HEAT TRANSER ANALYSIS OF HEAT PIPE WITH IRON OXIDE NANOFLUID MIXED WITH DI WATER

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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 (Fe2O3). 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 (Fe2O3) as working fluid.

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 Al2O3, 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. TECHNICAL PARAMETER AFFECTING THE PERFORMANCE OF HEAT PIPE

Heat pipe performance and operation are strongly dependent on shape, working fluid and wick structure. Certain heat pipes can be designed to carry a few watts or several kilowatts, depending on the application. The effective thermal conductivity of the heat pipe will be significantly reduced if heat pipe is driven beyond its capacity. Therefore, it is important to assure that the heat pipe is designed to transport the required heat load safely. But during steady state operation, the maximum heat transport capability of a heat pipe is governed by several limitations, which must be clearly known when designing a heat pipe.There are five primary heat pipe transport limitations;

Viscous Limit

Viscous force will prevent vapour flow in the heat pipe. This causes the heat pipe to operate below the recommended operating temperature. The potential solution is to increase the heat pipe operating temperature or operate with an alternative working fluid.

Sonic Limit

Vapour will reach sonic velocity when exiting the heat pipe evaporator resulting at a constant heat pipe transport power and large temperature gradient. The main reason is the power and the temperature combination. In other words, the heat pipe is due operating at low temperature with too much of power. This is a normal problem during a start-up. The potential solution for this limitation is to create large temperature gradient so that heat pipe system will carry adequate power as it warns up.

Entrainment Limit

This is where high velocity vapour flow prevents condensate vapour from returning to evaporator. The main reason is due to low operating temperature or high power input that the heat pipe is operating. To overcome this, the vapour space diameter or the operating temperature is increased.

Capillary Limit

It is the combination of gravitational, liquid and vapour flow and pressure drops exceeding the capillary pumping head of the heat pipe wick structure. The main cause is the heat pipe input power exceeds the design heat transport capacity of the heat pipe. The problem can be resolved by modifying the heat pipe wick structure design or reduce the power input.

Boiling Limit

It is described as a film boiling in a heat pipe evaporator that typically initiates at 5-10 W/cm2 for screen wick and 20-30 W/cm2 for powder metal wicks. This is caused by high radial heat flux. It will lead towards film boiling resulting in heat pipe dry out and large thermal resistances. The potential solution is to use a wick with a higher heat capacity or spread out the heat load

Effect of Fluid Charge

Filled ratio is the fraction (by volume) of the heat pipe which is initially filled with the liquid. There is two operational filled ratio limits. At 0% filled ratio, a heat pipe structure with only bare tubes and no working fluid, is pure conduction mode heat transfer device with a very high undesirable thermal resistance .A 100% fully filled heat pipe is identical in operation to a single phase thermosyphons. The thermosyphons action is maximum for a vertical heat pipe and stops for a horizontal heat pipe and heat transfer takes place purely by axial conduction. When the charge amount was smaller, there was more space to accommodate vapor and make the pressure inside heat pipe become relatively lower. It helped nanofluid undergo vaporization and enhance its heat transfer performance.

Effect of Wick Structure

A heat pipe is a vessel whose inner walls are lined up with the wick structure. There are four common wick structures:

- Groove
- Wire mesh
- Powder metal
- Fiber/spring.

The wick structure allows the liquid to travel from one end of the heat pipe to the other via capillary action. Each wick structure has its advantages and disadvantages. Every wick structure has its own capillary limit.

Effect of Working Fluid

A first consideration in the selection of a suitable working fluid is the operating vapour temperature range within the approximate temperature band (50 to 1500 C) several possible working fluids may exit .A variety of characteristic must be examined in order to determine the most acceptable of these fluids for the application considered the primary requirements are: compatibility with the heat pipe material (s),thermal stability, wettability, reasonable vapour pressure ,high latent heat and thermal conductivity, low liquid and vapour viscosities and acceptable freezing point. The increase in heat pipe wall temperature difference was smaller than that for a pure water filled heat pipe under various heat loads when silver nano particles dispersed in working fluid.

