Predicting the Performance of Heat Pipe at Different Inclination Angle

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Abstract. This paper focused an experimental study of heat pipe to predict the performance of the heat pipe at different tilt angle. The distilled water is used as a working fluid in this study. The temperature was measured with data acquisition system at various positions of heat pipe after steady state. The performance of heat pipe is predicted by the deviation of temperature at different section of heat pipe at different tilt angle and heat input power. Thermal resistance is also estimated to understand the behaviour of heat pipe. It is observed that behaviour of heat pipe is very poor at 90 degree inclination compare to other inclination angle. The optimum condition for getting high thermal performance from heat pipe is at 0 degree inclination for low power input however at high power input it is observed at 45 degree inclination angle.

Keywords: Heat Pipe, Working Fluid, Filling Ratio, Inclination Angle.

Nomenclature

D- Diameter of pipe (mm)
L- Length of pipe (mm) liq- liquid
T- Temperature (°C) vap- vapour
Q- Heat input (w) e- evaporator
g- Gravitational acceleration (9.8m/s²) a-adiabatic
Rₘₜ- Thermal resistance (°C/W) c- condenser
A- Surface area (m²) o- outer

1. Introduction

The transfer of heat in presence of phase change of the occupied fluid is a very effective process of heat transfer but the complicacy in this process is one of the challenges to the researchers. Therefore the advancements in this field are lesser as in the field of conduction and convection approach of heat transfer without phase change. The heat pipe is one of the heat transport device in which heat transfer take place due to vapour to liquid phase change from one part to the other. It is a passive heat transfer device that transports heat over long distance through the latent heat of vaporization of an occupied fluid. It has three sections as an evaporator, condenser and an adiabatic which separates other two sections. It is assemble for transporting heat over long distance with a small temperature drop due to
the binary phase characteristic. It is also making almost the isothermal surface for temperature stabilization. The quantity of heat that can be transported over the usage of latent heat is usually more than the quantity given by a sensible heat for a geometrical equivalent system. Heat pipe are one of the existing technology to manage with high density electronic cooling problem because of their high thermal conductivity, reliability and low weight.

In view of this, various researchers discussed the different concepts related to the performance as well as use of different working fluids for the heat pipe. The idea of heat pipe time constants was used to define transient performance of heat pipes, which can endorse the understanding of heat pipes heat-up and cool-down events [1, 2]. Wang and Vafai [3] proposed an analytical model to predict the transient performance of a flat plate heat pipe for startup and shut down processes. They concluded that heat pipe time constants are affected by thermal diffusivity, wall thickness and wick and power input pattern. The thermal resistance created by wicks, resulting in the largest temperature drop in the heat pipe, thereby affecting the performance of the heating pipe. Wange and Vafai [4] experimentally examined the behaviour of an asymmetrical flat plate heat pipe and present relationship for maximum temperature rise and maximum temperature alteration within the heat pipe. The experimental results in a steady state found good agreement with analytical results. Amir Faghri et al. [5] accepted a lumped model to simulate the reaction of heat pipes. This model predicted the temperature and steady-state time of the heat pipe.

