International Journal of Life Sciences Biotechnology Pharma Sciences

Volume 11 Issue1, 2023

HEAT PIPE PERFORMANCE WITH VARYING WORKING FLUIDS AND FILL PROPORTIONS

A. K. Mozumdehjk[1,*], A. F. Akonh[1], M. S. H. Chowdhury[1] and S. C. Banik[2]

Article Info

Received: 01- 10-2022 *Revised: 17 -11-2022* *Accepted: 22-12-2022*

Abstract: Miniature heat pipes of 5 mm in diameter and 150 mm in length with a 10 W thermal capacity are designed, fabricated, and tested. Different thermal loads were used in experiments to evaluate heat pipe performance with and without working fluid. Common solvents including water, methanol, and acetone were utilized in the experiment. Thermocouples were used to record the temperature profile throughout the length of the heat pipe. Thermal resistance and the total heat transfer coefficient were used to measure the heat pipe's effectiveness. It was found that the performance characteristics changed depending on the quantity of liquid stocked. Finally, the optimal liquid fill ratio is determined in terms of reduced temperature differential, increased heat transfer coefficient, and decreased thermal resistance. Researchers in this area will benefit greatly from having access to this study's published data. The Miniature heat pipe has its highest overall heat transfer coefficient while using acetone as the working fluid.

Keywords: Heat Exchanger, Supply of Working Fluid, and Filling Efficiency

INTRODUCTION

The heat pipe is a closed, hollow tube filled with a liquid having a boiling point near to the target temperature. The tube is submerged in two different temperatures, one at each end. The pipe's job is to carry heat from the warmer area to the cooler one.Both theoretical and practical studies were conducted to determine heat pipe's dominant factors and defining features.1, 2. Garcia et al. looked into the capillary structure of micro heat pipes to develop a mathematical model and its numerical solution for laminar two-phase flow of liquid and vapor of working fluid. 3. In the mathematical model, the vapor flows in a single dimension while the liquid flows in a quasi-single dimension in a steady state. For a micro heat pipe with a capillary structure with a cross section in the shape of a four-tipped asteroid, the authors provide data on the longitudinal distributions of the mass flow rate, the pressure, and the traverse section area of the phases, as well as the curvature radius of the liquid-vapor interface. Maximum heat transfer capacity in respect to capillary pressure is investigated. Results gained are verified with data given in the specialist literature to ensure the mathematical models are accurate.An analytical formula for the minimal meniscus radius was developed using the momentum conservation and Laplace-Young equations.limit was achieved in micro- and nano-sized heat pipes 4. The impacts of contact angle, vapor pressure drop, tilt angle, groove size, and channel angle were included into these calculations, as were shear forces at the liquid/solid and liquid/vapor interfaces.

In light of the latest experimental results 5, the original analytical model created by Cotter to estimate the maximum heat transmission capacity in micro heat pipes has been reevaluated. Although it produces trends that are inagreement with the actual data, the original model greatly overpredicts the maximum heat transfer capacity since it assumed a fixed evaporator zone, as is the case with most models. A semi-empirical correlation has been created in an attempt to give a more precise forecasting tool.

---

[1] Department of Mechanical Engineering, Bangladesh University of Engineering & Technology,Dhaka-1000, Bangladesh.
[2] Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chittagong, Bangladesh
*Corresponding email: aloke@me.buet.ac.bd

