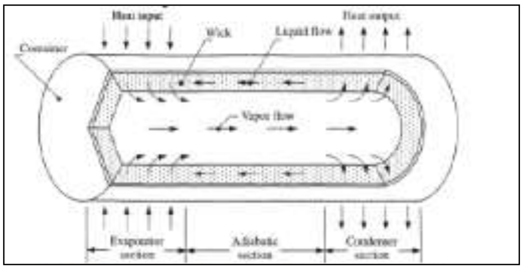

Fig: 1. Circular Heat Pipe Showing Different Sections

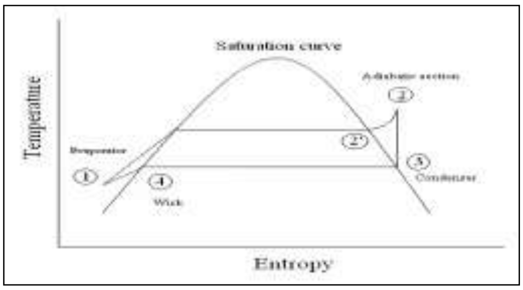

Fig: 2.T-S-Plot for Heat Pipe

1-2 Heat applied to evaporator through external sources vaporizes working fluid to a saturated (2') or superheated (2) vapor.
2-3 Vapor pressure drives vapor through adiabatic section to condenser.
3-4 Vapors condenses, releasing heat to a heat sink.
4-1 Capillary pressure created by menisci in wick pumps condensed fluid into evaporator section.

TECHNICAL PARAMETER AFFECTING THE PERFORMANCE OF HEAT PIPE

The following are some technical parameters that are affecting the performance of heat pipe:
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;

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/cm^2 for screen wick and 20-30 W/cm^2 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

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 thermosyphons. The thermosyphons 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.

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.

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 nano particles dispersed in working fluid.

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; favorable tilt and adverse tilt. Favorable tilt is the tilt position where gravity assists heat pipe operation. In favorable 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.

was set up to investigate the thermal performance of the UTHP samples under the impacts of incremental heat loads. The effects of each processing parameter on the thermal performance of the UTHP samples were analyzed and compared with a mathematical model incorporating effects of the evaporation and condensation heat transfer in a copper-water wick, results indicate that the most critical factor for thermal performance of UTHP is flattened thickness, as it decreases, the heat transport capability drastically decreases and the thermal resistance increases.

IDENTIFYING THE OPTIMUM FLUID FILL RATIO

Comparative plot of temperature difference between the evaporator and condenser section at varying fill ratio of working fluid as a percentage of evaporator volume for all the two working fluids with the heat. Loads of 6 W and 10 W are shown in the figure above. In all the cases nanofluid (DI water mixed with iron oxide) shows minimum temperature differences at all fill ratios. Hence it can be stated that for the temperature ranges tested in this study, iron oxide nanofluid forms the best working fluid. In the case of DI water, the fill ratio has minimum effect on the temperature difference between evaporator and condenser. On the other hand, nanofluid shows reduced temperature difference at higher fill ratios. With iron oxide mixed with DI water as working fluid, 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser.

RESULT AND DISCUSSION

The effect of fill ratio of working fluid on heat transfer coefficients and thermal resistances are shown in Fig 3 and 4.In case of water as working fluid it is observed that it shows maximum value of heat transfer coefficient and minimum value of thermal resistance at 70% fill ratio. Lower and higher than 70% fill ratio results in lower values of heat transfer coefficients and higher values of thermal resistances than that of 70%. So, it can easily be stated that for water as the working fluid, a heat pipe will perform its best at 70% fill ratio.

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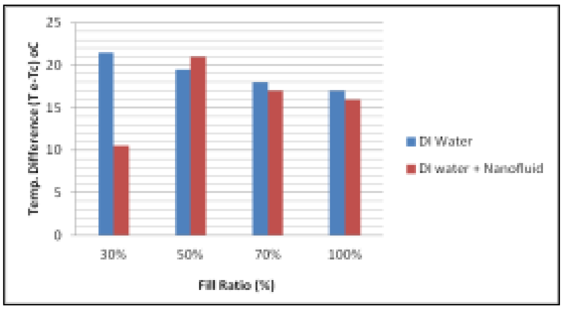

Fig.3. Temperature vs. fill ratio for different working fluids for input heat of 6W

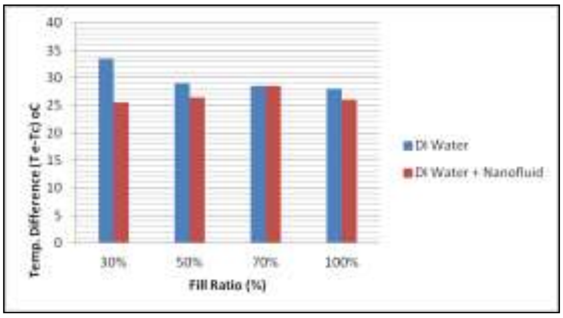

Fig.4.Temperature vs. fill ratio for different working fluids for input heat of 8W

