Experimental Investigation to Study Effect of Screen Intermeshing on Thermal Performance of Heat Pipe

Ashish Kamble[1], Prof. S. H. Barhatte[2]
[1, 2] Department of Mechanical Engineering
[1, 2] MAEER's MIT College of Engineering, Pune, India

Abstract- *The work presents the investigation of thermal performance of cylindrical heat pipe with multilayer screen mesh wicks which are made of stainless steel. Studies have shown that the use of multilayer channels enhances the thermal performance as compared to single layer by reducing the thermal resistance. Uniform heating was applied at the base end using nichrome heater and an isothermal jacket was surrounded at condenser section. At various heat loads the thermal resistance and heat transfer coefficient measurement was done. The intermeshing was done using screen mesh of 100 and 200 mesh/inch. Three working fluids were again tested against it. The result showed that a considerably low thermal resistance can be obtained for the configurations. No nucleate boiling was considered inside the heat pipe. The possibility of utilizing multiple screen mesh of dissimilar size can be explored.*

Keywords- Multilayer screen mesh wick, stainless steel mesh, porous media, two phase flow heat transfer.

I. INTRODUCTION

The heat pipes [1] are devices of high thermal conductivity which involves two-phase flow heat transfer with minimum temperature differences. They are highly efficient such that they do not involve any moving components neither does require any pumping power. They are reliable and passive devices. As compared to copper, the copper heat pipe with compatible capillary wick structures and suitable working fluids can have the thermal conductivity as high as 200 times as that of copper. The heat pipes consist of three regions viz. the evaporator section, adiabatic section and condenser section. The heat pipes have capillary wick structures on the inner side of the thick wall and a working fluid is charged inside at the evaporator region. When heat is applied at the evaporator region the fluid acquires the latent heat of vaporization and the fluid forms vapour. This vapour than travels through the adiabatic region and towards the condenser region. An isothermal cooling jacket is surrounded at the condenser section which gains the heat and cools the vapour. This vapour then travels back to the evaporator region through the capillary action of the wick which is lined inside the wall. Thus the cycle continues and the evaporation-condensation heat transfer takes place continuously.

Wong et. al [2] in his visualization of evaporation/ boiling phenomena placed two layers of screen mesh in his circular heat pipe. It was during this experiment found out that the nucleate boiling was possible only at a heat flux higher than 15 W/cm2 for the configuration of the heat pipe that he used. The presence of bubbles in heat pipe does not prevent the circulation of the fluid in contrary to as mentioned in the literature surveys and the presence of nucleate boiling improves the thermal performance of the heat pipes. This was as stated by Lips et. al [3] in his experiment with grooved FPHP for observing nucleate boiling at small fluxes. Dry-out also occurs at heat fluxes much higher than the heat flux of onset of nucleate boiling. Wong and Lin's [4] experimental investigation for different working fluid having different figure of merit showed that the surface wettability has an effect on the critical heat loads. Lower wettability causes the reduced critical heat loads for water rather than for working fluids like methanol and acetone. Kemperset al. [5] characterized the individual condenser and evaporator thermal resistances of a copper–water screen mesh wicked heat pipe. They examined the existence of boiling heat transfer in the heat pipe and its importance for the modeling of the heat pipe performance. Their results showed that a composite heat transfer model should be used for wicked heat pipes to take into account that either conduction or boiling can occur in the evaporator, with conduction only at the condenser. Fig. 1 shows the mathematical model of the heat pipe sections showing various region.