The intricate nature of micro heat pipe heat transfer necessitated the development of a mathematical model 6 to reliably predict the heat transport capacities and temperature gradients that contribute to the overall axial temperature decrease. The model's fluid and heat transfer are regulated using a third-order ordinary differential equation. analytical solution for the two-dimensional heat conduction equation that governs the macro evaporating film region in the triangular corners; effects of the vapor flow on the liquid flow in the micro heat pipe; flow and condensation of the thin film due to surface tension in the condenser; and capillary flow along the axial direction of the micro heat pipe. In comparison to micro heat pipes, the effects of the working limit, liquid locking, and length give MHP its own distinct physical phenomena. In other words, micro heat pipes smaller than 1 mm are susceptible to the liquid blockage phenomenon, which causes condenser liquid to gather at the condenser's outlet and results in incomplete heat transfer. In MHP, if the condenser is cooled too much, the vapor temperature will drop, resulting in a lower maximum heat transfer rate. Significant impacts due to the heat pipe's total length and the capillary limit show, too, among the heat pipe's operational restrictions. 7. The requirements, design restrictions, and financial resources of the project's creators will determine which heat pipe cooling method will be the most suitable. A simple analytical model was created to estimate the performance of counter-flow heat exchanger units using thermosyphon 8, and the properties of such units were tested experimentally. Heat pipes or a two-phase closed thermosyphon are used as the heat-transfer element. No matter the geometry of the element bundle, the maximum heat-transfer rate is proportional to the ratio of the heated-to-cooled lengths of the heat-transfer elements. In their work, Zuo and Gunnerson 9 analyzed the heat transport in an angled two-phase closed thermosyphon. Because the thin layer of liquid on the top side is simpler to boil off, the inclination-induced circumferential flow is bad for drying out but beneficial for flooding because the thick film on the underneath corresponds to a significant gravity force. Cao and Gao 10 looked into a network heat pipe idea that uses the boiling heat-transfer process in a compact area. Based on this idea, two wickless network heat-pipes (or thermal spreaders) are developed, manufactured, and tested. The copper or aluminum thermal spreaders are wickless, cross-grooved heat transmission devices. They disperse a localized heat source across a considerably broader area. Therefore, air cooling may be used to disperse the high heat flux produced by the concentrated heat source. Water and methanol are used to put the network of heat pipes through their paces in a variety of operational situations and orientations with respect to the gravity vector. Total heat input is 393 W, with maximal heat fluxes of roughly 40 W/cm2 for methanol and 110W/cm2 for water.

METHOD OF EXPERIMENT

A copper tube with an inner diameter of 5 mm and an outside diameter of 8 mm is used to create the heat pipe (Fig. 1). An evaporator heater of 230 volts and 50 watts was constructed out of a Ni-Cr wire of 8 millimeters in diameter and 50 millimeters in length. Asbestos is used for insulation in the heat pipe's evaporator and adiabatic sections to reduce heat loss. Both a variac and a multimeter were supplied for use in regulating and monitoring the power supply. We measured temperatures using K-Type thermocouple wires (the positions of the thermocouples are shown in Fig. 1; thermocouple 1 is located 20 mm from the base, while thermocouples 2, 3, 4, 5, and 6 are located at 40, 70, 90, 120, and 140 mm). To get an accurate reading, a simple 8-channel digital thermometer is employed. The condenser end has five copper fins brazed onto it; each fin is 50 mm in length, 15 mm in breadth, and 0.5 mm thick. Both dry run (no working fluid in the tube) and wet run (working fluid present) conditions were used in the experiments. When there is no fluid within the heat pipe, it acts much like a metal conductor. Heat pipes (those containing a working fluid) are evaluated according on how well they operate. Turning the heat "on" and keeping tabs on the steadily rising temperature until a steady state is reached is a common protocol. To optimize the fluid stockpile, the performance of the micro heat pipe was investigated by repeating the experiments with varying heat inputs and fill ratios.