Effect of Tilt Angle

The orientation is important for the operation of a heat pipe. Depending on conditions, a heat pipe can operate in horizontal position or in vertical position. For the horizontal position of a heat pipe, gravity has no effect. But in vertical position gravity can assist or oppose to the operation of the heat pipe. The tilt of a heat pipe is classified into two types; favorable tilt and adverse tilt. Favorable tilt is the tilt position where gravity assists heat pipe operation. In favorable tilt, condenser is positioned above evaporator. By this way, liquid return from condenser to evaporator is assisted by gravity. Therefore, capillary pumping pressure can overcome more pressure losses and this increases the heat transfer capacity of the heat pipe, in terms of capillary limit. Other type is adverse tilt. In this tilt condition, evaporator is positioned above condenser. Therefore, the liquid in the condenser shall overcome gravity force to return to evaporator. This creates extra drag for capillary pumping pressure to overcome.

3. EXPERIMENTAL METHODS

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 ±0.1oC, 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.

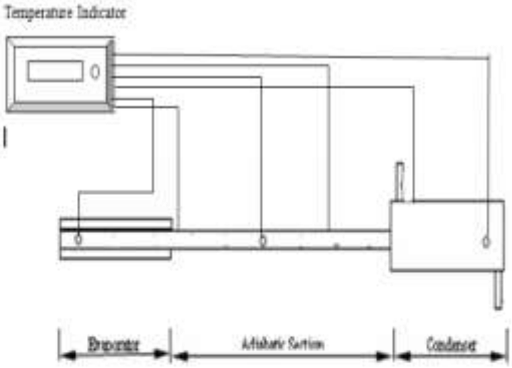

Fig: 1.1 Thermocouple Locations of Heat Pipe

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.

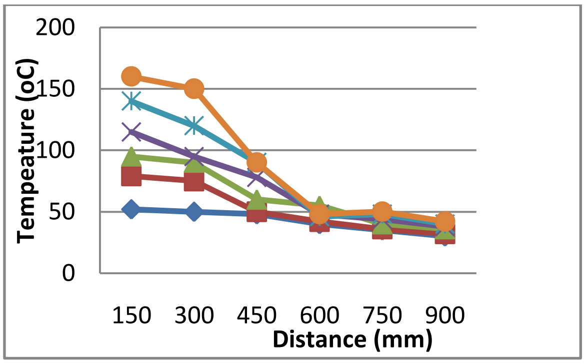

Fig.1.1.Axial temperature profile for DRY RUN

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.

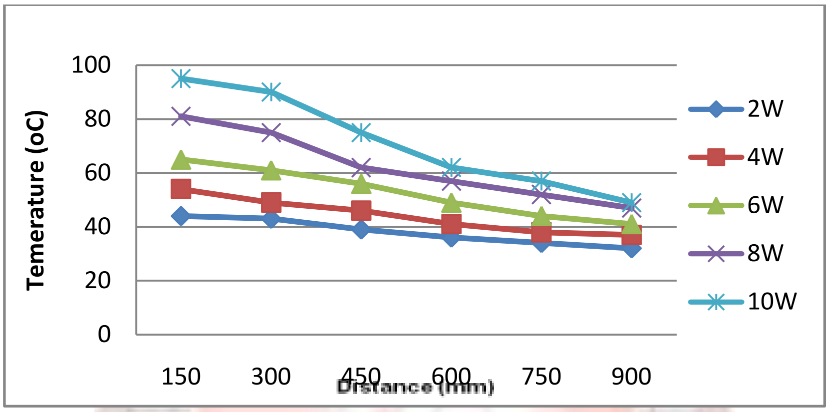

Fig. 1.4: Axial temperature profile for DI Water With 50% fill ratio

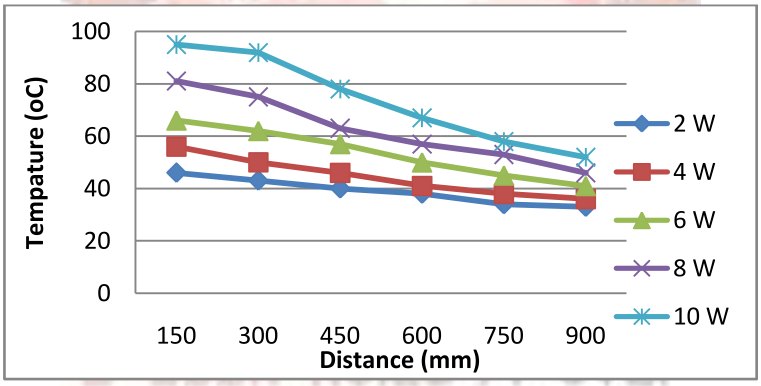

Fig. 1.5: Axial temperature profile for DI Water Mixed with Iron Oxide at 50% fill ratio

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

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

"R =" ("T" _"e" "-" "T" _"c")/"Q" " °" "C" /"W" " "

The overall heat transfer co-efficient is given by h= Q/A(T_e-T_c)   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.

