

Comparative Investigation and Operational Performance Characteristics of a Wick Assisted and Axially Square Grooved Heat Pipe

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Abstract- The present work reported here involves the experimental investigation and performance evaluation of wick assisted and axially square grooved heat pipes of outer diameter 8mm, inner diameter 4mm with a length of 150mm. The objective of this work is to design, fabricate and test the heat pipes with and without an axial square groove for horizontal and gravity assisted conditions. The performance of the heat pipes was measured in terms of thermal resistance and heat transfer coefficients. In the present investigation four different working fluids were chosen namely acetone, ethanol, methanol and distilled water. Experiments were conducted by varying the heat load from 2 W to 10 W for different fill charge ratios in the range of 25% to 75% of evaporator volume for wick assisted heat pipe and 8 W to 18 W for axially square grooved heat pipe. From the experiments, it was found that there is a steady increase in temperature with the increase in heat input. The overall heat transfer coefficient was found to increase with the increase heat load for wick assisted heat pipe. In case of axially square grooved heat pipe, an attempt was made to experiment the heat pipe in different orientations. The maximum heat transfer coefficient of 7000 W/m²°C is found for Acetone at 180° orientation.

1. Introduction

Thermal management is a contemporary issue which is increasingly gaining importance in different fields of technology like electronics, aerospace to name a few. Heat pipes have been widely used in ground and



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space applications where efficient and reliable thermal control is required. Heat transfer continues to be a major field of interest to engineering and scientific researchers, as well as designers, developers and manufacturers. The wealth of applications includes a wide variety of components and systems for energy devices, including general power systems, heat exchangers, high performance gas turbines and other power conversion devices. Other areas of interest include chemical processing, general manufacturing, bio-heat transfer, electronic cooling, comfort heating and a number of natural phenomena from upwelling currents in the oceans to heat transport in stellar atmospheres.

Heat pipes are found useful as a cooling means for modern electronic devices which utilize latent heat of vaporization of the working fluid instead of the sensible heat. It is a simple, self-contained device that can quickly transfer heat from one point to another. The effective thermal conductivity of heat pipe may be several orders of magnitude higher than that of the ordinary conductor [1]. At a specified pressure or temperature, the amount of heat absorbed per unit mass of liquid vaporizing is equal to the amount of heat rejected at the condenser. The condensate returns back to the evaporator section along the walls of the heat pipe with the assistance of gravity or due to capillary pumping of the wick. The heat transfer takes place by repeated cycles of condensation and evaporation of the working fluid within a sealed system. Hence the heat pipe transfers higher amount of heat compared to normal conductors with less temperature difference. Heat pipes are often referred to as the 'super conductors' of heat as they possess an extraordinary heat transport capacity.

Extensive theoretical analysis and experimental investigation on the miniature/micro-heat pipe have been conducted by Ma H B and Peterson [2], Wang P et al [3], Khrustalev D and Faghri A [4], North M T, Avedisian [5] and have shown that heat spreading performance comparable to diamond substrates can be achieved. Extensive experimental investigation of flexible bellows heat pipe for cooling discrete heat sources was reported by Babin and Peterson [6]. Three flexible bellow heat pipes of 40mm in length and 6mm in diameter were constructed and tested using three different wick configurations. The test pipes were found to be boiling limited over most of the operating temperature range tested. Heat flux of 200 W/cm² was obtained and thermal resistance of less than 0.7 °C/W was measured. Khrustalev et al. [7] developed a mathematical model for a low temperature axially grooved heat pipe with emphasis on capillary and boiling limitations. Mohammed S et al. [8] studied the uses of liquid metal and water heat pipes employed in space reactor applications. The design of heat pipe is a very complex process involving different physical variables such as the shape, size, weight and volume, thermophysical properties such as working fluid, wicking structure and container material. The thermal loads, transport length, evaporator and condenser length, operating temperature ranges, fluid inventories and temperature environments also play a major role in the design of the heat pipes.