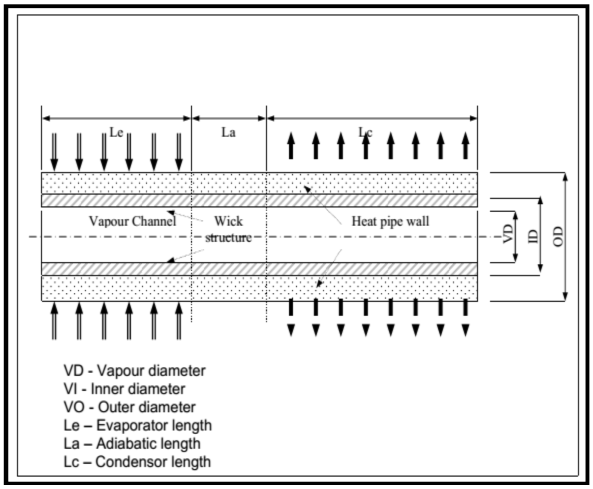

Figure no.1: CAD based model of Heat pipe

II. EXPERIMENTAL

Fig. 2 shows the Heat Pipe test rig. Fig. 3 shows the oxygen-less cylindrical heat pipe designed for the experimental study along with the positions of implanted thermocouples. The heat pipes consisted multiple layers of 100 and/or 200 mesh woven copper wire screen as wick. Three heat pipes were taken for testing during the study of this experiment. The detailed mesh configuration of the three heat pipes is as tabulated in table 1. The heat pipe is a 375 mm long and 39 mm outer diameter brass tube and both the ends sealed with end caps. One end cap carries the filling tube for charging the working fluid. A multi layered stainless steel screen mesh is inserted on inner tube which is 32 mm diameter and is held against it by tension. The Screen mesh heat pipe used consist of a smooth walled tube with a woven copper mesh as the wick structure. This wick structure is created from a metal fabric or mesh, the mesh is wrapped around a forming mandrel which is then inserted into the heat pipe. After placement, the mandrel is carefully removed leaving behind the wrapped mesh. The mesh tries to unwrap itself leaving the wick held by this tension against the inner wall of the heat pipe. The heat pipe is charged with 50 ml of working fluid, which approximately corresponds to the amount required to fill the evaporator. Theoretically, this amount of working fluid is sufficient enough to saturate the wick inserted inside the heat pipe. The working fluid used here are distilled water, methanol and acetone. Before charging the heat pipe is heated to a high degree, to removethe non-condensable present in the tube and then cleaned with acetone and evacuated using vacuum pump to pressure of 25 mm of Hg (vacuum). The evaporator, adiabatic and condenser sections are of length 100, 150 and 125 mm respectively. The detailed dimensions are shown in table 2. Heat input was applied at the evaporator section using a cartridge electrical heater attached to it with proper insulation and the heater has been energized with an AC supply through a variac. The desired heat input was supplied to the evaporator end of the heat pipe by adjusting the variac.

Water jacket was provided at the condenser end to remove the heat from the heat pipe. The cooling condenser was used to condense the vapour. The condenser section was cooled by cooling water. The water chilling unit was fixed at a constant temperature and a cold bath was used to provide cooling water. The temperature measurement of the three heat pipes is done by utilizing 12 thermocouples, each heat pipe having four thermocouples attached.

TABLE I
Characteristic of Different Wick Configurations Used In Heat Pipes

Wick Composition	Thickness (mm)	Porosity
4*200 Mesh	0.33	0.66
100+2x200 Mesh	0.34	0.64
100+200 Mesh	0.26	0.65

Figure no. 2: Experimental Test Rig

Figure no. 3: Heat Pipes used

TABLE II
Dimensions of different section of heat pipes

Specifications	Evaporator section	Adiabatic section	Condenser section
Length (mm)	100	150	125
Internal diameter (mm)	32	32	32
External diameter (mm)	39	39	39
Area (mm^2)	12,252.21	18,378.31	15,315.26

III. DATA REDUCTIONS

The thermal resistance, R_{th} is one of the most important parameters that reflects the performance of heat pipe during the heat transfer tests. The thermal resistance is defined as;

$$R_{th} = \frac{T_e - T_c}{Q_{in}} \qquad (1)$$

The effectiveness of the heat pipe is defined as the ratio of the amount of heat conducted at the condenser section to the amount of heat supplied at the evaporator section. Thus the Effectiveness (η) is given as;

$$\eta = \frac{m.C_p.\Delta T}{Q_{in}} \qquad (2)$$

$$Q_{in} = VI \qquad (3)$$

Heat transfer coefficient, h is given as,

$$h = \frac{1}{A.R_{th}} \qquad (4)$$

IV. RESULTS AND DISCUSSION

In our experiment there was no air leakage into the heat pipe; else its performance would degrade with accompanying abnormal increase in the lateral conduction. The following data presented is free from that problem.