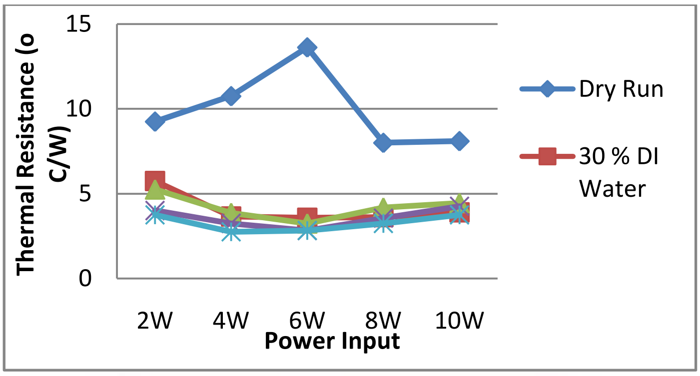

Fig. 1.6: Variations of thermal resistance with different heat inputs and fill ratios of DI water

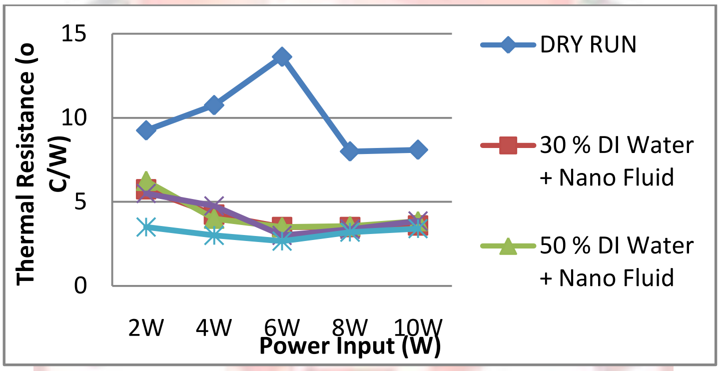

Fig. 1.7: Variations of thermal resistance with different heat inputs for different fill ratio of DI water mixed with Nano fluid

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.

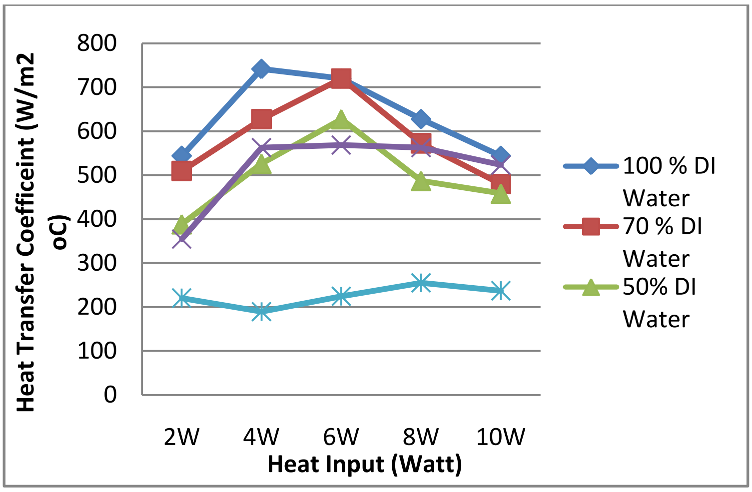

Fig. 1.8: Variations of heat Transfer Coefficient with different heat inputs for different fill ratio and DI water as working fluids

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.