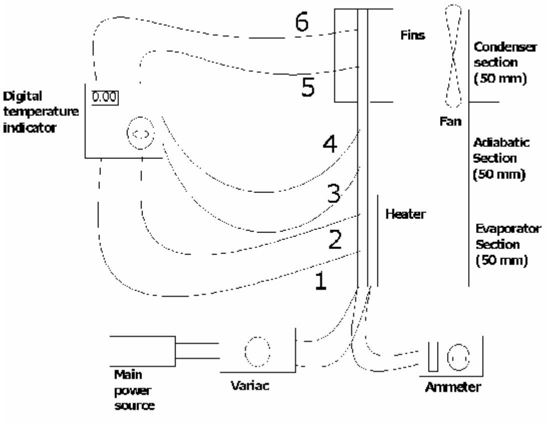


Fig. 1: Schematic Arrangement of experimental setup

METHOD OF EXPERIMENT

Evaporator, adiabatic, and condenser sections are the three components that make up the test section. Three liquids (distilled water, methanol, and acetone) were tested for their heat transfer properties. The properties were also evaluated in a dry run test. This led to the creation of two small heat pipes. Before the real thing provided that both ends of the heat pipe were properly sealed. Both the bottom and the top of the heat pipe that contained liquid were hermetically sealed with corks. The evaporator was wrapped with Ni-Cr thermic wire. The line supply was routed via a variac to power the heater. Forced convection was accomplished by attaching fins to the condenser and pointing a fan in their direction.Glue was used to secure six pairs of thermocouple wires to the chassis. Each set of thermocouples was fused together initially at the top, and it was made sure that, apart from that one location, the thermocouples would not come into contact with one another. They were later joined to the main body. Connecting cables were used to connect the thermocouple probes' other ends to the digital thermocouple reader. Six thermocouples were installed on the heat pipe's outside, two in each of the evaporator and condenser portions. Each segment has thermocouples installed every 20 millimeters.Wet run (with the working fluid within the tube) and dry run (without the working fluid inside) experiments were carried out. When there is no fluid within the heat pipe, it acts much like a metal conductor. The efficiency of the heat pipe (with the working fluid within) is used as a benchmark for its overall rating. Heat was applied to the heat pipe, and the temperature increase was measured intermittently until the system reached steady state. Once equilibrium was reached, the temperatures at each of the six sites were recorded by toggling the selection switch. This procedure was repeated using varying amounts of heat input, fill ratios, and workingfluids. Multiple graphs were generated to analyze the micro heat pipe's operation and determine the best way to distribute the fluid stock. By adjusting the variac's output voltage, we were able to provide varying degrees of heat input.The term "fill ratio" refers to the extent to which the working fluids fill the evaporator section's capacity. Each of the three working fluids was tested at fill ratios of 35%, 55%, 85%, and 100% of the evaporator capacity.After achieving steady state, temperatures were recorded at each of the six locations along the heat pipe's outside for each of the three working fluids and each of the fill ratios.

EQUATIONS USED IN MATHEMATICS

The heat pipe's efficiency is enhanced in a roundabout way thanks to thermal resistance -

Results and Suggestions

Both dry (no working fluid) and wet (with working fluid) experimental conditions were used. Experiments conducted in dry mode are analogous to the heat transfer characteristics of a standard conductor, whereas those conducted in wet mode are analogous to those of a real heat pipe. In this investigation, the temperature-adaptive properties of three commonly used working fluids—distilled water, methanol, and acetone—are compared. Different heat inputs and working fluids were used to conduct experiments in which the heat pipe was filled to 35, 55, 85, and 100 percent of the evaporator volume.Temperature data collected at various axial distances along the heat pipe body is used to construct an axial temperature profile.