A. Thermal Resistance

Experiments were conducted using various heat pipe wick configuration as shown in Table I.

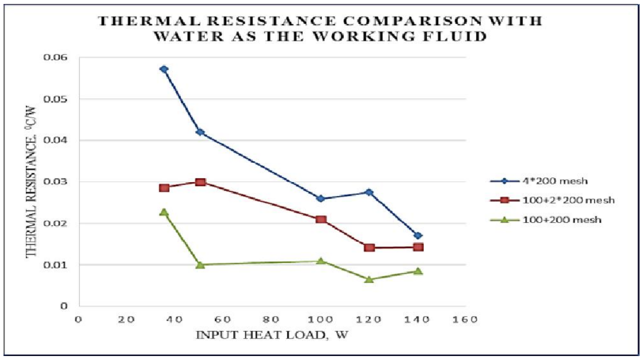

Chart-1: Thermal resistance comparison between heat pipes with water as working fluid.

For a specific wick composition, the heat pipe performance with respect to water was first examined. Chart-1 compares the resistances for different heat pipes with water at various heat loads. The trend of thermal resistance shows that the thermal resistance of heat pipe decreases with the increase of the heat input. The reduction in thermal resistance is due to the activation of larger number of nucleation sites inside the layers of screen mesh in the evaporator section which extends the regime of nucleate boiling to very high heat fluxes. The temperature difference of the evaporator and condenser temperature are very low, which indicates that the heat pipes have a very good isothermal characteristic as in case of water. Thus the thermal resistance is very low in case when working with water as working fluid. Thus further when the heat pipe reaches the heat transfer limit it approaches to a decreasing thermal resistance. All the heat pipes show relatively low thermal resistance. The mesh configuration with 100+200 mesh has the lowest resistance as shown in chart-1.Similar comparison have been done for the wick configuration using methanol and acetone as the working fluid as shown in chart-2 and chart-3 respectively. The analysis shows that the thermal resistance is found to be very low in case of water as compared to the later working fluids. The value of thermal resistance is in the order of 10-2 as compared to that of the value of methanol and acetone. Thus a profound reduction in the value of thermal resistance can be seen in case of using stainless steel-water configuration.

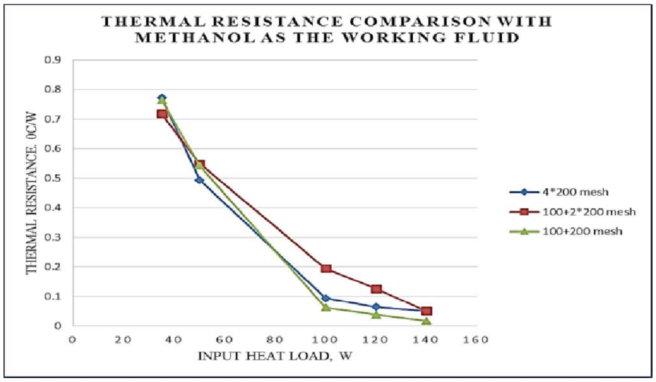

Chart-2: Thermal resistance comparison between heat pipes with methanol as the working fluid.

At a lower heat input, subsequently a small part of upper mesh was exposed and the water surface was very smooth. At this stage the corresponding resistance was very large. With the increasing heat load, the water film recedes into the lower mesh and the resistance reduces concurrently.