Hussain H. Ahmad [6] investigates that for 50-75% filling ratio and at 50° tilt angle heat pipe gives ideal behaviour. Riehl and Dutra [7] have studied the behaviour of loop heat pipe experimentally. It dealt by miniaturization as well as the usage of different functioning fluid. Salah R. agha [8] uses Taguchi method to investigate the effects of various factors on the thermal conductivity of heat pipe. Water as a functioning fluid provides the best performance. Srinivas Rao et al. [9] have studied the behaviour of pulsating heat pipe experimentally. From the result it was found that superior heat transfer performance was obtained for zero and 30° orientations and at a fill ratio of 80%. R. Kempers et al. [10] considered the separate condenser, evaporator thermal resistances of a copper–water screen mesh wicked heat pipe. They inspected the presence of boiling heat transition in heat pipe, also its significance for the modelling of heat pipe performance. From outcomes was indicated that a combination heat transmission model must be used for wicked heat pipes. Ahmed A. A. Attia et al. [11] have done an investigational study to assess thermal behaviour of a heat pipe with water and methyl alcohol as working fluid for diverse filling proportions. The mixture of propylene glycol and water were also investigated at different proportions to study the result of surfactant as improvement agent for occupied fluid performance. Shukla [12] discussed the development of heat pipe for hypersonic cruise vehicles, loop heat pipes (LHP) with greater conductance in 10K range. Loop heat pipes and capillary driven loops with various evaporators, condensers were the effective thermal management. R. Manimaran et al. [13] have done a review study related to various factors that affect thermal performances of heat pipe and suggested that the optimum fill ratio is (40%-80%) which gives maximum heat transfer rate. The alignment of heat pipe was essential for everyday applications. Paisarn et al. [14] have discussed that the heat pipe effectiveness rises by increasing tilt angle because the gravitational force has major influence on the flow of occupied fluid among evaporator and condenser. However, when heat pipe tilt angle go beyond 60° for de-ionic water and 45° for alcohol, heat pipe thermal performance tends to decline.

The present experimental study focussed the performance of heat pipe at different tilt angles and power input. The temperature was measured at various positions of heat pipe with DAQ system under a steady state to understand thermal behaviour of heat pipe. Thermal resistance was also estimated to optimize the inclination angle as well as heat input condition of heat pipe.

2. Experimental setup
The heat pipe is manufactured by using a copper tube of 33 cm length and 2.54 cm (1 inch) inner diameter and 4.54 cm outer diameter as shown in Fig.1. Ni-Cr wire heater of 230 V, 450 W capacity was used to supply the heat. The required amount of heat was supplied to the evaporator section with the help of heater. For minimize the heat loss through heat pipe both the evaporator and adiabatic sections are insulated using asbestos as insulating material. A variac was used to control the input power and multimeter used for measuring power input. The K-type thermocouples were used to measure the temperature at different location of evaporator and condenser region. Thermocouples are positioned at eight points on the exterior of heat pipe three at heating section which is evaporator 1 at adiabatic section and four at cooling section as condensers. Thermocouples at evaporator section are placed at a distance of 20 mm each and at condenser section are placed at distance of 30 mm each. The temperature is recorded in the computer with help of LabVIEW 15.1 software through DAQ system. The experiments were conducted with wet run with distilled water as working fluid inside the heat pipe. In the presence of constant heat input the temperature growth was perceived at fixed intervals to verify the steady state. All the measurements were done after steady state. Further sets of experiments were done for various heat inputs (10W-50W) and various inclination angles (0-90°) at 50% filling ratio with -60 cm Hg vacuum pressure inside the heat pipe to evaluate the thermal performance of miniature heat pipe.

3. Results and Discussions:

The experiments were conducted in wet manner (with water in it). The wet manner represents the real heat pipe characteristics. The distilled water was used as the operational fluids. Heat pipe was filled with 50% was tested for different heat input (10W-50W), pipe orientation (0-90°). The heat pipe performance is calculated in relation of thermal resistance. Thermal resistance(R) is calculated by the Equation (1)[15].

\[ R_{th} = \frac{T_e - T_c}{Q} \]
Figure 2. Verification of steady state of heat pipe for water

Figure 2 displays the variation of temperature with time to verify steady state of heat pipe for water. The DAQ system is used for performing the experiment and the experiment is conducted at surrounding temperature of 8.9°C when the heat pipe is vertical and the power given is 10 W. The pressure inside the pipe is -60 cm Hg, so that the fluid evaporates below its boiling temperature. It is shown that the steady state comes at about 27 minutes after the start of experiment. Therefore all experiments are conducted more than 27 minutes for measuring the temperature at diverse location of heat pipe.