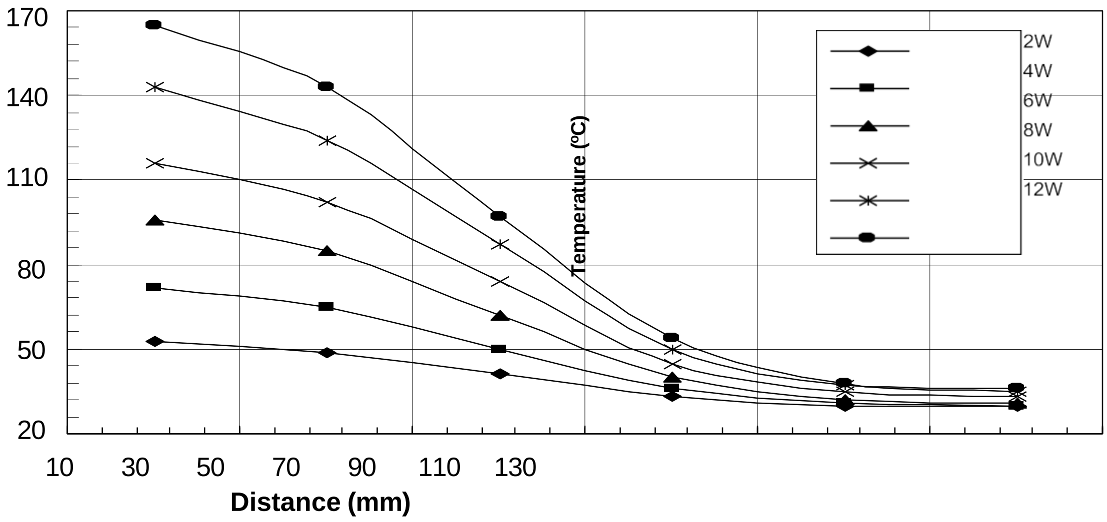
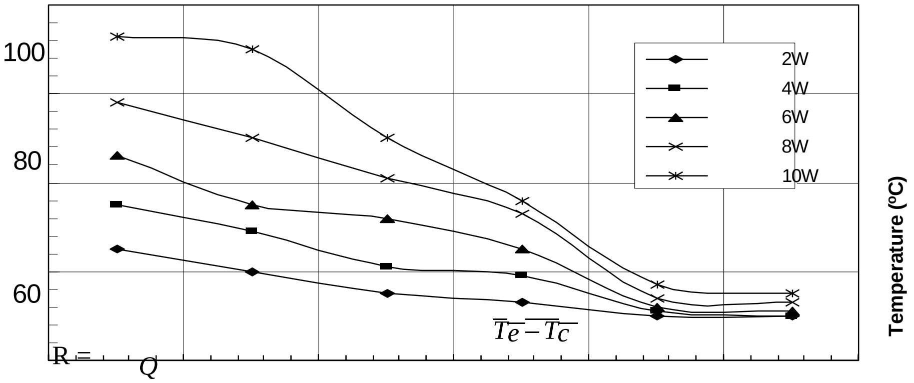


Fig. 2: Axial temperature profile for DRY RUN

Figures 2–5 depict the axial temperature distribution throughout the heat pipe during dry run and wet run (55% fill ratios).

Figure 2 depicts the temperature changes in the evaporator, adiabatic section, and condenser as a function of distance during a dry run. The results demonstrate that when heat is added, the temperature gradient between the condenser and evaporator becomes steeper. Since a steeper temperature gradient is



$$R = \frac{\overline{Te} - \overline{Tc}}{Q}$$

C/W (1)