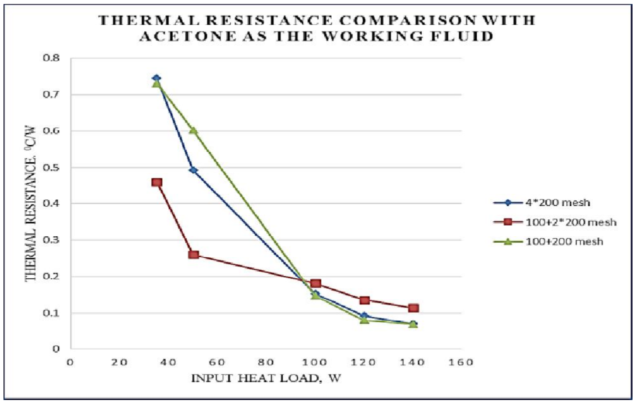

Chart-3: Thermal resistance comparison between heat pipes with acetone as the working fluid

B. Heat Transfer Coefficient:

The comparison for heat transfer coefficient has been done based on the formula as stated in eqn. 4. The data reduction shows an inverse relation with the thermal resistance.

Thus it is evident that for such a relatively small resistance the heat transfer coefficient will be hugely high. Comparing with water, chart-4 the heat transfer coefficient for a relatively low resistance which is 0.005 0C/W. the mesh configuration with 100+200 mesh emerges as the best suitable configuration of heat pipe. This can be attributed to the fact that not only a good capillarity is responsible for a good transfer but also a high permeability in the wick is necessary. The 4*200 mesh has the strongest capillarity but weak permeability and the 100+200 mesh has a good permeability and low capillarity.

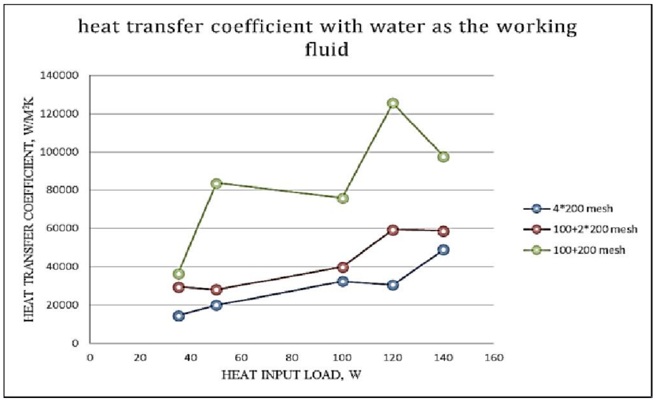

Chart-4: Comparison for heat transfer coefficient with Water as the working fluid.

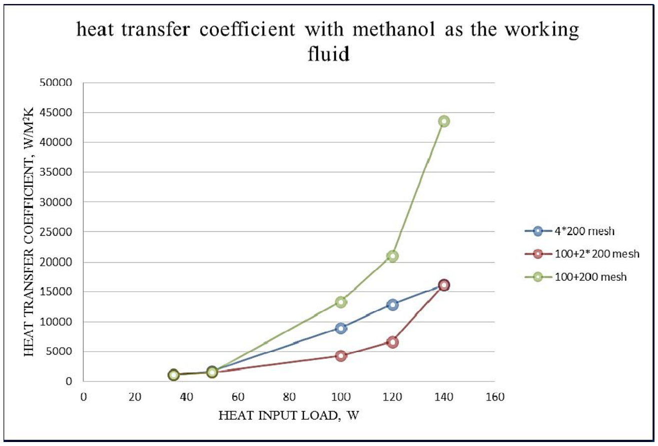

Chart-5: Comparison for heat transfer coefficient with methanol as the working fluid.

While experimenting with the configurations using methanol and acetone as the working fluid chart-5 and chart-6, the evaporator temperature rose suddenly but the condenser temperature increased steadily and slowly. Thus there was not a proper amount of heat dissipation at the terminal and the water bath temperature was sufficiently at the nominal temperature. This can be related to the fact of poor compatibility of stainless steel mesh wick used with the working fluids. Thus the heat transfer coefficient had decreased value as compared to the water.

The reason for the increasing values of heat transfer coefficient is due to increase heat transport capacity. The decrease in thermal resistance leads to increasing heat transfer coefficient.

