Proceedings of the
International Conference on Mechanical Engineering 2009
(ICME2009) 26- 28 December 2009, Dhaka, Bangladesh

ICME09-TH-18

EXPERIMENTAL INVESTIGATION OF A HEAT PIPE FOR DIFFERENT WORKING FLUIDS AND FILL RATIOS

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ABSTRACT

During last thirty years, component density on integrated circuits has grown from about six thousand on the Intel 8080 microprocessor to over five million transistors on a similar-sized Intel microprocessor. Power and component densities on these integrated circuits have required the development of innovative cooling methods. Miniature heat pipes appear promising for use in microelectronics cooling. The heat pipe though has a wide application; the information available towards the development of an efficient heat pipe is seldom seen in the open literature. In the present study, investigations are carried out for optimizing the fluid inventory in a typical heat pipe. A “flooded” (with exceedingly large amount of working fluid) heat pipe has slow response and has limited lower range of operation in terms of operating temperature. On the other hand, “starving” (with too little amount of working fluid) heat pipe although Exhibits fast response to heat loads, shows severe limit at high temperature conditions. In the present study, an attempt is made to design, fabricate and test a miniature heat pipe with 5 mm diameter and 150 mm length with a thermal capacity of 10 W. Experiments were 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 observed. 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.

Keywords: Miniature Heat Pipe, Working Fluid Inventory

1. INTRODUCTION

Heat pipe is a form of heat exchanger useful for transporting very large quantities of heat with small temperature differences. The heat pipe consists of a hollow tube closed at both ends and partially filled with a liquid that boils at a desired temperature. One end of the tube is immersed in the warm region and the other end in the cold region. The objective is to transfer heat through the pipe from warmer to the colder region. Due to space constraints in most of personal computers and telecommunication systems placed constraints on the size of heat pipes, normally miniature heat pipes of diameter 3 to 6 millimeter and less than 400 millimeters are preferred. The MHP applications for cooling telecom boots and notebooks computers were started in the last decade and now 80% of notebook PCs are using MHP. MHP has unique physical phenomenon contrary to micro heat pipes in view of affects of the operating limit, liquid locking, and length. That is, while the liquid blocking phenomenon occurs in the micro heat pipes of less than 1 mm, the condenser liquid are accumulated at the end of the condenser and heat is not delivered completely. The phenomenon of reducing the vapor temperature and thus reducing the maximum rate of heat transfer occurs in MHP if the condenser is cooled excessively. And there appear significant effects caused by the entire length of a heat pipe and the effect by the capillary limit among operating limits of a heat pipe [1]. The selection of the proper heat pipe cooling solution is dependent upon the developer’s specifications, design constraints and budget. Thermal designers have widely accepted the MHP for their thermal design solution and the utilization as well as area of application of MHP has been increased day by day. But MHP is relatively a new technology; its data and information are quite scarce. So a through comprehension of the heat transfer capability of MHP at different fluid inventory and fill ratio.

Akon and Chowdhury [2] found that 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. A heat transfer analysis of an inclined two-phase closed thermosyphon was developed by Zuo and Gunnerson [3]. The inclination-induced circumferential flow was unfavorable with respect to dry out because the thin top-side liquid film was easier to boil off, but contrastingly was favorable with respect to flooding because the thick underside film corresponded to a large gravity force. Minimum working fluid inventory remained almost constant for a large range of inclination angles (0-70 ^{o}) and then significantly increased for further increase of inclination angle. At a certain inclination angle, the mean heat transfer coefficient of the thermosyphon reached a maximum value, which was related to the heat transfer behavior in both condenser and evaporator. The highest flooding limit was at inclination angle ranging from 30 to 45 o, which corresponded to the best balance of the two opposing effects: secondary circumferential flow and gravity reduction.

Zhang and Wong [4] studied heat transfer and fluid flow in an idealized micro heat pipe with the support of NASA and LaSPACE. They made an analysis for four different values of length to width ratio of an idealized micro heat pipe, viz. 20, 50, 100, and 200. From the liquid temperature distribution along the length of the micro heat pipe, they found that the temperature profile is relatively flat except the region near the evaporator, and for a micro heat pipe with larger length to width ratio, the length of the evaporator is shorter. From the vapor pressure distribution, they found that the pressure goes approximately linearly and is not strongly affected by the length to width ratio. On evaluating the effective thermal conductivity of a micro heat pipe increases with increase in the evaporation area at the evaporator, and length or width of the micro heat pipe. They also added that a fluid with larger latent heat would produce larger effective thermal conductivity.

