Thermal performance of a selected heat pipe at different tilt angles

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Abstract. An attempt is made to design, fabricate and test a copper heat pipe with 12 mm diameter, 300mm length and thickness of 1mm with a heat input of 7.29W. Experiments were conducted with and without working fluid for different inclinations to assess the thermal performance of heat pipe. The working fluids chosen for the study are acetone and distilled water and are compared. The thermal performance of the heat pipe was quantified in terms of thermal resistance and overall heat transfer coefficient by measuring temperature distribution across the heat pipe. The heat pipe was aligned for different inclinations and an optimum tilt angle was found experimentally, validated the same with simulation result obtained by computational fluid dynamics analysis and also with a reference paper. The copper heat pipe is found to be effective when acetone is used as working fluid. The optimum inclination angle of heat pipe for maximum rate of heat transfer is found to be 60^o for both the working fluids tested. Even the cost of the heat pipe fabricated is very less compared to the commercial heat pipes available in the market.

1. Introduction

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 vapour flow from the evaporator to the condenser is caused by the vapour 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. Heat pipe technology is used in many applications such as electronic equipments cooling, aerospace applications and solar applications [1, 2]. In general heat pipe is a device which will allow the heat to transfer at a faster rate which is because of the working fluid and its phase change process with in the heat pipe vacuum sealed. Not only the working fluid even the wick structure used for the capillary effect and cyclic process of the phase change of the working fluid is also an important part of the heat pipe. Therefore one needs to know the basic parts of a heat pipe, which includes evaporator section, adiabatic section and condenser section. Within the heat pipe it has a wick structure and working fluid filled. And the most important point to be remembered is that the heat pipe is vacuum sealed. In the present study we have selected a pipe of copper material which has the dimensions of 12 mm diameter, 300 mm length and thickness of 1 mm. We have attempted to check the performance of the heat pipe without wick structure. And then an experimental set up is arranged for obtaining the necessary inputs in getting the results. Once the experimental results are obtained they are compared with the simulation results obtained by computational fluid dynamics analysis. Also the results are validated with a pre-existing paper [3].

2. Experimental set up

Heat pipe is fabricated as per the dimensions mentioned in the introduction section. To close the ends of the heat pipe copper caps are turned on lathe taking a copper rod of 16 mm diameter, shown in figure 1(a).Brazing is done to seal the ends of the pipe with copper caps, shown in figure 1(b).A hole is drilled on one end of the copper cap to inject the working fluid into the heat pipe. Here acetone and distilled water are used as working fluids to fill in the heat pipe. And we have chosen to fill the working fluid in the heat pipe by 20 percent of the total volume. Once the fluid is filled the heat pipe is heated from one end and when the fluid starts boiling the hole of the copper cap is sealed with screw. This is done to create vacuum in heat pipe which is now filled with vapour and the liquid phase of the working fluid. Figure 1(c) shows the heat pipe filled with 20 % of water.

(a) Copper caps (b) After Brazing (c) Heat pipe filled with working fluid, water

Figure 1. Fabrication of heat pipe starting from making of (a) copper caps (b) after brazing and (c) heat pipe filled with working fluid

Figure 2 shows the schematic diagram of the experimental set up which shows the line diagram of the set up as well as the control panel connected to the heat pipe set up. One can observe the inclination of the heat pipe as well.

