Performance Analysis of Heat Pipe With Different Working Fluid and Fill Ratios

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Abstract- An attempt is made to design, fabricate and test a heat pipe with 25 mm diameter and 1000 mm length with a thermal capacity of 10 W. Experiments were conducted with and without working fluid for, different thermal loads to assess the performance of heat pipe. The working fluids chosen for the study were same as those commonly used namely, DI water and DI water mixes with iron oxide (Fe_2O_3). The temperature distribution across the heat pipe was measured and recorded using thermocouples. The performance of the heat pipe was quantified in terms of thermal resistance and overall heat transfer coefficient. The amount of liquid filled was varied and the variation of the performance parameters for varying liquid inventory is observed. Finally, optimum liquid fill ratio is identified in terms of lower temperature difference and thermal resistance and higher heat transfer coefficient. The effectiveness of circular copper heat pipe is found to be the maximum when the DI water mixed nanofluids (Fe_2O_3) as working fluid.

Keywords: Heat pipe, Fill Ratio ,Nanofluid.

1. INTRODUCTION

A heat pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces. At the hot interface of a heat pipe a liquid in contact with a thermally conductive solid surface turns into a vapor by absorbing heat from that surface. Many researchers have investigated the performance of heat pipe. Some researcher has presented research on the design and experimental analysis of heat pipe. In this work different types of working fluids are taken for study. The different working fluid like Al_2O_3, CuO and SiC nanofluid with base fluid are used for enhancement of performance, this study observed the greater enhance in performance of heat pipe with nanofluids. [1][2][3][4].Some researcher has been worked on the circular shape copper heat with commonly used working fluids [5]. Chin-Chun et.al. [6] Performance testing of Micro Loop Heat Pipes. The MLHP is analyzed and tested for grooved wick structure; this study observed that small diameter of wick improved the performance of heat pipe. Some investigation of ultra-thin flattened heat pipes with sintered wick structure capillary and ternary fluid is used in the heat pipe for enhancing the performance of heat pipe [7][8][9].Shahryari et.al.[10] presented works on behavior of nanofluid in a cylindrical heat pipe with two heat sources is performed to analyze the nanofluid application in heat-dissipating satellite equipment cooling.

2. HEAT PIPE THEORY & DESIGN

In the design of heat pipe, the characteristic of the three main components: the working fluid, the wick and the container are of important to attain the required heat transport capacity. In order the heat pipe to work, the pressure drop in the fluid flow has to be compensated by the pumping pressure in the wick by capillarity.

$$\Delta P_p = \Delta P_l + \Delta P_v + \Delta P_g$$

Where are $\Delta P_p, \Delta P_l, \Delta P_v$ and ΔP_g the total pumping pressure, pressure drop for liquid return from condenser, pressure drop for vapor flow in the evaporator and gravity head, respectively.

3. EXPERIMENTAL METHODS

a. Experimental Setup

The schematic diagram of the heat pipe under consideration is shown in Fig.4.1 along with thermocouple locations .The experiment part consists of a 25.40 mm outer diameter copper-water heat pipe with a length of 1000 mm and a wall thickness of 1.2 mm. The wick consists of two wraps of a copper wire mesh with a wire diameter of 0.183 mm and 2365 strands per meter. The heat pipe is charged with 10 ml of working fluid, which approximately corresponds to the amount required to fill the evaporator. The wall temperature distribution of the heat pipe in adiabatic zone is measured using K-type thermocouples with an uncertainty of ±0.1^{o}C, at an equal distance from the evaporator. In addition the thermocouples are also located in evaporator surface (two locations), condenser surface (two locations), and fins of condenser section. The electrical power input is applied at the evaporator section using cylindrical electric heater attached to it with proper electrical insulation and the heater is energized with 230V AC supply using a variance and measured using a power transducer with an uncertainty of ±1 W.