A network heat pipe concept employing the boiling heat-transfer mechanism in a narrow space was investigated by Cao and Gao [5]. Two flat-plate wickless network heat-pipes (or thermal spreaders) are designed, fabricated, and tested based on this concept. The fabricated thermal spreaders, which are made of copper or aluminum, are wickless, cross-grooved heat transfer devices that spread a concentrated heat source to a much larger surface area. As a result, the high heat flux generated in the concentrated heat source may be dissipated through a finned surface by air cooling. The network heat pipes are tested under different working conditions and orientations relative to the gravity vector, with water and methanol as the working fluids. The maximum heat fluxes achieved are about 40W/cm^2 for methanol and 110W/cm^2 for water with a total heat input of 393 W.

2. EXPERIMENTATION

The heat pipe was fabricated using a copper tube of 150 mm length and 5 mm inner dia and 8 mm outer dia as shown in (as shown in the Fig.1). Ni-Cr wire having inner diameter 8 mm and length 50 mm was used to make a heater of 230V, 50W capacity and heater was used for providing the required heat source at the evaporator. The evaporator and adiabatic sections of the heat pipe are insulated using asbestos to minimize the heat loss through these portions. Variac and Multimeter were provided to control and measure the power input respectively. K- Type thermocouple wires were used as temperature sensors. A simple 8- channel digital temperature indicator is used to measure the temperature. Five copper fins of length 50mm, width 15 mm, and thickness 0.5mm were brazed on the condenser end. Experiments were conducted with dry run (i.e. without working fluid in the tube) and wet run (with working fluid inside). The heat pipe without working fluid essentially represents metallic conductor. Its performance is considered as the base for the evaluation of heat pipe (i.e. with working fluid in it). The heater is put "on" and the temperature rise was observed at regular intervals till the steady state is achieved, Experiments were repeated for different heat inputs with different fill ratios and various plots were drawn to study the performance of miniature heat pipe to optimize the fluid inventory.

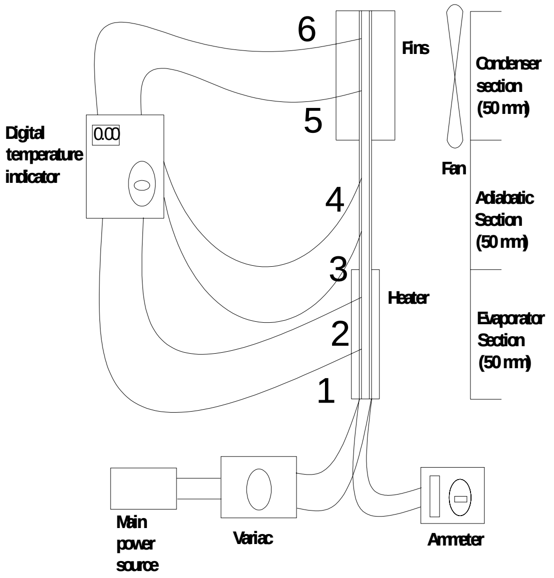

Fig 1. Schematic Arrangement of Experimental Setup

3. RESULTS AND DISCUSSIONS

Experiments were carried out in dry mode (without working fluid) and wet mode (with working fluid in it). The dry mode experiment represents the heat transfer characteristics in an ordinary conductor, while the wet mode depicts the live heat pipe characteristics. Three different working fluids namely distilled water, methanol and acetone which have varying useful working range of temperature are tested in this study. The heat pipe was filled with 35%, 55%, 85% and 100% of the evaporator volume tested for different heat input and working fluids.