CONCLUSION

A heat pipe of a 10 W capacity has been successfully developed, fabricated and tested. Different operating characteristics are presented at different heat inputs viz, 2W, 4W, 6W, 8W; 10W.The system reaches steady state early in case of wet run when compared to dry run. From the investigation, the following findings are obtained: The steady state temperature increases with increased heat loads. Slope of axial temperature distribution in dry run increases with the heat input, on the other hand the wet run shows an averaged constant temperature slopes.The operating heat pipe with wet run has lesser overall thermal resistance when compared to dry run. For a 2W heat input capacity, the thermal resistance observed in the dry run was 9.25 °C/W and that in wet run was 5.75°C/W. The heat transfer coefficient of heat pipe increases with increase in heat input, in the range of inputs tested for Nano fluid (Fe_2O_3) mixed with DI water; while water filled heat pipe shows a nearly constant value.The heat transfer coefficient of heat pipe with different heating input shows maximum value and lower thermal resistance when DI water mixed with iron oxide nanofluid. The fill ratio of working fluid as a percentage of evaporator volume is shown to have minimum effect on the performance of heat pipe with respect to the temperature difference when water is used as working fluids.In case of Nano fluid mixed with DI water, the temperature difference across evaporator and condenser continues to drop down with an increase in the fill ratio.With Nano fluid mixed with DI water as the working fluid, 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser.In general, fill ratios of working fluid greater than 70% 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.

REFERENCES

1. Saffa Riffat, Recent developments in heat pipe technology and applications: a review, Institute of Sustainable Energy Technology, School of the Built Environment, University of Nottingham, Nottingham, NG7 2RD, UK.
2. X.F. Yang, Z. Liu, J. Zhao, “Heat transfer performance of a horizontal microgrooved heat pipe using CuO nanofluid”, J. Micromech. Microeng. vol.18, 2008, no. 035038.
3. Ryoji Oinuma, Fundamental study of heat pipe design for high heat flux source, Department of Nuclear Engineering, Texas A&M University.

4. R.A. Hossain, M.A.K Chowdhuri , C. M. Feroz Design, Fabrication and Experimental Study of Heat Transfer Characteristics of a Micro Heat Pipe.J.heat and mass transfer,vol.24,2010, Elsevier.
5. Chin-Chun Hsu, Shung-Wen Kang, Performance Testing of Micro Loop Heat Pipes,J.Heat and Mass transfer,Elsevier.
6. M. Ghanbarpour N. Nikkam,R. Khodabandeh and M.S. Toprak, July 2014 "Thermal Performance of screen mesh heat pipe with Al2O3 nanofluid".Int.journal Heat & Mass Transfer, Elsevier Science Direct, Volume 40, Issue 15, July 2014, Pages 445–450.
7. Kyung Mo Kim, Yeong Shin Jeong,InGuk Kim, and In Cheol Bang,Comparison of thermal performances of water-filled, SiC nanofluid-filled and SiC nanoparticles-coated heat pipes, Int.journal Heat & Mass Transfer, Elsevier Science Direct, Volume 45, Issue 15, July 2013, Pages 235-240.
8. Hamdy Hassan and SouadHarmand , Effect of using nanofluids on the performance of rotating heat pipe,Int.J,Applied Mathematical Modelling, Volume 39, Issue 15, 1 August 2015, Pages 4445–4462.
9. Yong Li, Jiabin He and Hengfei He Investigation of ultra-thin flattened heat pipes with sintered wick structure, Int.J.Thermal Engg. Received 25 August 2014, Accepted 9 April 2015, Available online 22 April 2015.
10. K.V. Paiva and M.B.H. Mantelli ,Wire-plate and sintered hybrid heat pipes: Model and experiments.Int.J. Applied Thermal Engineering, Volume 81, 25 April 2015, Pages 51-57.
11. Xinjun Su, ,Ming Zhang,Wei Han and XianminGuo,Enhancement of heat transport in oscillating heat pipe with ternary fluid,Int.J. Applied Thermal Engineering, Received 26 January 2015.
12. Sihui Hong, Xinqiang Zhang, Experiment study on heat transfer capability of an innovative gravity assisted ultra-thin looped heat pipe,Int.J. of Thermal Sciences Volume 95, September 2015, Pages 106–114.
13. Dr.R.N.Panchal , Anant Awasare, P.S.Jadhav, P.R.Pawar, V.M.Jamadar, R.M.Shetenawar, A.M.Zende "Performance in Heat Pipe with Variation of Thermal Resistance DI Water Mixed with Nano Fluid", *International Engineering Research Journal (IERJ),* Special Issue 2017 ISSN 2395-162 Page 94-96.
14. Anant Awasare, Dr.R.N.Panchal, P.S.Jadhav "Analysis of Heat Transfer Coefficient in Heat Pipe" *Journal of Advances in Science and Technology* Vol. 13, Issue No. 1, (Special Issue) March-2017, ISSN 2230-9659 PP: 46-49.