2. Design Considerations

The maximum heat transport capability of the heat pipe is governed by several limiting factors which must be addressed while designing the heat pipe. There are five primary heat transport limitations which include: viscous limit, sonic limit and capillary pumping limit, entrainment or flooding limit and boiling limit. The heat pipe transport limitations are found using appropriate analytical equations and the limits are tabulated and summarized in Table 1 for Acetone:

Table 1. Summary of heat transport limitation of wick assisted heat pipe

Working fluid	Desired Heat Input (W)	Temperature (°C)	Viscous Limit ' q_v ' x 10 ³ kW	Sonic Limit ' q_s ' x 10 ³ kW	Entrainment Limit ' q_e ' W
Acetone	10	40	769.02	313	22
		50	1747	732	26
		60	2986	1302	30

3. Experimental setup

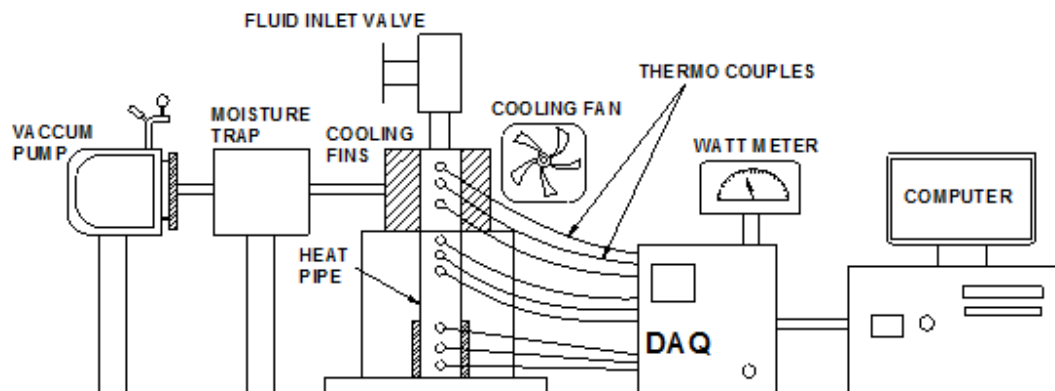


Figure 3. Experimental configuration of a Wick Assisted Heat Pipe

The experimental setup consisted of a container, wick assisted heat pipe, a 15 channel Data Acquisition System and a power supply unit. The experimental schematic of the wick assisted heat pipe is shown in Figure 3. similar set up is considered for axially square grooved heat pipe. The Heat Pipe to be tested is charged with computed amount of working fluid using the charging system. J type thermocouples are used to measure the temperature variations along the pipe are connected to the data acquisition system which records the temperature readings. Wattmeter is used to measure the heat input to the system. The heat pipe is fabricated using a copper tube of inner diameter 4 mm and an outer diameter of 8 mm. The condenser section is brazed with six annularly spaced circular cooling copper fins of diameter 50mm and thickness 1mm. A coil heater made of Kanthal with a rating of 40 W, 400 Ω , 100 V and 50 Hz is used as the heat source. The evaporator and adiabatic sections of the heat pipe are insulated using 20 mm thick glass wool to minimize the heat loss from the outer surface of the heat pipe. Autotransformer and multi meter are provided to regulate the heat input to the heater. Calibrated nine J-type (Iron-Constantan, 1 mm diameter) thermocouples with a temperature range of -40°C to $+750^{\circ}\text{C}$ having a sensitivity of $\sim 52 \mu\text{V}/^{\circ}\text{C}$ are considered for the present investigation. Three

thermocouples each are placed in the evaporator, condenser and adiabatic section. A fan with a duct is placed at the condenser fins to achieve forced convection cooling. The working fluid is metered and charged through the fluid inlet valve with the help of syringe.

3.1 Experimental Procedure

Steady state experiments are conducted to derive various output parameters such as temperature difference, thermal resistance and convective heat transfer co-efficient. Following procedure is adopted during the experimentation.

- Heat pipe is cleaned adopting the procedure discussed in the previous section. The required amount of the working fluid (Acetone, Ethanol, Methanol and Distilled Water) is introduced into the graduated glass tube.
- The valves of the auxiliary glass tube are closed to ensure that the setup is air tight.
- The valve between the graduated glass tube and heat pipe is opened for few minutes to allow the working fluid to be charged into the Heat Pipe.
- Autotransformer is set to the required wattage (2, 4, 6, 8 and 10 W for wick assisted heat pipe) and (8, 10, 12, 15 and 18 W for axially grooved heat pipe) and the data logger application is switched ON.
- The set up is allowed to run until the steady state was reached.
- The experiment is repeated for consistency of results.
- The above procedure is repeated for different parameters.