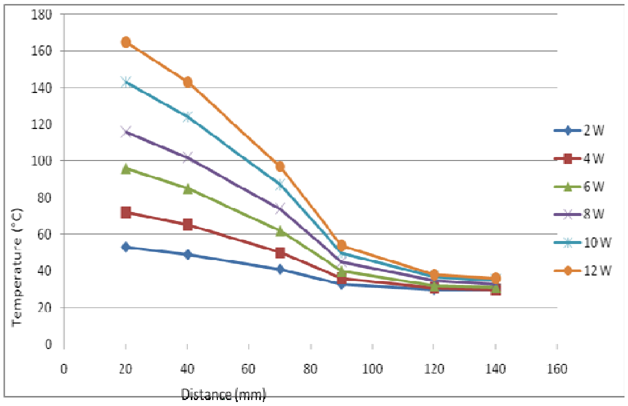

Fig 2. Axial temperature profile for DRY RUN

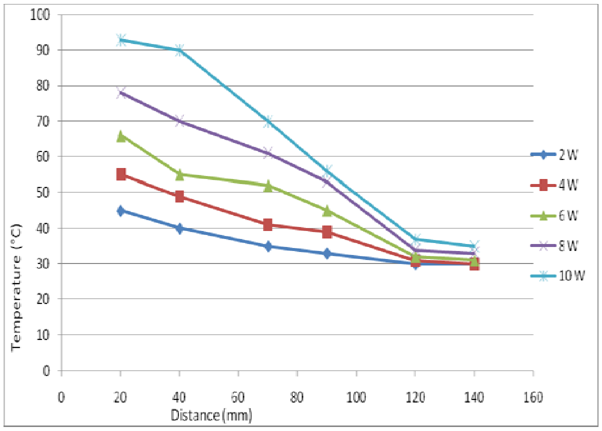

Fig 3. Axial temperature profile for Water With 55% fill ratio

3.1 Axial Temperature Profiles

Axial temperature profiles are drawn from the data of temperatures that is obtained at different axial distances on the heat pipe body. The axial temperature distribution along the heat pipe for dry run and water with 55% fill ratio are shown in Figs. 2 and 3 respectively. It shows that the slope of axial temperature distribution increases with heat input and shows larger temperature differences across the condenser and evaporator section. The trend is obvious since greater temperature slope is required for increased heat transfer in case of simple conduction heat transfer.

On the other hand, water shows reduced slopes of axial temperature distribution at similar heat inputs, indicating the effective augmentation of heat transfer at even reduced temperature slopes.The abrupt change in the slope of axial temperature distribution for water at 10W heat input (Fig. 3) indicates the seizure of heat pipe operation. At this stage, the rate of evaporation at evaporator is higher than condensation rate at condenser. Similar trends are found for all other working fluids.

3.2 Thermal Resistances and Heat Input

The variations of thermal resistances with different heat inputs for dry run and wet run for 35% are shown in above Fig. 4. In general wet run shows the reduced thermal resistances for all levels of heat input and all types of working fluids. The dry run shows the largest values of thermal resistances and it is almost constant for varying heat loads. Acetone shows the minimum thermal resistances at all heat inputs for all fill ratios.

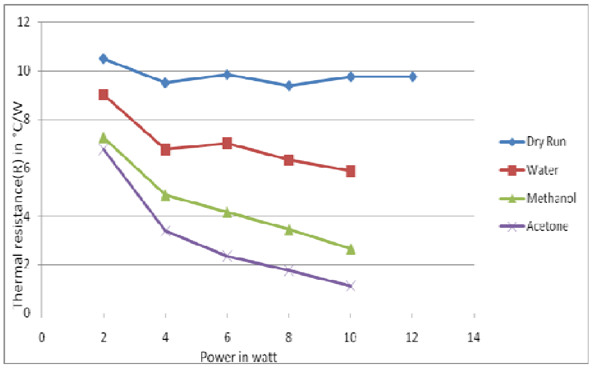

Fig 4. variations of thermal resistances with different heat inputs for 35% fill ratio

3.3 Variation of Heat Transfer Coefficient with Heat Input

The dry run shows an overall heat transfer co-efficient of around 2000 W/m^2-°C corresponding to the forced convective heat transfer at the fin end. When the heat pipe is charged with working fluids, there are remarkable increase in heat transfer co-efficient owing to the augmentation of heat transfer rate by the evaporation and condensation process in side the heat pipe. For 100% fill ratio (Fig. 5), water and methanol shows almost similar pattern of heat transfer co-efficient, but acetone shows greater values for higher heat inputs.

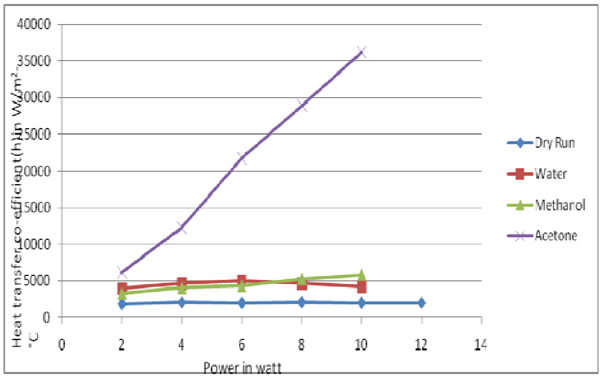

Fig. 5: variations of overall heat transfer co-efficients with different heat inputs for 100% fill ratio

3.4 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 three working fluids with the heat loads of 10 W are shown in the Fig. 6. In case of methanol and water, the fill ratio have minimum effect on the temperature difference between evaporator and condenser. On the other hand, acetone shows reduced temperature difference at higher fill ratios. With acetone as working fluid, 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser.