And the overall heat transfer co-efficient is given by-

Fig. 3: Axial temperature profile for Water With55%fill ratio

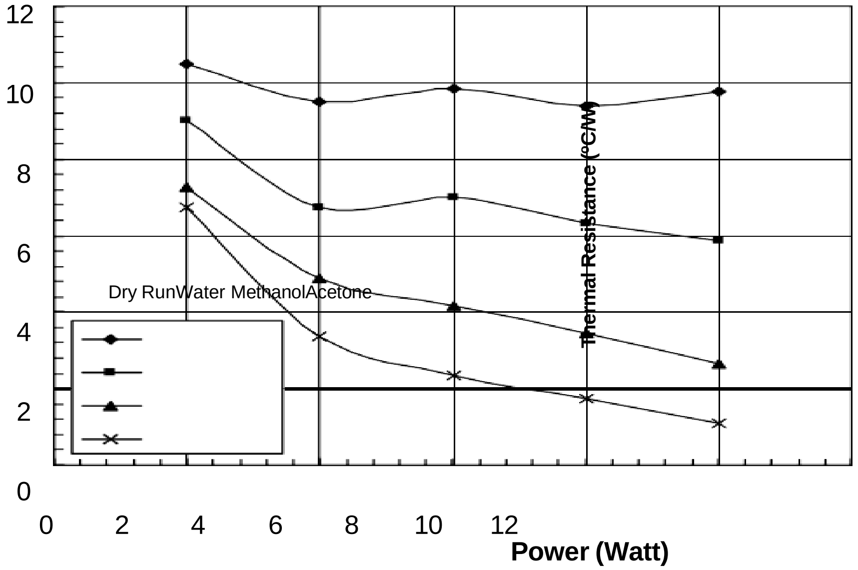


Fig. 4: Axial temperature profile for Methanol With55% fill ratio

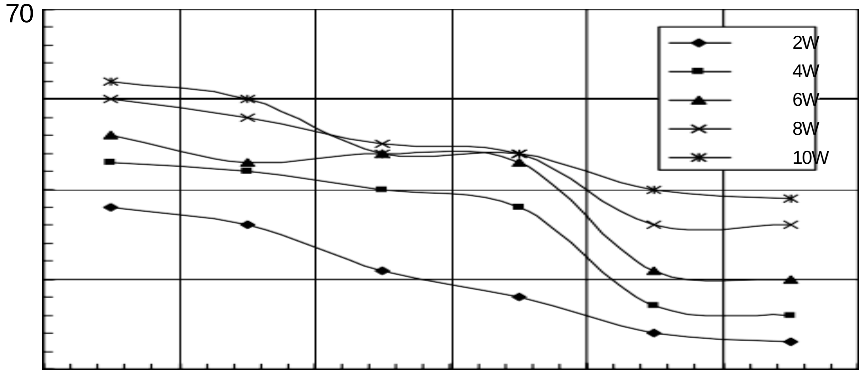


Fig. 6: variations of thermal resistance with differentheat inputs for 35% fill ratio

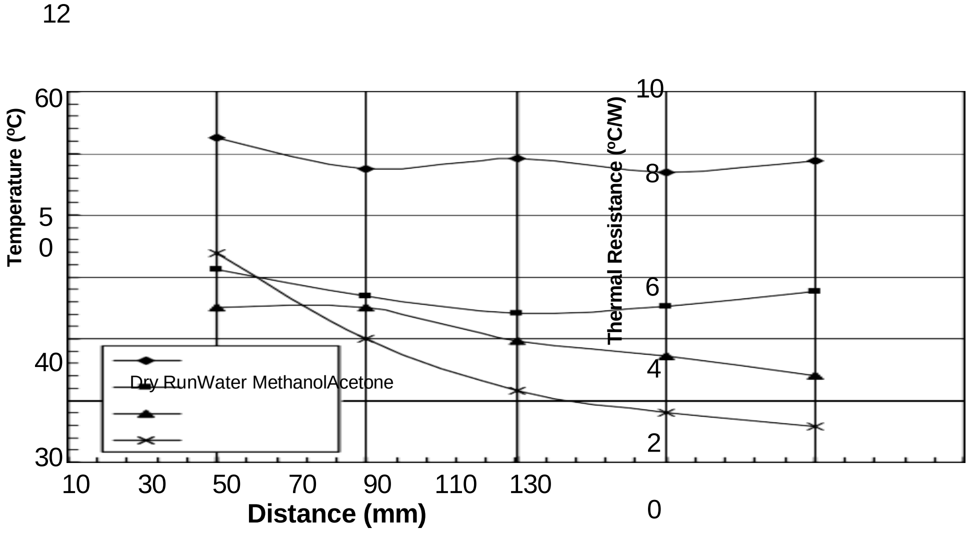


Fig. 5: Axial temperature profile for Acetone With 55% fill ratio

necessary in the case of simple conduction heat transfer to enhance heat transmission.