Experiments are also conducted with dry run for wick assisted heat pipe as well as axially grooved heat pipe (i.e. without working fluid in the tube) as heat pipe without working fluid essentially represents metallic conductor and its performance is considered as the basis for the evaluation of Heat Pipe. In case of axially grooved heat pipe, the heat pipe is evacuated to a pressure of 500 mbar before filling the working fluid.

4. Results and Discussions

Experiments are conducted for wick assisted heat pipe with and without working fluids and variations of temperature with time are recorded. The different working fluids used are Acetone, Methanol and Ethanol. The experiments are conducted with vertical orientation till steady state is reached. The setup is operated with bottom heating mode i.e. evaporator down and condenser up. Experiments are conducted to derive various output parameters such as temperature difference between evaporator and condenser section, thermal resistance and convective heat transfer coefficient. Experiments are repeated for different heat inputs and fill ratios with respect to evaporator volume. Various plots are drawn to analyze the performance of wick assisted heat pipe.

Figure 4(a). represents the variation of thermal resistance with respect to heat input for a fill ratio of 60%. The figure shows a decreasing trend with increase in heat input throughout the operating range. It is also observed that the thermal resistance of Acetone is low compared to Methanol and Ethanol. As the temperature difference between evaporator and condenser is low for Acetone which results in lower thermal resistance.

Figure 4(b). shows the effect of fill ratio on the thermal resistance of the Heat Pipe for various heat inputs. It is clear from the figure that the thermal resistance decreases with increase in heat load for all fill ratios. A significant variation in thermal resistance is observed after 5W of heat input. The fill ratio with 60% indicates better performance.

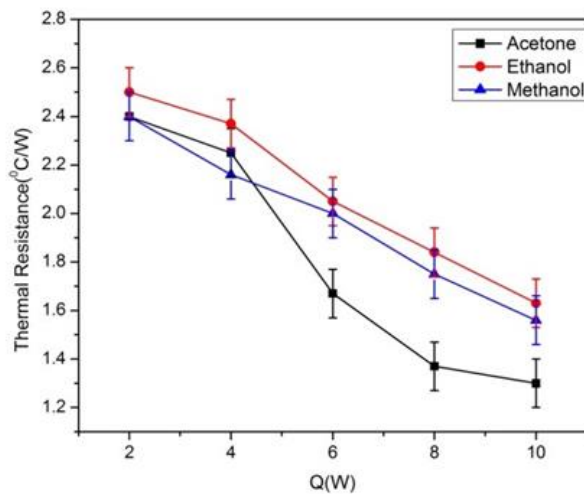


Figure 4(a).

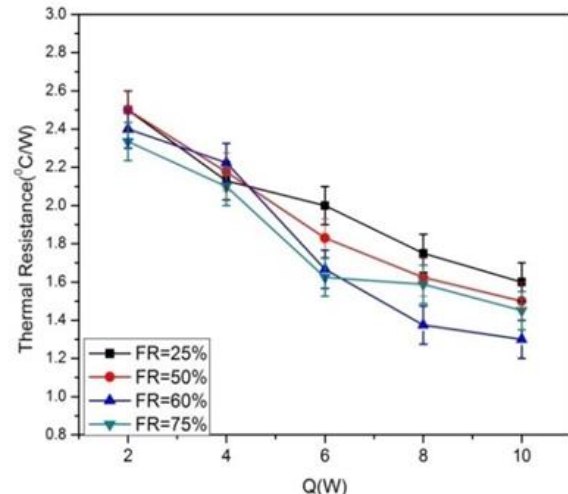


Figure 4(b).

Figure 4(c). shows the variation of heat transfer coefficient with heat input for different working fluids at a fill ratio of 60%. Heat transfer coefficient increases with increase in heat input for all three fluids. Acetone is found to be better working fluid compared to other fluids for all heat inputs due to the fact that temperature difference between evaporator and condenser is lower.

Figure 4(d). shows the effect of fill ratio on the heat transfer coefficient of the Heat Pipe for various heat inputs. It is clear from the figure that the heat transfer coefficient increases with increase in heat load for all fill ratios. The heat transfer coefficient is observed to be better at 60% fill ratio at higher heat input of 6 W, 8 W and 10 W compared to lower heat input. This may be due to the fact that the energy levels for the movement of the working fluid is less at lower heat input which consequently indicates nearly the same values of heat transfer coefficient for all fill ratios. Thus, it is to be noted that the Wick Assisted Heat Pipe is to be maintained at relatively higher fill ratio for effective heat transfer at higher heat loads.