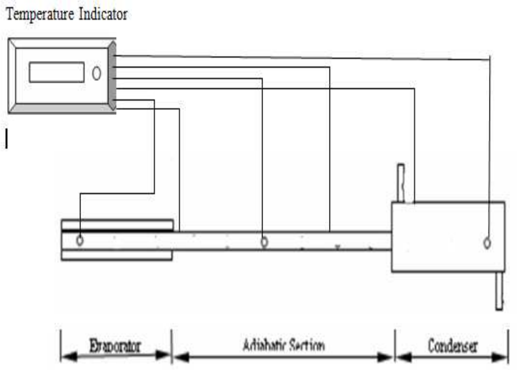

Fig: 1.1 Thermocouple Locations of Heat Pipe

b. Experimental Procedure

The experiments are conducted using heat pipe which is manufactured as per mentioned dimensions. The heat pipe is initially filled with de-ionized water, secondly with solution de-ionized water and iron oxide nanofluid. The power input to the heat pipe is gradually raised to the desired power level. When the heat is supplied to the evaporator end by means of heating source, the surface temperatures along the adiabatic section of heat pipe are measured at regular time intervals until the heat pipe reaches the steady state condition. Simultaneously the evaporator wall temperatures and condenser wall temperatures are measured. Once the steady state is reached, the input power is turned off and cooling water is allowed to flow through the condenser to cool the heat pipe and to make it ready for further experimental purpose. Then the power is increased to the next level and the heat pipe is tested for its performance. The output heat transfer rate from the condenser is computed by applying an energy balance to the condenser flow. The test section consists of three parts, as mentioned earlier, evaporator, adiabatic and condenser sections. In the experiment the heat transfer characteristics were measured for three different liquids (distilled water and Distilled water with iron oxide). Also the characteristics were measured for dry run condition (without any liquid). So, two heat pipes were fabricated.

For dry run condition the heat pipe was sealed at bottom and top. In case of the heat pipe where liquids were used the bottom was sealed and top was at the end. The evaporator section equipped with the band heater. Power to the heater was provided from line supply through a variac. Fins were attached at the condenser section and a fan was directed towards the fins for forced convection to occur at this section.

Fig: 1.2 Heat Pipe under study with control panel

Six sets of thermocouple wires were fixed with the body by means of glue. At first each thermocouple sets were fused together at the top point and it was ensured that except the top point, they do not touch at any other points. Then they were attached with the body. The other ends of the thermocouple wires were connected with the digital thermocouple reader by means of connecting wires. Thermocouples were placed at six points on the surface of the heat pipe, two at evaporator section, two at adiabatic sections and two at condenser section. Thermocouples at each section were placed at an interval of 250 mm.Experiments were conducted with dry run (without any working fluid in the tube) and wet run (with working fluid inside). The heat pipe without working fluid essentially represents metallic conductor. Its performance is considered as the base for the evaluation of the heat pipe (with working fluid in it). The transient tests were conducted on the heat pipe, in which heater was put on and the temperature rise was observed at regular intervals till the steady state was achieved. After achievement of steady state the temperatures at the six points were noted by changing the positions of the selector switch. This experiment was repeated for different heat inputs, different fill ratios and for different working fluids. Various plots were drawn to study the performance of the miniature heat pipe to optimize the fluid inventory. The different heat inputs were achieved by changing the output voltage from the variac.Fill ratio means the percentage of the evaporator section volume that is filled by the working fluids. The fill ratios used in this experiment were 30%, 50%, 70% and 100% of the evaporator volume for all three different working fluids. All the temperature readings, at the six points on the heat pipe surface, were taken for all three working fluids for all the fill ratios after reaching steady state condition.

3. RESULTS AND DISCUSSIONS

Experiments were carried out in dry mode (without working fluid) and wet mode (with working fluid in it). The dry mode experiment represents the heat transfer characteristics in an ordinary conductor, while the wet mode depicts the live heat pipe characteristics. Two different working fluids namely distilled water, and DI water with iron oxide which have varying useful working range of temperature are tested in this study. The heat pipe was filled with 30%, 50%, 70% and 100% of the evaporator volume tested for different heat input and working fluids.