When compared to dry run, where the axial temperature distribution has steeper slopes for the same heat inputs, the wet run has shallower slopes, suggesting enhanced heat transmission at even lower temperatures.At 10W heat input, the heat pipe stops working as seen by the sudden shift in the slope of the axial temperature distribution for water (Fig. 3). At this point, more heat is lost via the evaporator than is gained by the condenser. All the other working fluids follow the same general patterns.

The slopes of the axial temperature distributions are less for methanol than they are for water or dry run, and they are much smaller for acetone as the working fluid than they are for water or methanol.

Changes in Thermal Resistance (R) as a Function of Temperature: varying fill ratios for the three working fluids result in varying thermal resistances, as shown in Figures 6-8, for the same amount of heat input. These charts are helpful for comparing thermal resistances of various working fluids at varying fill ratios.

Temperature-resistance differences with material

Fig. 7: Variations of thermal resistance with differentheat inputs for 55% fill ratio

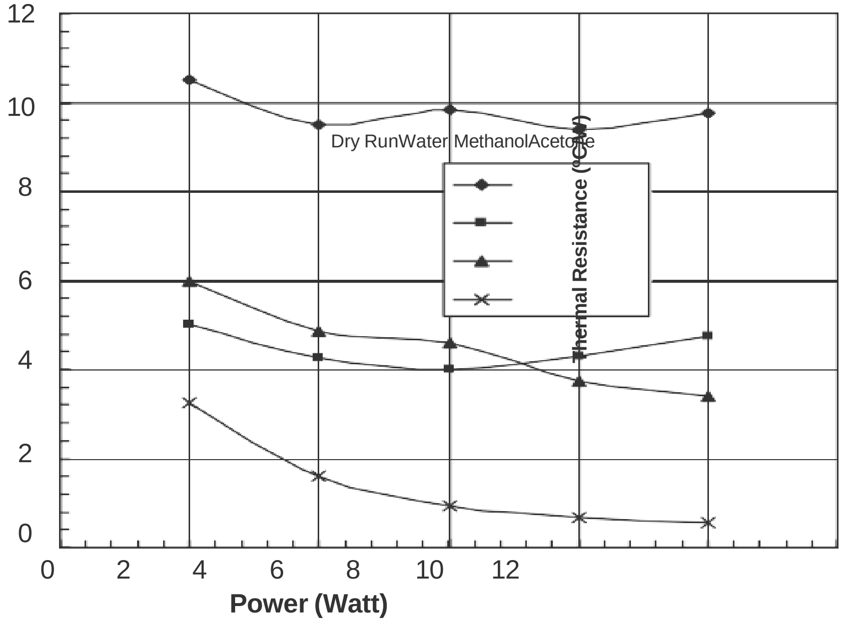


Fig. 8: Variations of thermal resistance with differentheat inputs for 100% fill ratio

Above three figures (Figs. 6-8), we see the heat inputs for dry run and wet run (for 35%, 55%, and 100%). The lower thermal resistances shown in wet run are consistent across heat input intensities and material kinds. liquids used for mechanical operations. The greatest thermal resistance values are seen during the dry run, and they remain almost constant throughout a wide range of heat inputs. Acetone has the lowest thermal resistance for any fill ratio and any heat input. The graph pattern in Fig. 6 shows that, just as with other fill ratios, lower thermal resistances may be produced for larger heat loads when using 35% fill. ratios. Figure 7 shows that at a fill ratio of 55%, the thermal resistance values fall for methanol and acetone but rise for water after 6W. The efficiency of water increases to 6W at 55%.Water and methanol exhibit almost identical thermal resistance values at 100% fill ratio (Fig. 8), but acetone displays minimal values for greater heat inputs.

