



Experimental Study of Thermal Performance of Conventional Heat Pipe

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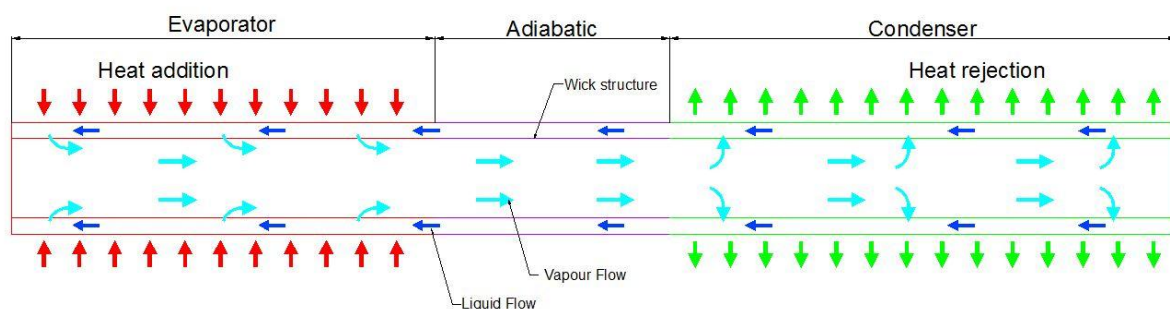
Abstract: A conventional heat pipe is an efficient device that is used to achieve high rate of heat transfer. The purpose of this experimentation was to analyse the effect of variation in heat input and inclination angle on heat transfer of conventional heat pipe. The heat input was varied at various levels and inclination angle was varied for each heat input. The condenser was above the evaporator section in inclined and vertical positions of the heat pipe. For conducting the experiments, conventional heat pipe (HP) was fabricated with SS 304 of total length 900 mm and outer diameter 53 mm with water as a working fluid. The temperature was found to decrease from the evaporator section to condenser section along the length of heat pipe. The typical isothermal characteristic of the heat pipe was observed for all the positions and mainly for inclined and vertical positions of the heat pipe. The time observed to achieve steady state was the least for vertical position. The results conclude that with increase in heat input the thermal resistance decreased. The thermal resistance was found to be the least for the inclined position.

Keywords: Conventional heat pipe; Heat Input; Inclination angle; Thermal resistance; Isothermal Characteristic

I. Introduction

Heat pipe is a passive heat transfer device. It is a hollow sealed pipe containing wick structure all round its inner periphery. Working fluid is present inside heat pipe which is sufficient enough to be absorbed by the wick. The heat pipe consists of evaporator section, adiabatic section and condenser section. Fig. 1 shows the working of heat pipe. Heat is supplied at the evaporator section and thus the working fluid present in the liquid form evaporates. The vapour thus generated moves towards the condenser section due to pressure difference. In the condenser section, heat is rejected in the form of latent heat of condensation and hence the vapour is converted back to liquid form and this liquid is pumped back to the evaporator section due to capillary action of wick structure. The main advantage of heat pipe is that it transfers large amount of heat with low temperature drop.

Figure 1 Working of Conventional Heat Pipe



Many researchers have performed experimentations on heat pipe to study the thermal characteristics and behaviour of heat pipe in various conditions. Mahjoub and Mahtabroshan [1] simulated the steady, two dimensional, heat transfer and flow equations in both vapour region and porous media using numerical model. The results showed that the thermal resistance of heat pipe increased with increasing wick porosity and decreased with increasing wall thermal conductivity and heat pipe radius. Bock et al. [2] investigated the experimental methods of testing capillary performance of wick structure from micro to nano scale. Ahmad and Rajab [3] carried experimentations on heat pipe to investigate the performance of heat pipe. It was found that the thermal conductivity of heat pipe was higher than a solid piece of stainless steel. Manimaran et al. [4] studied the detailed literature review about various parameters that affected the optimal characteristics of heat pipe. Mozumder et al. [5] carried experimentations on heat pipe for dry condition and with various working fluids for different fill ratio. It was found that 85% fill ratio was optimum for heat pipe performance. Annamalai and