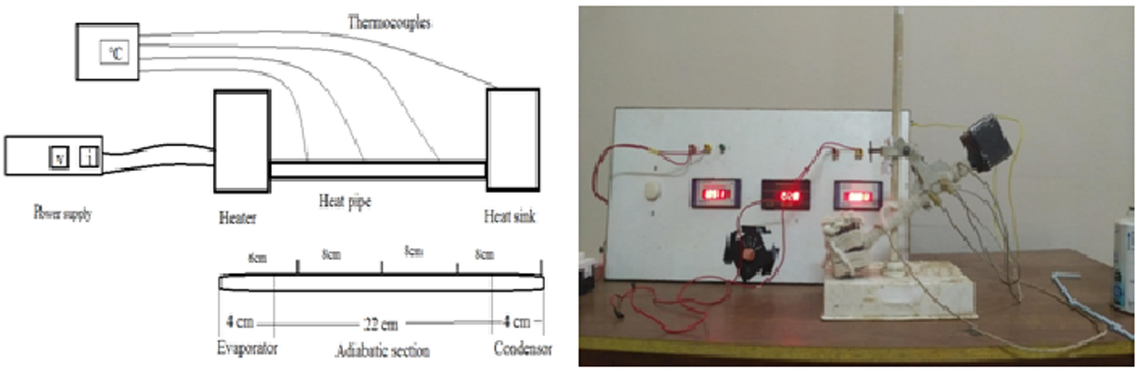
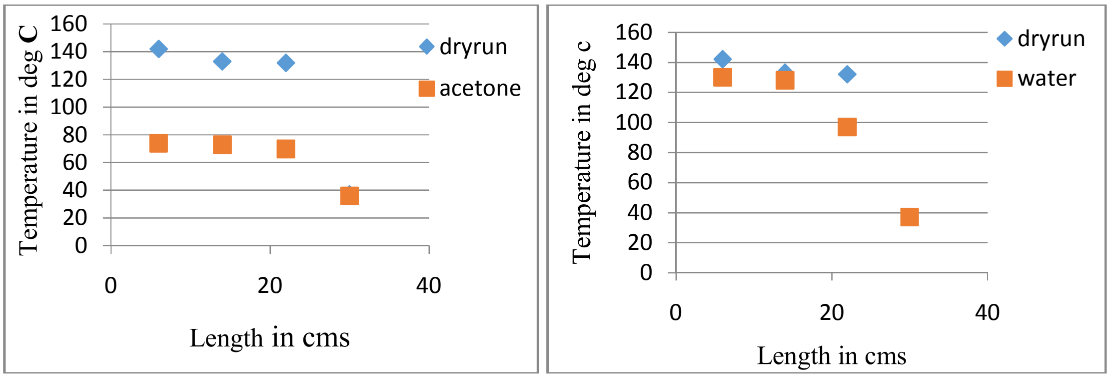


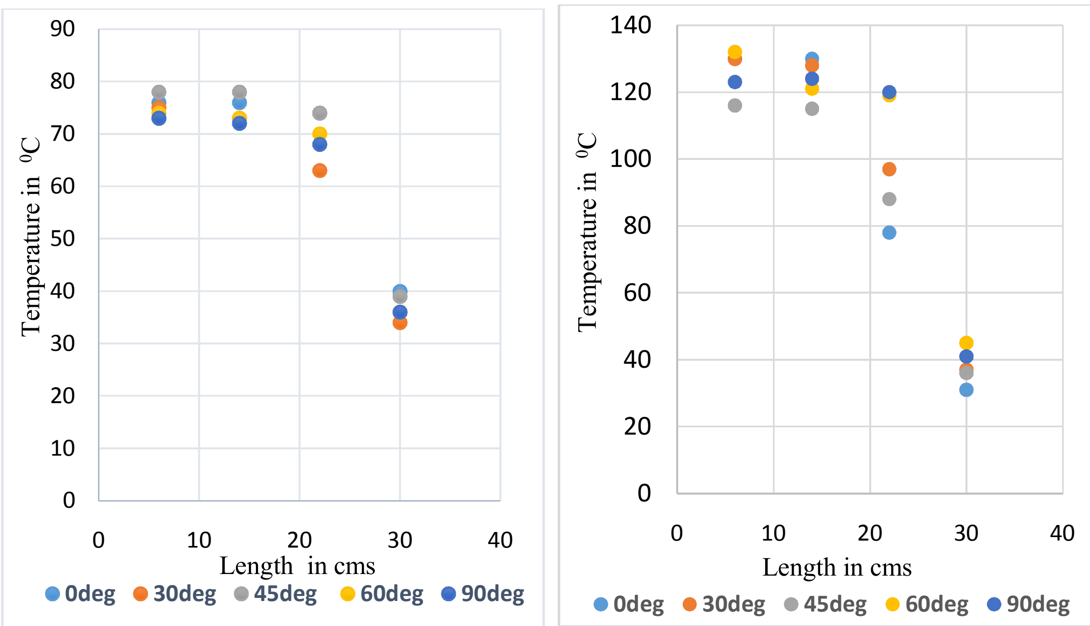
Figure 2. Experimental set up of the heat pipe apparatus.