Variations in the global heat transfer coefficients for a fill factor of one hundred percent

According to the results of the dry run, the forced convective heat transfer at the fin end has an overall heat transfer co-efficient of around 2000 W/m2-°C. By increasing the heat transfer rate via evaporation and condensation inside the heat pipe, charging the heat pipe with working fluids results in a significant increase in heat transfer co-efficient.

Heat transfer coefficients for water at 35% fill ratio (Fig. 9) are almost constant, whereas those for working fluid methanol rise slightly with increasing heat input. The heat transfer coefficient for acetone dramatically rises.

Fig. 9: Overall heat transfer co-efficients withdifferent heat inputs for 35% fill ratio

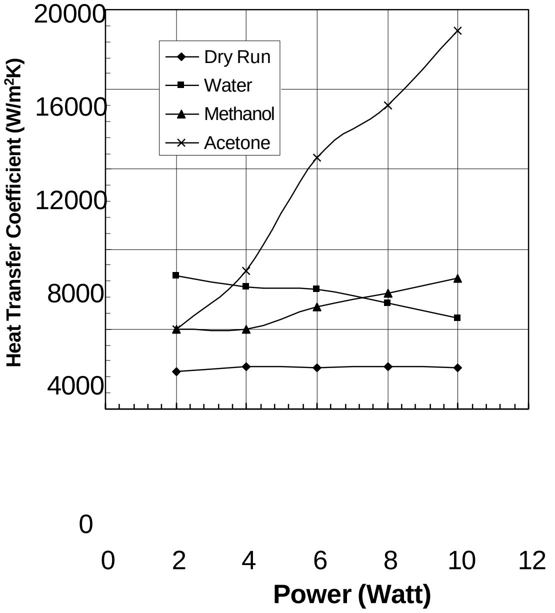


Fig. 10: Overall heat transfer co-efficients withdifferent heat inputs for 85% fill ratio

quickly with enhanced heat capacity.

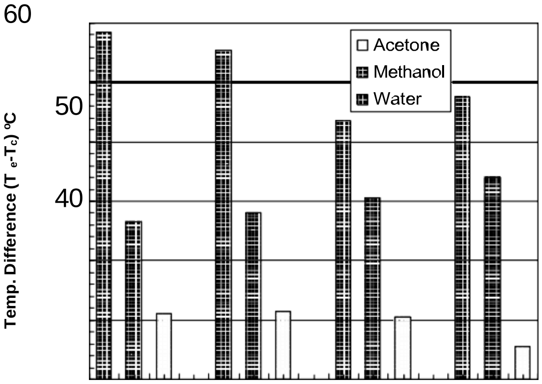
Fig. 10 shows that at a fill ratio of 85%, the heat transfer co-efficient value decreases very slowly for water, grows very slowly for methanol, and increases extremely fast for acetone as the working fluid.

Heat transfer coefficients for water and methanol are quite comparable at 100% fill ratio (Fig. 11), but those for acetone are higher for increasing heat inputs.

Acetone-filled heat pipes have a very high heat transfer coefficient. However, the burn out at maximum heat input limits this monotonic rise in heat transfer co-efficient value with load. It was previously mentioned that this condition leads to "starving" in the evaporator section because the rate of condensate return is lower than the rate of evaporation.

Calculating the Ideal Fluid Filling Ratio

Evaporator-to-condenser temperature differential vs working fluid fill ratio as a percentage of evaporator volume for all three heat transfer fluids.



In Figs. 12 and 13, we have loads of 6 W and 10 W, respectively. At any given fill ratio, acetone exhibits the smallest temperature fluctuations. Acetone was shown to be the most effective working fluid throughout the investigated temperature ranges.

When working with methanol and water, the fill ratio has a negligible impact on the temperature gap between the two phases. At greater fill ratios, however, acetone exhibits a smaller temperature differential. When using acetone as the working fluid, the optimal result is achieved with a 100% fill ratio of the evaporator volume, resulting in a minimal temperature gradient between the two components.