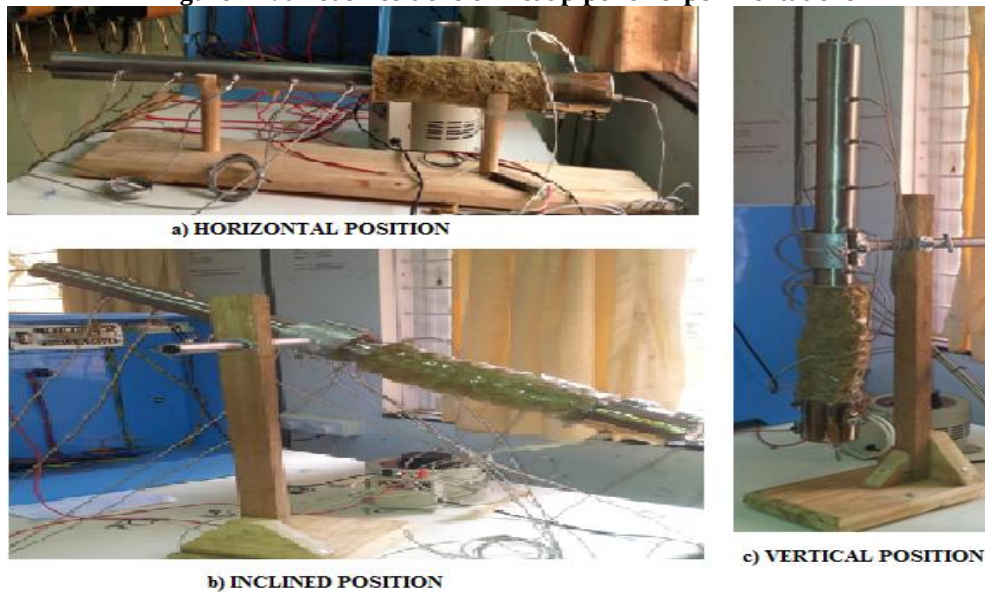
Ramalingam [6] carried computational fluid dynamics (CFD) analysis of heat pipe to determine the temperature distribution. The CFD results were compared with experimental results and showed good agreement between the two. Ahmed *et al.* [7] performed numerical analysis of heat pipe to find out the temperature distribution on the wall of heat pipe. Gavtash *et al.* [8] simulated the effect of nano fluids on the heat pipe using ansys-fluent CFD package to find out temperature distribution on heat pipe wall. Boukhanouf and Haddad [9] investigated the thermal performance of a miniature flat plate heat pipe for applications in electronic cooling. Sukchana and Jaiboonma [10] investigated the thermal performance of heat pipe using R-134a as working fluid by varying the fill ratio and adiabatic length.

The literature review showed that most of the work carried earlier on heat pipe was to investigate the thermal performance of heat pipe. Most of the researchers conducted experimentations and determined the surface temperature distribution on heat pipe using copper as the container material. In the present study experimentation was conducted on stainless steel as the container material and water as the working fluid in conventional heat pipe to investigate the effect of variation in inclination angle (0° , 45° and 90° with respect to horizontal) on thermal performance of heat pipe. Different levels of heat input were applied to study the behaviour of heat pipe and overall effective thermal resistance was calculated.

II. Experimental Setup

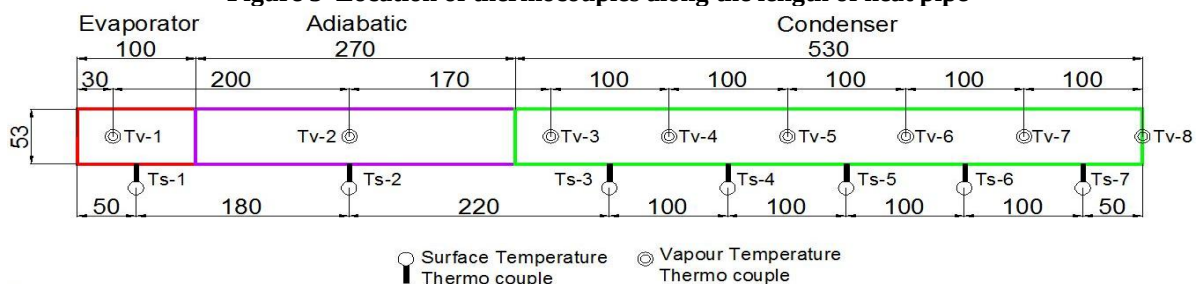
SS304 heat pipe of 900 mm. was fabricated, having 100 mm. of evaporator section, 270 mm. of adiabatic section and 530 mm. of condenser section. The outer diameter of the heat pipe was 53 mm. with 2 mm. thickness. Wick structure of SS302 with single layer, 120 mesh and 0.13 mm. wire diameter was lined inside the heat pipe. 80% fill ratio was considered in present study. Band heater of 230 volt, 500 watt capacity was used to supply heat to the evaporator section. Adiabatic section was insulated with glass wool of 2 inch thickness to minimise heat losses. Number of thermowells were welded along the entire length of heat pipe for insertion of K type thermocouples which were used to measure the vapour temperature.