3.1. AXIAL TEMPERATURE PROFILES

Axial temperature profiles are drawn from the data of temperatures that is obtained at different axial distances on the heat pipe body. The axial temperature distribution along the heat pipe for dry run and wet run (with different fill ratios) are shown in fig.4.1 to 4.9, repectively.

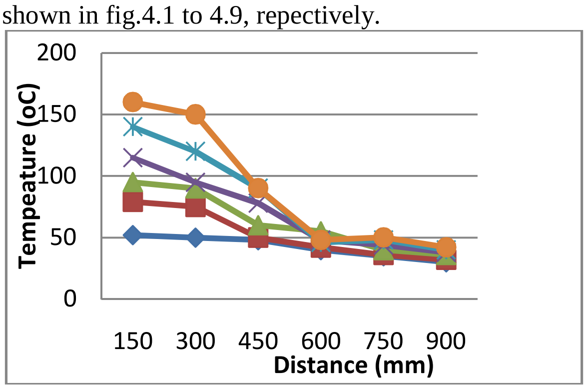

Fig.1.1.Axial temperature profile for DRY RUN

The evaporator, adiabatic section and condenser temperature variations with distance for dry run are shown in fig.1.3. It shows that the slope of axial temperature distribution increases with heat input and shows larger temperature differences across the condenser and evaporator section. The trend is obvious since greater temperature slope is required for increased heat transfer in case of simple conduction heat transfer.

Axial temperature profiles are drawn from the data of temperatures that is obtained at different axial distances on the heat pipe body. The axial temperature distribution along the heat pipe for dry run and wet run (with 50% fill ratios) are shown in Figs. 1.4 to 1.5 respectively.

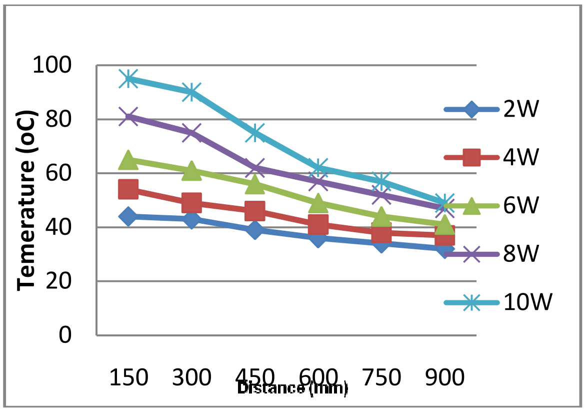

Fig. 1.4: Axial temperature profile for DI Water With 50% fill ratio

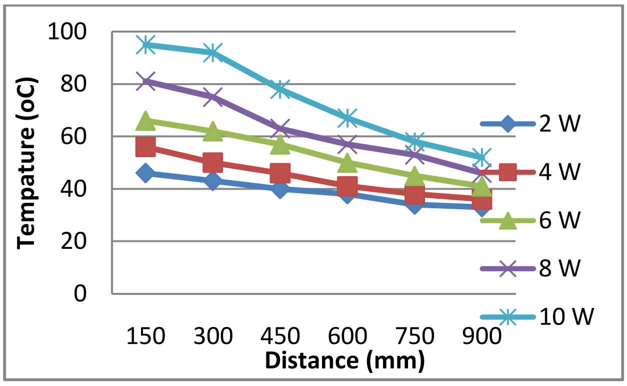

Fig. 1.5: Axial temperature profile for DI Water Mixed with Iron Oxide at 50% fill ratio

On the other hand, wet run shows reduced slopes of axial temperature distribution at similar heat inputs, indicating the effective augmentation of heat transfer at even reduced temperature slopes. The abrupt change in the slope of axial temperature distribution for water at different heat input (shows in fig.1.4 and 1.5) indicates the seizure of heat pipe operation. At this stage, the rate of evaporation at evaporator is higher than condensation rate at condenser.