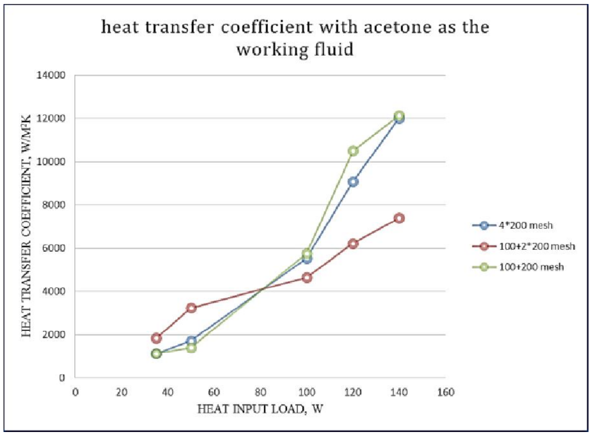

Chart-6: Comparison between heat transfer coefficientwith acetone as the working fluid.

C. Effectiveness Comparison:

The effectiveness comparison for the heat pipes has also been done. By far the major point to be discussed is about the orientation of the heat pipe while discussing the efficiency of the heat pipe. The heat pipes are gravity assisted. Thus the phenomena regarding the pressure drop and vapour flow velocity are difficult to predict and is not in the scope of this context. Thus the efficiency of the heat pipe would not be good enough but a valid comparison is observed between the heat pipes with different working fluid

The effectiveness of the heat pipes with water as the working fluid shows a unique trend wherein the effectiveness is the highest at the low heat loads and decreases gradually as higher load input is applied. This is affiliated to the water-steel combination compatibility. It is been found that the combination of water-steel results in the formation of a thick plunge of hydrogen gas inside. This cold-plunge of gas gets trapped in the condenser section of the heat pipe.

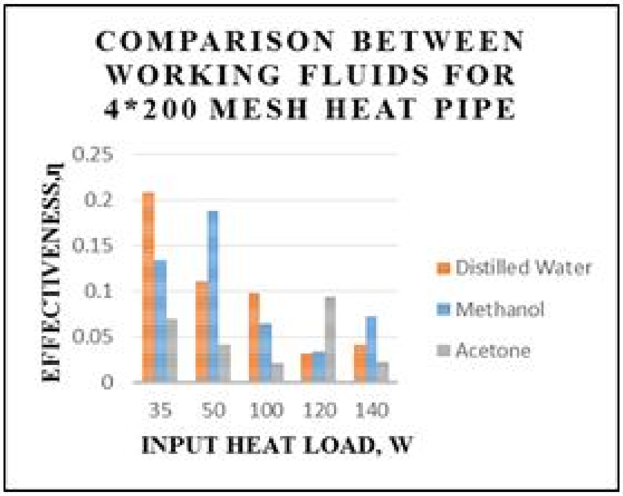

Chart-7: Effectiveness comparison of 4*200 Mesh heat pipe with different working fluids.

As a result it acts as a barrier to remove any excess heat from the inside, thus with the course of time the condenser gets eventually more heated than the evaporator section. The temperature of the evaporator is less than that of condenser at this stage. Thus the effectiveness is affected.

From all the figures, initially it is found that the gravitational force has a significant effect on the flow of working fluid for methanol and acetone between the evaporator and the condenser section along with capillary action of the wick. But with higher loads it tends to decrease, the reason being the formation of liquid film on the inner side of the condenser sectionwhich is at higher rate.Besides, the thermal effectiveness decreases with increasing heat flux due to the decrease in the temperature difference between the evaporator and the condenser section, a constant trend is also observed in case of heat pipes with methanol and acetone.The behaviour is nearly same and can be related to the specific thermo physical properties of the working fluids.