Figure 2 Various Positions of Heat pipe for experimentations



Thermocouples were also used on the surface of the heat pipe along the axial length, to measure the surface temperature of heat pipe. Dimmerstat of 230V, 0-4 amp was used to vary the heat input at evaporator section. Thermocouples were connected to 12-channel digital temperature indicator to display the temperatures at various positions. The experiments were conducted for inclination angle 0° , 45° and 90° from horizontal as shown in Fig. 2. Heat input was varied from 150 W to 300 W with an interval of 50 W. All the observations of temperature i.e. surface temperature and vapour temperature were recorded. Fig. 3 shows the location of thermocouples along the length of heat pipe.

Figure 3 Location of thermocouples along the length of heat pipe



III. Results and Discussions

Vapour temperature and surface temperature profile were obtained along the length of heat pipe as shown in the following figures.

Figure 4 Vapour temperature distribution along length of heat pipe for 150W for horizontal position

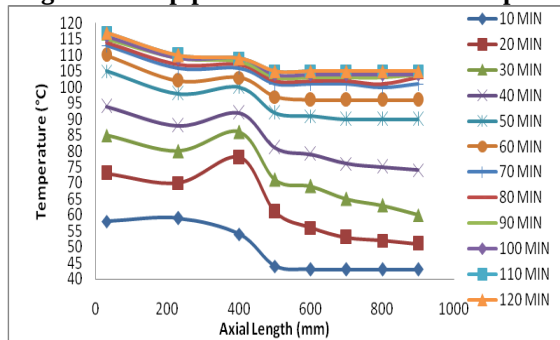


Figure 6 Vapour temperature distribution along length of heat pipe for 150W for inclined position

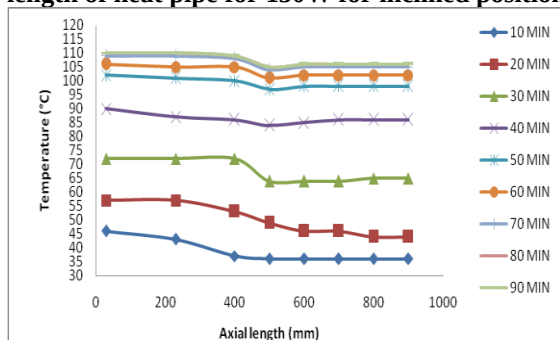


Figure 8 Vapour temperature distribution along length of heat pipe for 150W for vertical position

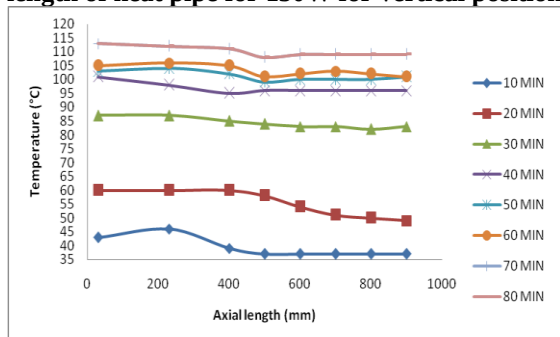


Figure 5 Vapour temperature distribution along length of heat pipe for 200W for horizontal position

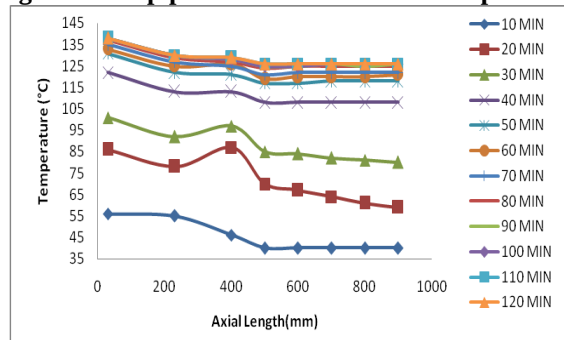


Figure 7 Vapour temperature distribution along length of heat pipe for 200W for inclined position