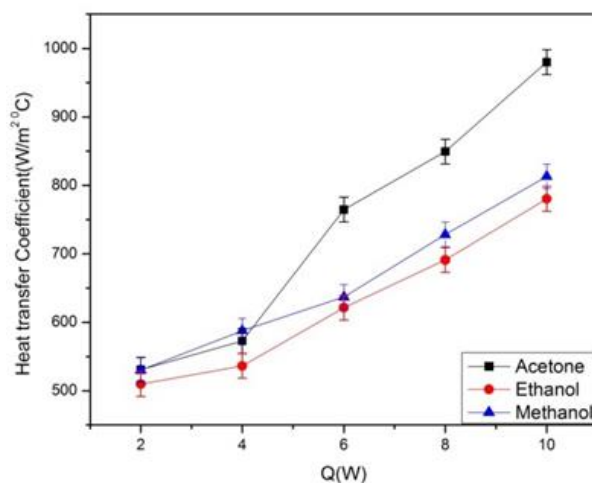


Figure 4(c).

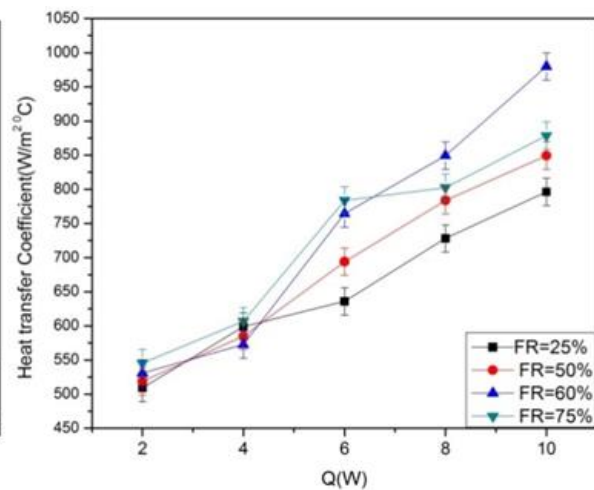


Figure 4(d).

Experiments are also conducted on Axially Square Grooved Heat Pipe with and without working fluids. The working fluids considered in this experiment are Methanol, Acetone and Distilled water with constant vacuum pressure of 500 mbar and fill ratio of 60% for three different orientations. Transient tests are conducted to derive output parameters such as thermal resistance and convective heat transfer coefficient.

Figure 4(e). shows the variation of thermal resistance with heat input for different working fluids at 0° orientation. The variation of thermal resistance for Acetone, Methanol, and Distilled Water shows a decreasing trend with increase in heat input throughout the operating range. It is evident that the thermal resistance of Acetone is lower compared to Methanol and Distilled Water. As the temperature difference between evaporator and condenser is found to be lower for Acetone, which results in lower value of thermal resistance. The figure also shows that the thermal resistance is higher in dry run compared to the wet run operation.

Figure 4(f). shows the effect of orientation on the thermal resistance of the heat pipe for Acetone at various heat inputs. It is clear from the figure that the thermal resistance decreases with increase in heat load for all orientations. A lower value of thermal resistance is observed at 180° orientation compared to other orientation. This indicates that the axially square grooved heat pipe works at 180° orientation with good heat transport capability.

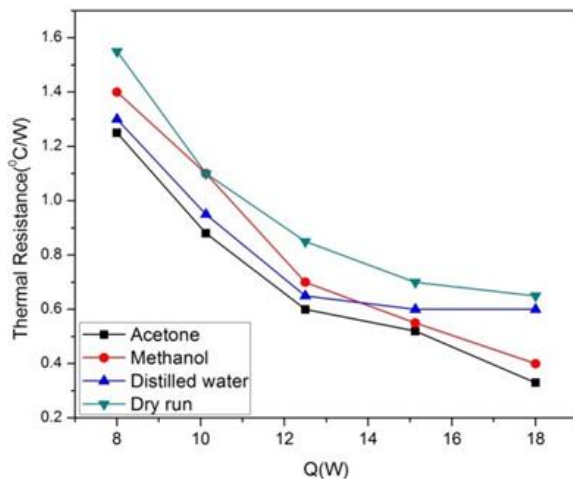


Figure 4(e).