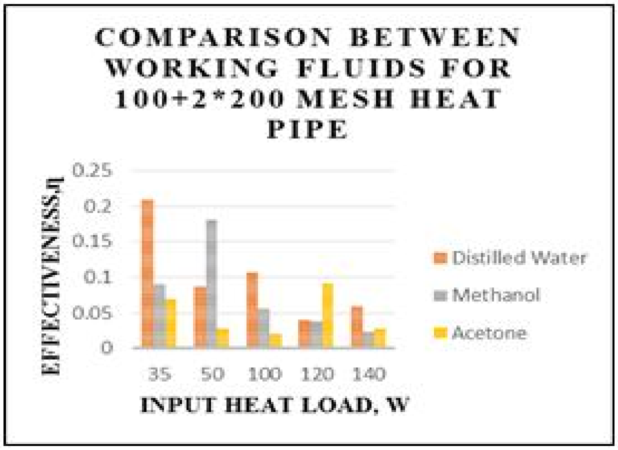

Chart-8: Effectiveness comparison of 100+2*200 Mesh heat pipe with different working fluids.

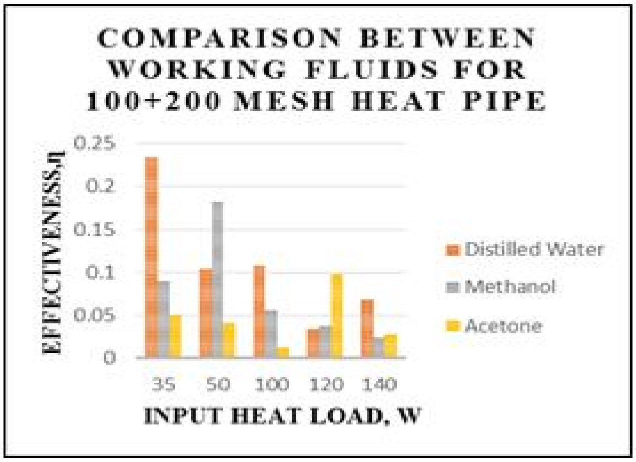

Chart-9: Effectiveness comparison of 100+200 Mesh heat pipe with different working fluids.

The effectiveness for methanol increases steadily for all the heat pipes but at the heat input of 50 W it is more and then with further increase in heat input it decreases. Similarbehaviour is seen as in case of acetone as shown in the chart-7, chart-8 and chart-9.Thus it commonly helps us to predict the suitable working heat transfer limit for the working fluids. Thus effectiveness comparison are important.

V. CONCLUSIONS

In this study, thermal performance of multilayer screen mesh wick heat pipes using three different working fluids namely Distilled water, methanol and acetone were investigated and following results were obtained.

Water emerged as the best working fluid amongst the other fluids in regards with having higher heat transfer coefficient and lower thermal resistance. The heat pipe with configuration 100+200 mesh is found to be the best combination since it has lower capillarity but higher permeability. The thermophysical properties of the working fluid plays a major role, more important being the figure of merit. The effectiveness of the heat pipe is found to be more in case with water at lower heat loads but it consequently decreases with the increasing heat loads. In the study no nucleate boiling was found but quiescent surface evaporation is observed which is in significance with the literature survey too. Low wick permeability limits causes the reduction in resistance and this leads to dry-out. Initially a film of water layer can be imagined on the upper side of the mesh but with the increase in the heat loads this film recedes into the fine corrugated mesh and dry-out takes place. Thus out of the above discussed configurations 100+200 Mesh and water as the working fluid emerged to be the best combination in the experiment.

REFERENCES

[1] Faghri, A., 1995, Heat Pipe Science and Technology, 1st ed., Taylor & Francis, Washington, D.C.

[2] Wong, S.C., Kao, Y.H., Visualization and performance measurement of operating mesh wicked heat pipes, Int. J. Heat Mass Transfer, 51, pp. 4249-4259, 2008.

[3] Lips, S., Lefèvre, F., Bonjour, J., Nucleate boiling in a flat grooved heat pipe, International Journal of Thermal Sciences, 48, pp. 1273–1278, 2009.

[4] Wong SC, Lin YC. Effect of copper surface wettability on the evaporation performance: tests in a flat-plate heat pipe with visualization. Int J Heat Mass Transfer 2011; 54: 3921–6.

[5] Kempers R, Robinson AJ, Ewing D, Ching CY. Characterization of evaporator and condenser thermal resistances of a screen mesh wicked heat pipe. Int J Heat Mass Transfer 2008; 51: 6039–46.