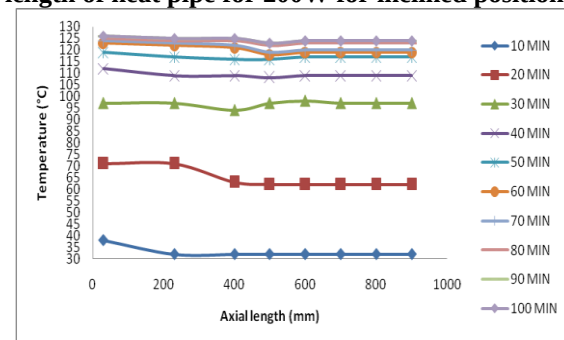


Figure 9 Vapour temperature distribution along length of heat pipe for 200W for vertical position

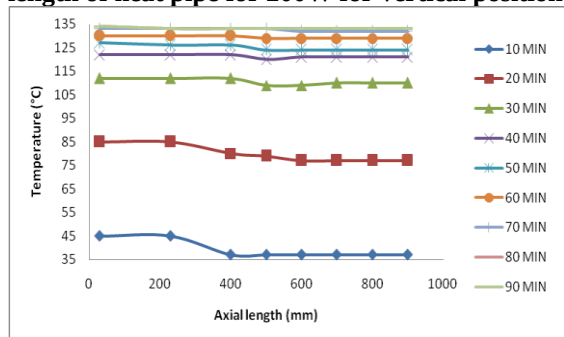


Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8 and Fig. 9 show the graphs of vapor temperature Vs axial distance for various positions of heat pipe. These graphs depict the difference of temperature between the evaporator section and condenser section and was observed to be maximum for horizontal position of heat pipe, where as this was reduced for inclined and vertical positions. This clearly states the isothermal behaviour (a typical characteristic of heat pipe) for the inclined and vertical position of the heat pipe. This depicts that gravity plays an important role even though the experiments were conducted on heat pipe with wick.

Figure 10 Surface temperature distribution along length of heat pipe for 150W for horizontal position

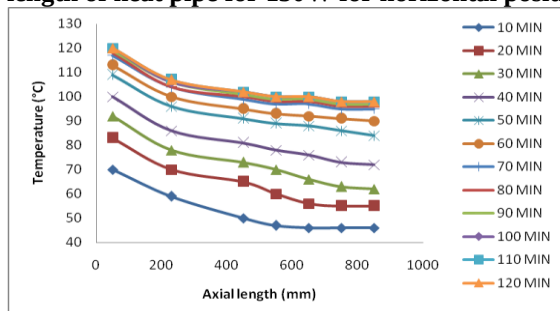


Figure 11 Surface temperature distribution along length of heat pipe for 200W for horizontal position

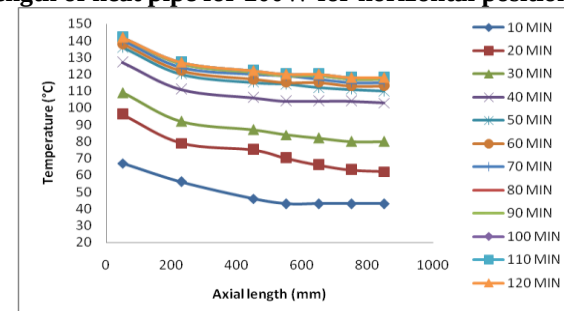


Figure 12 Surface temperature distribution along length of heat pipe for 150W for inclined position

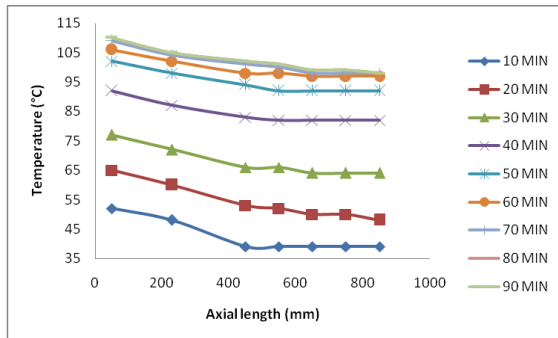


Figure 13 Surface temperature distribution along length of heat pipe for 200W for inclined position