CONCLUSIONS

The design, fabrication, and testing of a miniaturized heat pipe with a power output of 10 W have all met with great success. Various power outputs (2W, 4W, 6W, 8W, and 10W) are shown, each with its own unique operational characteristics.In wet run, the system achieves steady state faster than in dry run. The research yields the following results: When heat loads are increased, the steady-state temperature rises. While the dry run's axial temperature distribution slopes upward in response to added heat, the wet run's axial temperature distribution slopes downward on average. Wet run reduces the total thermal resistance of the working heat pipe compared to dry run. The thermal resistance was 10.5 °C/W in the dry run and 7.25 °C/W in the wet run, both with a 2W heat input capacity. In the range of inputs measured for acetone and methanol, the total heat transfer coefficient of heat pipe rises with increase in heat input, but the value for a heat pipe filled with water remains practically constant. Heat pipe performance in terms of temperature difference is demonstrated to be least affected by the fill ratio of working fluid as a percentage of evaporator volume when water and methanol are employed as working fluids. The acetone fill ratio has a negative effect on the temperature differential between the evaporator and condenser. There is a minimum temperature differential between the evaporator and the condenser when the evaporator is filled to 100% of its capacity with acetone as the working fluid. The heat transfer coefficient, thermal resistance, and temperature differential between the evaporator and condenser all improve with fill ratios of working fluid more than 85% of the capacity of the evaporator.

REFERENCES

[1] July 2009 "study of two phases heat transport capacity in a micro heat pipe", WSEAS Transactions on Information Science and Applications, Volume 6, Issue 7, pp. 1104-1114, ISSN:1790-0832 Hsu, C. H., Kung, K. Y., Hu, S., and Chang, C. C.

[2] In March 1994, "A heat pipe transient analysis model," International Journal of Heat and Mass Transfer, [2] Tourniera, J. M., and El-Genka, M. S.

[3] Pages 753-762, Issue 5 of Volume 37

[4] [3] Universidad, Ciencia y Tecnologia, Volume 4, Issue 14, Pages 59–66, June 2000, "Thermal Fluid Dynamic Steady State Behavior of Micro Heat Pipes" Garcia, F., J. Segura, and S. Zarea

[5] [4] J. Heat Transfer, Vol. 120, No. 1, p. 227 (7 pages), February 1998, Ma, H. B., and Peterson, G. P., "The Minimum Meniscus Radius and Capillary Heat Transport Limit in Micro Heat Pipes," doi:10.1115/1.2830046.

[6] [5] The Heat Transport Capacity of Micro Heat Pipes, by J. M. Ha and G. P. Peterson, J. Heat Transfer, Volume 120, Issue 4, 1064 (8 pages), November 1998, doi:10.1115/1.2825891.

[7] [6] May 1999, Peterson, G. P., and Ma, H. B., "Temperature Response of Heat Transport in a Micro Heat Pipe", J. Heat Transfer, 121(2), 438 (8 pages), doi:10.1115/1.2825997.

[8] The third edition of Heat Pipes by Paul Dunn and David A. Reay was published in 1982 by Pergamon Press in New York.

[9] In February 1978, Lee Y. and Bedrossian A. published "The characteristics of heat exchangers using heat pipes or thermosyphons" in the International Journal of Heat and Mass Transfer (Volume 21, Issue 2), pages 221-229.

[10] The Journal of Heat Transfer, Volume 117, Pages 1073–1075, 1995, "Heat Transfer Analysis of an Inclined Two Phase Closed Thermosyphon" [9] Zuo, Z. J., and Gunnerson, F. S."Wickless network heat pipes for high heat flux spreading applications," Cao, Y., and Gao, M., June 2002 Applications of wickless network heat pipes for dispersing high heat flux, International Journal of Heat and Mass Transfer, 45(12), 2539-2547(9).