The heat pipe is charged with 16 ml of working fluid, which approximately corresponds to the amount required to fill (20%) the evaporator. The temperature distribution of the heat pipe is measured using K-type thermocouples with an uncertainty of ±0.1^{o}C, at 6cm, 14 cm, 22 cm and 30 cm from the evaporator. Heat Q is supplied with the help of a heater at the evaporator section. And the heat input is given around 7.29 W by adjusting voltmeter and ammeter to 2.7 volts and 2.7 amps respectively. Once the steady state is reached the temperature readings are taken for further calculations. The experiment is conducted for dry and wet run, which indicates the former is without the working fluid and the later indicates with working fluid. The temperature distribution for both the cases is shown in figure 3. Results show that heat pipe with acetone as working fluid has lesser slope when compared with water, which indicates acetone is a better fluid when compared to water for a better thermal performance. The experiment is also conducted with working fluids chosen at different inclinations or tilt angles (0^o, 30^o, 45^o, 60^o and 90^o) as well. The temperature variation along with the length of the heat pipe is shown in figure 4. At 60^o tilt angle, the heat pipe shows a lesser thermal resistance when compared to other tilt angles.



(a) Dry run Vs Wet run (Acetone) (b) Dry run Vs Wet run (Water)

Figure 3. Temperature distribution of dry run and working fluids (acetone and water)



(a)Acetone (b) Water

Figure 4. Temperature distribution at different tilt angles towards the length of heat pipe

Figure 5 shows the experimental results with respect to the paper taken for validation. Thermal resistance values for water and acetone are found to be 13.5°C/W and 5°C/W respectively. The deviation in the values is because of the difference in the fill ratio and the usage of wick structure in the reference paper. The heat transfer coefficient for heat pipe with water is found to be 53 W/m^2 K (experiment) and 55 W/m^2 K (Simulation) respectively. The values obtained by simulation are found to be in good agreement with experimental result. The two mathematical equations used in calculating thermal resistance, overall heat transfer coefficient are given by $R = (T_1 - T_2)/Q$ °C/W, $h = \frac{Q}{A(T_1 - T_2)}$

W/m^2 ^{o}C respectively. Where T_1 , T_2 are evaporator and condenser temperatures in ^{o}C, A is surface heat transfer coefficient at the evaporator in square metres.

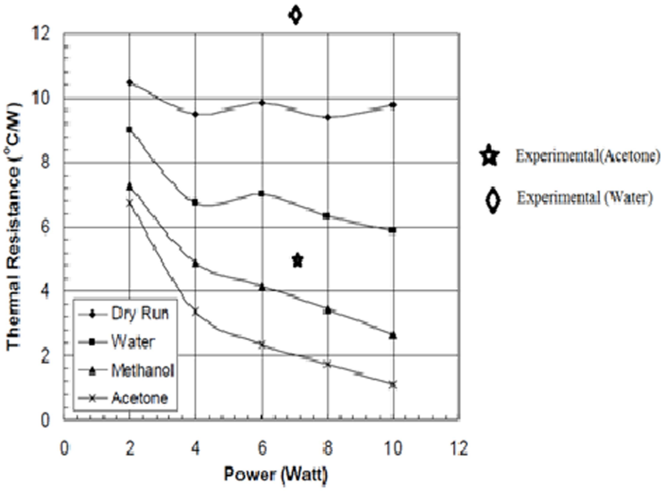
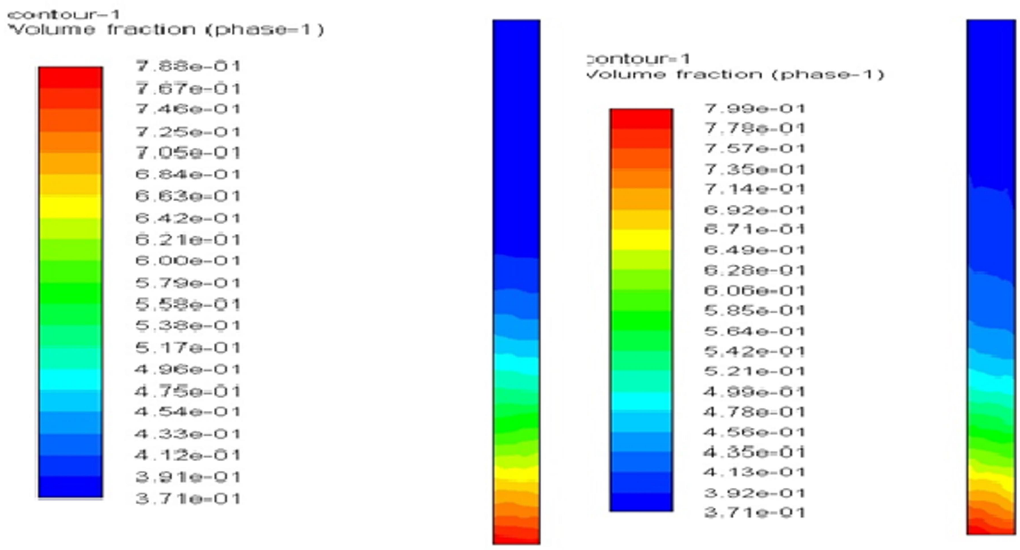