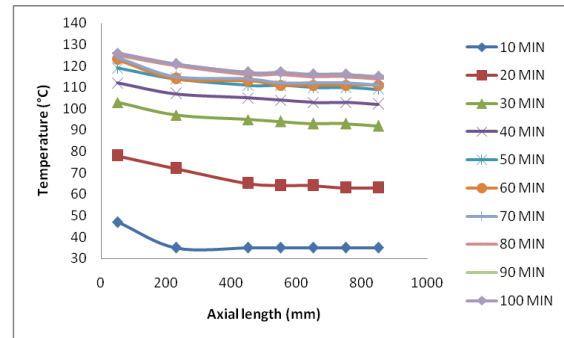


Figure 14 Surface temperature distribution along length of heat pipe for 150W for vertical position

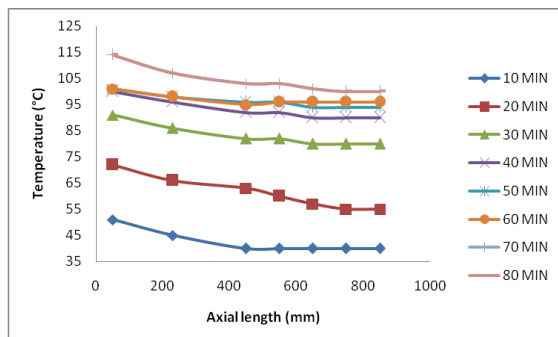


Figure 15 Surface temperature distribution along length of heat pipe for 200W for vertical position

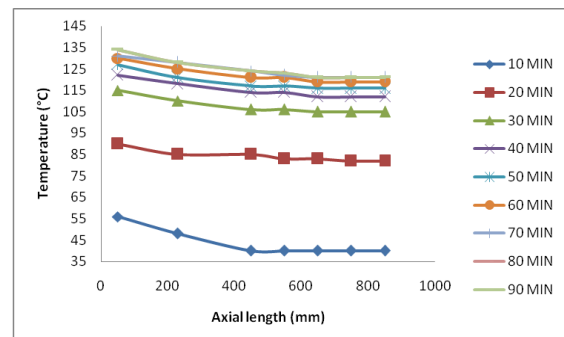


Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14 and Fig. 15 show the graphs of surface temperature along the axial distance for horizontal, inclined and vertical positions. From these graphs, it could be observed that for heat input of 150 W in horizontal position, during the initial 60 min. of heat supply there was a continuous and sharp rate of decrease of temperature throughout the length of heat pipe from evaporator section till the condenser section which may be due to heat supplied to evaporator section being utilized only to heat the water in heat pipe. During the next 60 minutes, before attainment of steady state, the rate of temperature rise decreased sharply indicating the process of evaporation and condensation in the respective sections. Similar trend was observed when experiments were conducted for heat input of 250W and 300W also.

Figure 16 Vapour temperature variation along length for various heat input at horizontal position

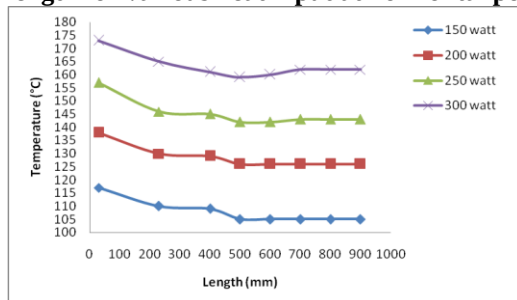


Figure 17 Surface temperature variation along length for various heat input at horizontal position

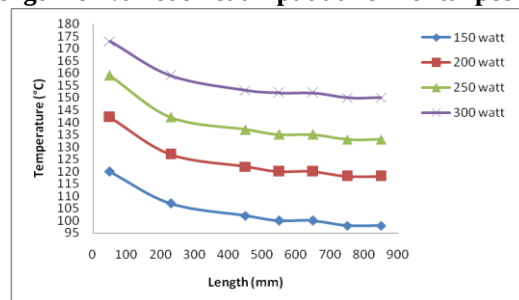


Fig.16 shows the graph of vapour temperature distribution along the length of heat pipe for horizontal position. From the graph it is visible that for low heat input of 150 W and 200 W the temperature of vapour decreased continuously in the axial direction from evaporator section to condenser section. At high heat input where the overall vapour temperature was also high, a slight increase of the vapour temperature was found towards the end of condenser. A very possible reason may be that vapour did not have enough space to expand and being a heat rejection section, superheating of vapour may have taken place although marginally.