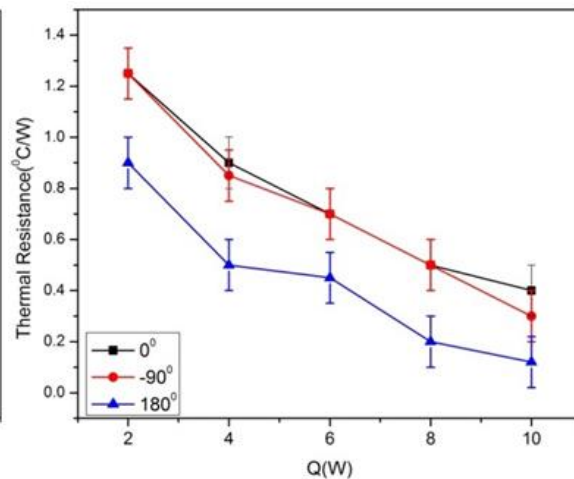


Figure 4(f).

Figure 4(g). shows the effect of heat transfer coefficient with varying heat input for different working fluids at 0° orientation. Heat transfer coefficient for all the three fluids show an increasing trend with the increase in heat input throughout the operating range. Acetone and Distilled water have the higher values of heat transfer coefficient compared to Methanol. This is due to the fact that the temperature difference between evaporator and condenser is lower for acetone and distilled water.

Figure 4(h). shows the effect of orientation on the heat transfer coefficient of the Heat Pipe for Acetone at various heat inputs. It is clear from the figure that the heat transfer coefficient increases with increase in heat load at all orientations. Heat transfer coefficient is observed to be higher for 180° orientation compared to other orientations with Acetone. This indicates that the axially square grooved heat pipe works effectively at an orientation of 180° for effective heat transfer.

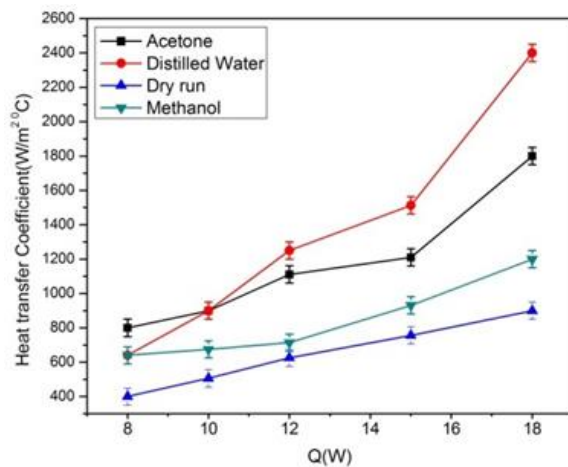


Figure 4(g).

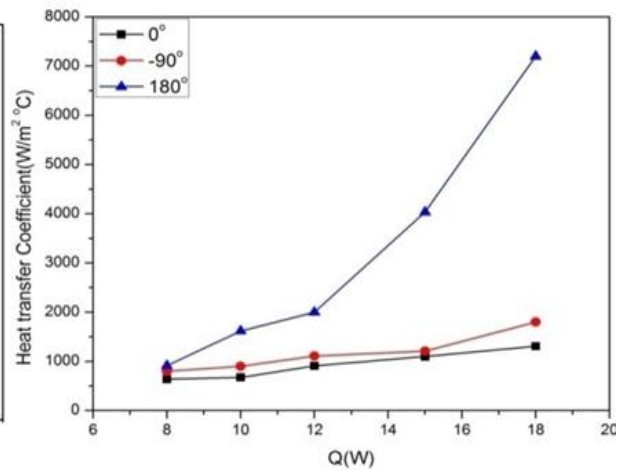


Figure 4(h).

5. Conclusions

In the present research, the characteristics of wick assisted heat pipe and axially square grooved heat pipe are studied. The thermal performances of both heat pipes are studied in terms of thermal resistance and heat transfer coefficient. It is observed that Acetone is the better working fluid in terms of less temperature difference between the evaporator and condenser. Axially square grooved heat pipe is found to be better compared to wick assisted heat pipe in terms of heat transport characteristics. The thermal resistance and heat transfer coefficient found to vary from 0.2 °C /W to 1.5 °C /W and 400 W/m² °C to 7000 W/m² °C respectively.

6. References

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