4. CALCULATION FOR EFFECTIVENESS OF HEAT PIPE

a. Effectiveness of the heat pipe is indirectly brought in terms of thermal resistance.

$$R = \frac{T_e\text{-}T_c}{Q} \circ \frac{C}{W}$$

b. The overall heat transfer co-efficient is given by

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$$h = \frac{Q}{A(T_e - T_c)} \qquad \frac{W}{m^2 o_C}$$

Figures 1.6-1.7 show the variations of thermal resistances that occur at different fill ratios for the three different working fluids at different heat input. These graphs are used for comparison of thermal resistances at different fill ratios of different working fluids. The variations of thermal resistances with different heat inputs for dry run and wet run (for 30%, 50% and 100%) are shown in below.

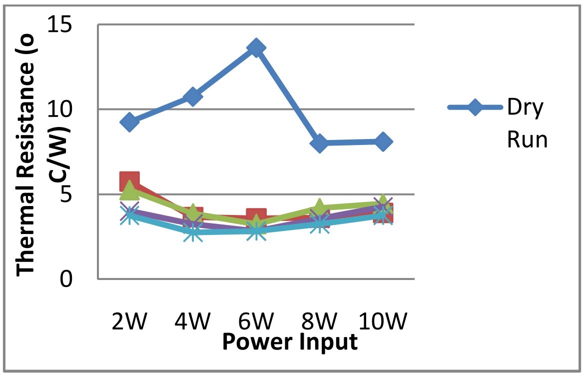

Fig. 1.6: Variations of thermal resistance with different heat inputs and fill ratios of DI water

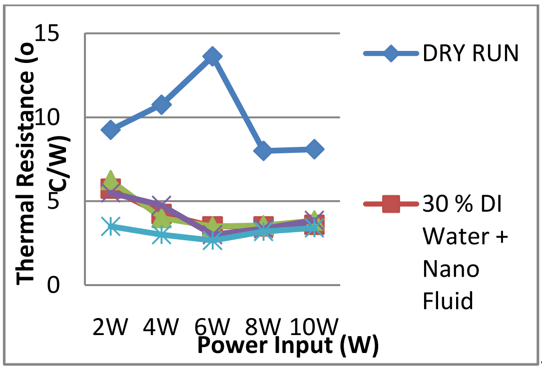

Fig. 1.7: Variations of thermal resistance with different heat inputs for different fill ratio of DI water mixed with Nano fluid

In general wet run shows the reduced thermal resistances for all levels of heat input and all types of working fluids. The dry run shows the largest values of thermal resistances and it is almost constant for varying heat loads. Acetone shows the minimum thermal resistances at all heat inputs for all fill ratios.

5. VARIATION OF HEAT TRANSFER COEFFICIENT (h) WITH HEAT INPUT

Figures 1.8-1.9 show the variations of heat transfer co-efficient that occur at different fill ratios for the two different working fluids at different heat input. These graphs are used for comparison of heat transfer coefficients at different fill ratios of different working fluids.

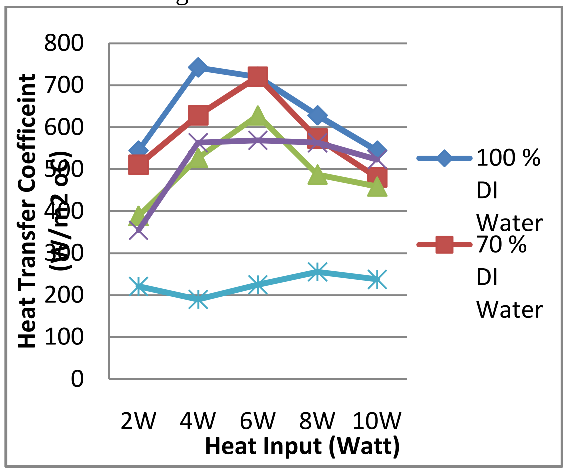

Fig. 1.8: Variations of heat Transfer Coefficient with different heat inputs for different fill ratio and DI water as working fluids

The dry run shows an overall heat transfer coefficient of around 250 W/m2-°C corresponding to the forced convective heat transfer at the fin end. When the heat pipe is charged with working fluids, there is remarkable increase in heat transfer coefficient owing to the augmentation of heat transfer rate by the evaporation and condensation process inside the heat pipe.