Figure 18 Vapour temperature variation along length for various heat input at inclined position.

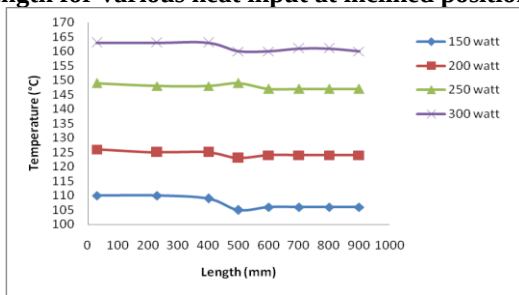


Figure 19 Surface temperature variation along length for various heat input at inclined position

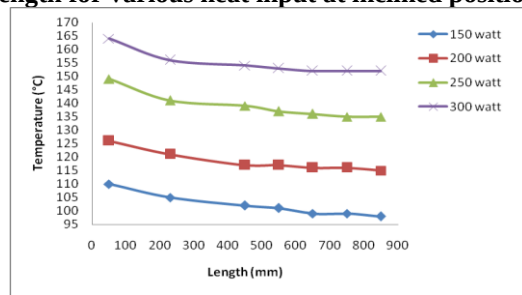


Fig.18 and Fig. 20 show the graphs of vapour temperature along axial distance for inclined and vertical positions of the heat pipe. Decrease in temperature distribution from evaporator section to condenser section for all heat input was observed. The time required to achieve the steady state condition at inclined position was found to be lesser than for horizontal position. Maximum temperature reached was also less for inclined position.

Figure 20 Vapour temperature variation along length for various heat input at vertical position.

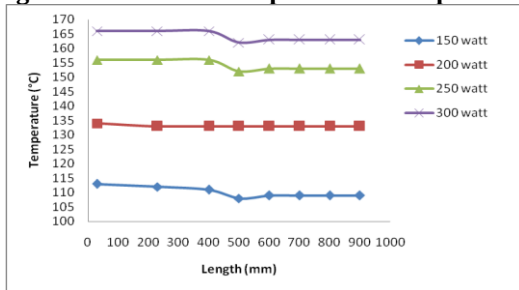


Figure 21 Surface temperature variation along length for various heat input at vertical position

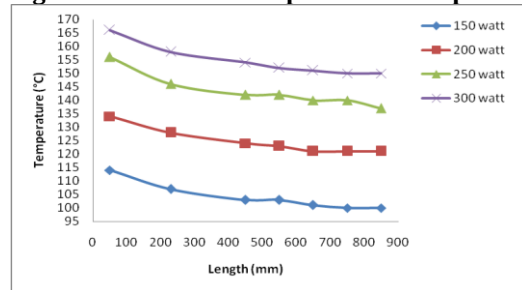


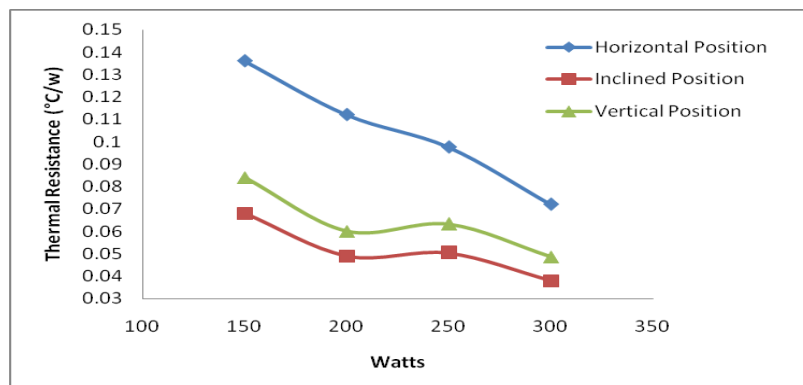
Fig.17, Fig. 19 and Fig. 21 show the graphs of surface temperature along the axial distance for horizontal, inclined and vertical positions of the heat pipe respectively. Temperature of the surface was observed to decrease continuously from evaporator section to condenser section. From these graphs it was concluded that the temperature drop was the least for inclined position of the heat pipe.