3.5 Heat Transfer Coefficients and Thermal Resistances

The effect of fill ratio of working fluid on heat transfer co-efficients and thermal resistances for water is shown in Fig. 7. It is observed that it shows maximum value of heat transfer co-efficient and minimum value of thermal resistance at 85% fill ratio. Lower and higher than 85% fill ratio results in lower values of heat transfer co-efficients and higher values of thermal resistances than that of 85%.

4. CONCLUSIONS

i. 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.

ii. The operating heat pipe with wet run has lesser overall resistance when compared to dry run. For a 2W heat input capacity, the thermal resistance observed in the dry run was 10.5 °C/W and that in wet run was 7.25 °C/W.

iii. The overall heat transfer coefficient of heat pipe increases with increase in heat input, in the range of inputs tested for acetone and methanol, while water filled heat pipe heat pipe shows a nearly constant.

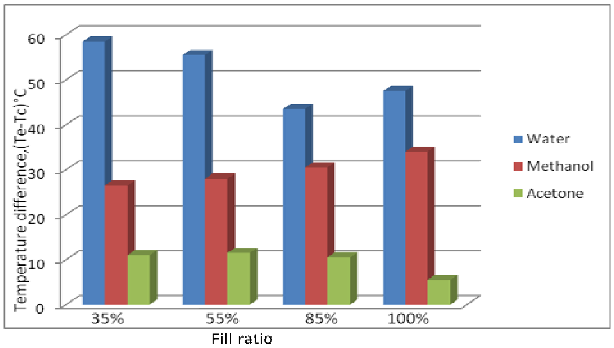

Fig 6. Temperature vs fill ratio for different working fluids for input heat of 10 W

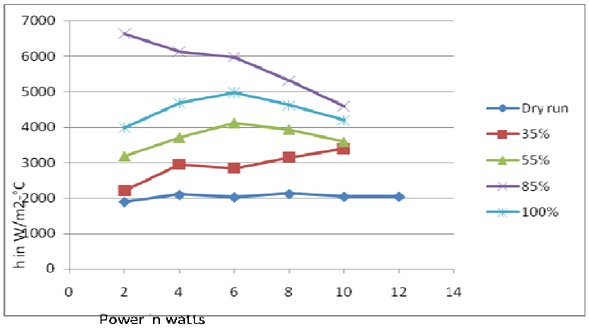

Fig 7. Variations of heat transfer co-efficients with varying heat loads for water

iv. 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 and methanol are used as working fluids. However, in case of acetone, the temperature difference across evaporator and condenser continues to drop down with an increase in the fill ratio. With acetone as the working fluid, 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser.

v. 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.

5. REFERENCES

1. Dunn P.and Reay D.A.,1982, *Heat Pipes*,Pergamon Press New York, Third Edition, 1982
2. Akon, A. F. and Chowdhury M. S. Hasib., “Performance Test of a Heat Pipe for Different Working Fluid and Fill Ratio”, Undergraduate Thesis, Dept. of Mechanical Engineering, BUET, Dhaka, 2009
3. Zuo, Z. J. and Gunnerson, F. S., 1995, “Heat Transfer Analysis of a Inclined Two Phase Closed Thermosyphon”, Journal of Heat Transfer, Vol. 117 pp 1073-1075.
4. Zhang, J., 2002, “M. S. Thesis: Heat Transfer and Fluid Flow in an Idealized Micro Heat Pipe”, *2002 ME Graduate Student Conference*, LSU.
5. Cao, Y.' and Gao, M., “Wickless network heat pipes for high heat flux spreading applications Wickless network heat pipes for high heat flux spreading applications”, International Journal of Heat and Mass Transfer, Volume 45, Number 12, June 2002 , pp. 2539-2547(9)

6. NOMENCLATURE

Symbol	Meaning	Unit
T_e	Average Evaporator Temperature	°C
T_c	Average Condenser Temperature	°C
R	Thermal Resistance	°C/W
h	Overall heat transfer Coefficient	W/m^2-^{0}C
Q	Heat Input	W
A	Heat transfer surface area at the evaporator	m^2

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