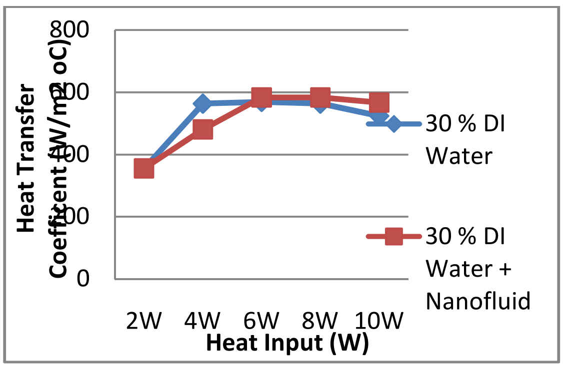

Fig. 1.9: Variations of heat Transfer Coefficient with different heat inputs for different 30% fill ratio of DI water and Nanofluid as working fluids

For 30% fill ratio (Fig. 1.9), water shows nearly constant value of heat transfer coefficients, values for DI water mixes with nanofluid, as working fluid, increases slightly with the increment of heat input. In case of nanofluid the heat transfer coefficient increases very rapidly with input heat.

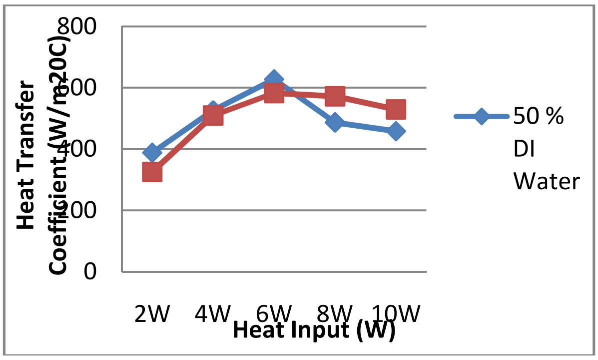

Fig. 1.10: Variations of heat Transfer Coefficient with different heat inputs for different 50% fill ratio of DI water and Nanofluid as working fluids

For 50% fill ratio (Fig.1.10), the value of heat transfer co-efficient falls very slowly with the increment in heat input for water as working fluid, increases slowly for DI water mixed with nanofluid and decreases very rapidly when DI water is acting as working fluid.

6. CONCLUSION

A heat pipe of a 10 W capacity has been successfully developed, fabricated and tested. Different operating characteristics are presented at different heat inputs viz, 2W, 4W, 6W, 8W; 10W.The system reaches steady state early in case of wet run when compared to dry run. From the investigation, the following findings are obtained:

- The steady state temperature increases with increased heat loads. Slope of axial temperature distribution in dry run increases with the heat input, on the other hand the wet run shows an averaged constant temperature slopes.
- The operating heat pipe with wet run has lesser overall thermal resistance when compared to dry run. For a 2W heat input capacity, the thermal resistance observed in the dry run was 9.25 °C/W and that in wet run was 5.75°C/W.
- The heat transfer coefficient of heat pipe increases with increase in heat input, in the range of inputs tested for Nano fluid (Fe2O3) mixed with DI water; while water filled heat pipe shows a nearly constant value.
- The heat transfer coefficient of heat pipe with different heating input shows maximum value and lower thermal resistance when DI water mixed with iron oxide nanofluid.
- The fill ratio of working fluid as a percentage of evaporator volume is shown to have minimum effect on the performance of heat pipe with respect to the temperature difference when water is used as working fluids.

NOMENCLATURE

A_s	Surface Area (m^2)
^oC	Degree Celsius
d	Inner Diameter of PHP (m)
h	Heat Transfer Coefficient (W/m^{2}K)
k	Thermal Conductivity (W/m K)
FR	Fill ratio
L_c	Length of condenser section (m)
L_e	Length of evaporator section (m)
PHP	Pulsating Heat Pipe
$Q, Q(w)$	Heat Input in Watts
R, R_{th}	Thermal Resistance (K/W)
$t(s)$	Time in Seconds
T_c	Condenser Temperature (^{o}C, K)
T_e	Evaporator Temperature (^{o}C, K

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