Thermal Resistance of heat pipe was calculated by the equation given below [5]

$$R_{th} = \frac{\bar{T}_e - \bar{T}_c}{Q}$$

Where, T_e is average temperature of evaporator, T_c is average temperature of condenser and Q is heat input in watts.

Figure 22 Graph of Thermal resistance w.r,t, Heat Input for 0°, 45° and 90° positions



Thermal resistance was calculated for 150 W, 200 W, 250 W and 300 W for horizontal position, vertical position and inclined position as shown in Fig. 22. The nature of the graph was found to be almost similar for all the three positions. With increase in heat input, the thermal resistance decreased at all inclination angles. Maximum resistance was noted for 150 watts and minimum resistance was calculated for 300 watts for all the three positions of heat pipe. The graph clearly indicates that for inclined position the overall thermal resistance was observed to be the least (0.035 °C/W) of all the heat input supplied.

IV. Conclusions

The experimental analysis of natural convection, stainless steel heat pipe with water as the working fluid was performed. The results concluded that steady state was achieved after 120 minutes of heat input for horizontal position of heat pipe, for all the ranges of power supplied. This time was reduced to 100 minute from 120 minute for the inclined position and was observed to be lowest (90 minute) for vertical position. The variation of temperature in axial direction of heat pipe explains the evaporation and condensation phenomenon after certain period of time. The thermal resistance of inclined position was found to be the least for all heat input. With increase in the heat input for a particular position, the thermal resistance decreased which clearly states the improvement of nucleate boiling in the evaporator section and hence the heat pipe performance was better at high heat input. The performance of heat pipe was found to be the best at inclined position (45° from the horizontal). Isothermal behaviour of the heat pipe was also ascertained by experimental results.

REFERENCES

- [1] Shoeib Mahjoub, and Ali Mahtabroshan, "Numerical Simulation of a Conventional Heat Pipe," World Academy of Science, Engineering and Technology, pp. 117-122, 2008.
- [2] H. Peter J. de Bock, Kripa Varanasi, Pramod Chamarthy, Tao Deng, Ambarish Kulkarni, Brian M. Rush, Boris A. Russ, Stanton E. Weaver, "Experimental Investigation of Micro/Nano Heat Pipe Wick Structures," in International Mechanical Engineering Congress and Exposition IMECE2008-67288, 2008.
- [3] Dr. Hussain H. Ahmad and Raqeeb H. Rajab "An Experimental Study of Parameters Affecting a Heat Pipe Performance," Al-Radidain Engineering, Vol. 18, pp. 97-115, 2009.
- [4] R. Manimaran, K. Palaniradja, N. Alagumurthi and J. Hussain "Factors Affecting the Thermal Performance of Heat Pipe – a Review," Elixir Thermal Engg. 37A, pp. 4143-4146, 2011.
- [5] Alope Kumar Mozumder, Mohammed Shafiul Hasib Chowdhari and Abul Fahad Akon, "Characteristics of Heat Transfer for Heat Pipe and Its Correlation," ISRN Mechanical Engineering, vol. 2011, 2011
- [6] Arul Selvan Annanalai and Velraj Ramalingam, "Experimental Investigation and Computational Fluid Dynamic Analysis of a Air Cooled Condenser Heat Pipe," Thermal Science, Vol. 15, No. 3, pp. 759-772, 2011.
- [7] Nouman Zahoor Ahmed, Pawan K. Singh, Isam Janajreh, Youssef Shatilla "Simulation of Flow Inside Heat Pipe: Sensitivity Study, Conditions and Configuration," in International Conference on Energy Sustainability ES2011, 2011.
- [8] Barzin Gavatash, Khalid Hussain, Mohammad Layeghi, Saeed Sadeghi Lafmejani, "Numerical Simulation of the Effect of Nanofluid on a Heat Pipe Thermal performance," World Academy of Science, Engineering and Technology, pp. 549-555, 2012.
- [9] R. Boukhanouf and A. Haddad, "Simulation and Experimental Investigation of Thermal Performance of a Miniature Flat Plate Heat Pipe," Advance in Mechanical Engineering vol. 2013, 2013.
- [10] Thanaphol Sukchana, Chaibun Jaiboonma "Effect of Filling Ratios and Adiabatic Length on Thermal Efficiency of Long Heat Pipe Filled with R-134a," Eco-Energy and Material Science and Engineering, pp. 298-306, 2013.