Figure 5. Thermal resistance variation at different heat inputs

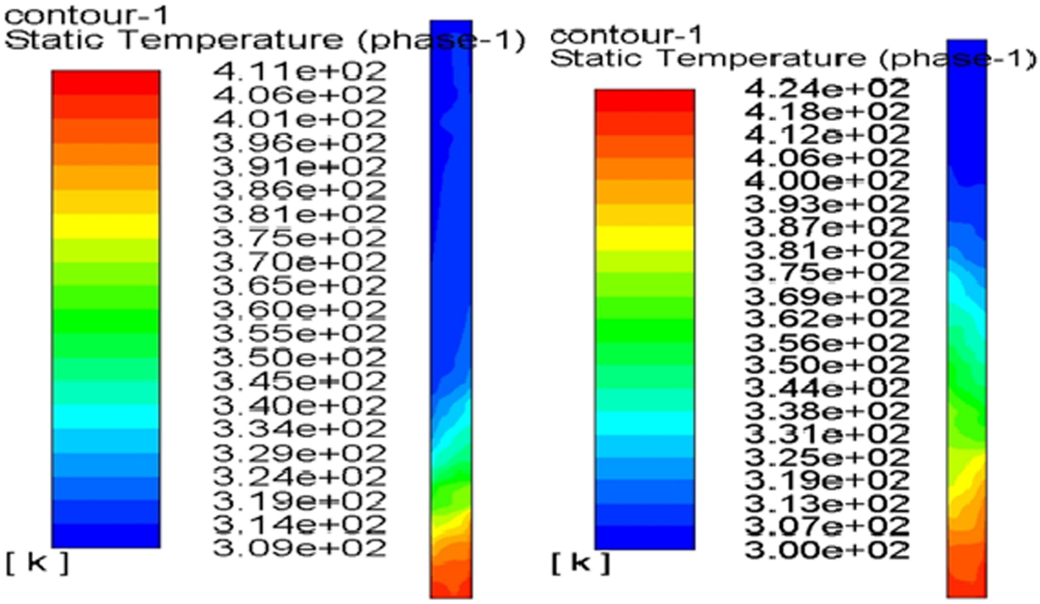
3. Modeling

Computational fluid dynamics analysis is carried out and the results are compared with the experimental result. A two dimensional unsteady mixture model is applied along with the k-ε turbulence model. The inlet condition is given as heat input which is 7.29 W. And then the volume fraction contours, static temperature contours are obtained for water as shown in figure 6 and figure 7 respectively. Maximum volume fraction of water is 0.788 and 0.799 at evaporator section for 60^o and 90^o tilt angles respectively. And the minimum is found to be 0.371 at condenser section for both the tilt angles. And from the static temperature contours we can see that the temperature at the evaporator section is 411 K (138 ^{o}C) and 424 K (151 ^{o}C) respectively for 60^o and 90^o tilt angles respectively. At 60^o tilt angle the simulation result is meeting with the experimental result for water.



(a) Volume fraction at 60^o tilt angle (b) Volume fraction at 90^o tilt angle

Figure 6. Volume fraction contour for water as working fluid at 60^o and 90^o tilt angles



(a) 60^o tilt angle (b) 90^o tilt angle

Figure 7. Temperature contour of heat pipe for water at 60^o and 90^o tilt angles

4. Conclusion and Future Scope

The heat pipe selected showed a better thermal performance with wet run when compared to dry run. Experimental results showed that acetone is a better working fluid than water as the thermal resistance is very low, which is almost half of the thermal resistance of water. The variation obtained showed a good agreement with the reference paper. It is also found that for both the working fluids at the fill ratio of 20 % the heat pipe is very effective at 60^o tilt angle, which is also matching with the literature review. The fabrication of heat pipe is found to be cheaper when compared to readily available commercial heat pipes. There is lot of scope for future work in enhancing the heat transfer using heat pipe [4-10]. One can perform a three dimensional analysis for even more accurate results by choosing appropriate turbulence model. The heat pipe can be constructed with different wick structures and various available working fluids. Even nanofluids can be used as working fluid which many researchers are trying out. Heat pipes are getting replaced by micro heat pipes in many of the electronic equipments cooling. Optimization can be performed between various heat pipe models, shapes, working fluids, wick structures, fill ratios, tilt angles and heat inputs. Even different phase change materials can be used along with the heat sink.

5. References

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