3.1 Thermal behaviour of heat pipe for water on variable power input with inclination angle

Figure 3 shows that the isotherms at condenser section are having spaces between them, thereby showing a wide range of temperature distribution in condenser section. Thus the performance parameter at this angle will be good. The similar trend is being shown by the evaporator section.
Figure 4. Variation of temperature with heat pipe length at 15 degree inclination

Figure 4 shows that the isotherms in condenser section at starting power widens and after 30W power it starts decreasing thus showing that the performance is reduced at higher power. Thus in comparison with heat pipe at 0 degree inclination the performance of heat pipe is decreasing. It can be clearly understood in Fig.5 that the isotherms in condenser section are shortening slowly thus decreasing the thermal behavior of heat pipe. Although wide range of temperature distribution is seen but not quite enough for improvement of thermal performance of heat pipe.

Figure 5. Variation of temperature with heat pipe length at 30 degree inclination

It can be clearly seen that the distribution of range of temperature is of high quality and thus the isotherms in condenser section widens in Fig.6. Further in the results a fine improvement in thermal operation of heat pipe is observed. It is clearly seen that at 45 degree inclination of heat pipe thermal performance is best as compared to other inclinations of heat pipe. The isotherms in condenser region are shrinking as compared to the isotherms formation at 45° given in Fig.6. The temperature in evaporator section keeps on increasing there by showing a wide range of evaporation.
Figure 6. Variation of temperature with heat pipe length at 45 degree inclination

Figure 7. Variation of temperature with heat pipe length at 60 degree inclination

Figure 8. Variation of temperature with heat pipe length at 75 degree inclination
The isotherms in condenser region are shows a less wide range of temperature distribution is given in Fig.7 and 8. Show the decreasing thermal behavior of heat pipe. The temperature in evaporator portion keeps on increasing there by showing a wide range of evaporation. Figure 9 shows the temperature behavior at an inclination of 90° of heat pipe the condition is worst as compared to other angles. Thus, this is surely not the inclination where the performance is increased. The range of condenser temperature is reduced and hence performance is poor.

**Figure 9.** Variation of temperature with heat pipe length at 90 degree inclination

3.2 Thermal behaviour of heat pipe for water at constant heat input and different inclination angle

**Figure 10.** Temperature variations with the length of heat pipe on 10W power
Figure 11. Temperature variations with the length of heat pipe on 20W power

Figure 12. Temperature variations with the length of heat pipe on 30W power

Figure 13. Temperature variation with the length of heat pipe on 40W power
Figure 10 to 14 show the variation temperature in condenser and evaporation region at constant power to different angle of inclinations from 0 to 90°. It can be predicted that at different power supplies the temperature variation occurs. The variation of temperature at 60 degree inclination for different power input (10W-50W) shows a constant temperature increase for low power supply whereas when power input is increased much better temperature variation comes out for 45 degree inclination. This is due the gravitation influence on the movement of employed fluid in the heat pipe.

3.3 Effect of tilt over thermal resistance of heat pipe

The density of water is 100 kg/m³. It is seen that at 45 degree inclination the gravity effect is minimum as shown in Fig.15. Thermal resistance is decreases with increase in power input. Figure 15 shows that at low power input minimum thermal resistance occurs at vertical arrangement. However high power range the thermal resistance is minimum at 45 degree inclination.

It is observed from above study that at 90 degree inclination the performance of heat pipe is very poor compare to other inclination angle. Therefore the optimum condition for getting high thermal performance from heat pipe is at 45 degree tilt for high power supply and 0 degree tilt for low power supply.
4. Conclusions

The experimental study was done on heat pipe. The effect of various tilt angle and power input on thermal behavior of heat pipe were analyzed. This study comprises the effect of various factors on its performance. The steady state of heat pipe during experiment is verified with the help of DAQ system. The behavior of heat pipe in presence of water as a working fluid is evaluated by calculating the thermal resistance. The thermal resistance is minimum when heat pipe inclined at 45 degree due to gravity effect on inclination. At low power input minimum thermal resistance occurs at vertical arrangement. However high power input ranges the thermal resistance is minimum at 45 degree inclination. The performance of heat pipe is very poor at 90 degree inclination compare to other inclination angle. The optimum condition for getting high thermal performance from heat pipe is at 45 degree inclination for high power input however at low power input it is observed at 0 degree inclination angle.

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