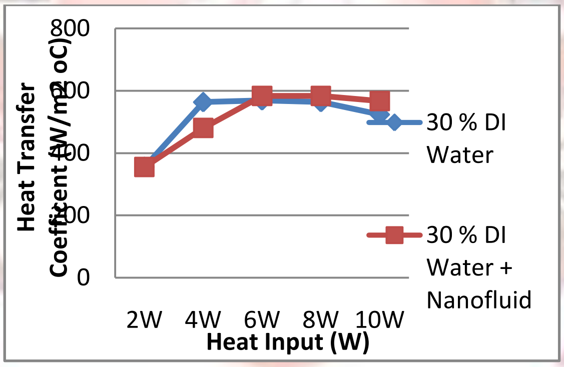

Fig. 1.9: Variations of heat Transfer Coefficient with different heat inputs for different 30% fill ratio of DI water and Nanofluid as working fluids

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.

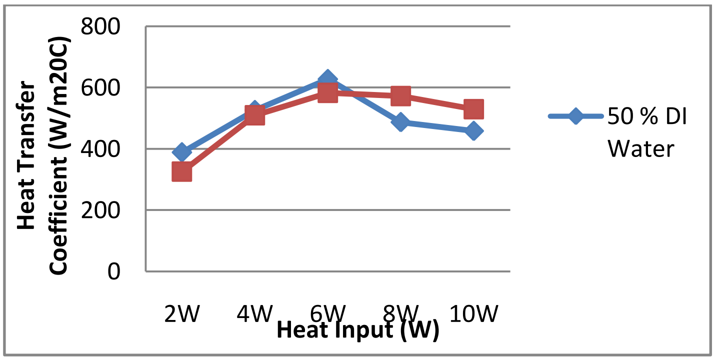

Fig. 1.10: Variations of heat Transfer Coefficient with different heat inputs for different 50% fill ratio of DI water and Nanofluid as working fluids

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. IDENTIFYING THE OPTIMUM FLUID FILL RATIO

Comparative plot of temperature difference between the evaporator and condenser section at varying fill ratio of working fluid as a percentage of evaporator volume for all the two working fluids with the heat. Loads of 6 W and 10 W are shown in the figure above. In all the cases nanofluid (DI water mixed with iron oxide) shows minimum temperature differences at all fill ratios. Hence it can be stated that for the temperature ranges tested in this study, iron oxide nanofluid forms the best working fluid. In the case of DI water, the fill ratio has minimum effect on the temperature difference between evaporator and condenser. On the other hand, nanofluid shows reduced temperature difference at higher fill ratios. With iron oxide mixed with DI water as working fluid, 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser.

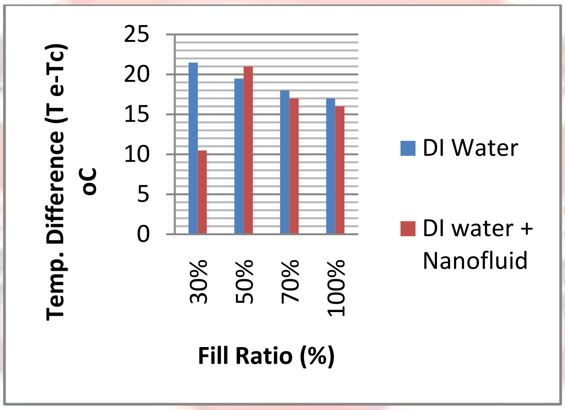

Fig.4.19: Temperature vs. fill ratio for different working fluids for input heat of 6W

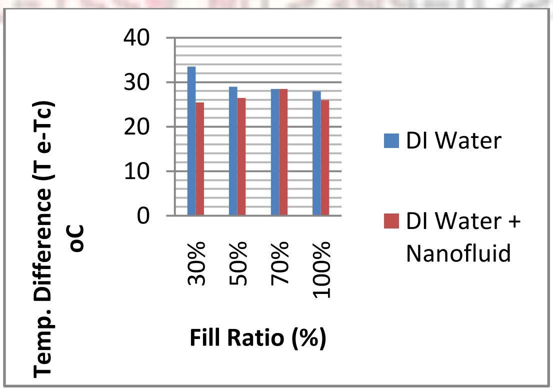

Fig.4.20 Temperature vs. fill ratio for different working fluids for input heat of 8W .

The effect of fill ratio of working fluid on heat transfer coefficients and thermal resistances are shown in Figs. above In case of water as working fluid it is observed that it shows maximum value of heat transfer coefficient and minimum value of thermal resistance at 70% fill ratio. Lower and higher than 70% fill ratio results in lower values of heat transfer coefficients and higher values of thermal resistances than that of 70%. So, it can easily be stated that for water as the working fluid, a heat pipe will perform its best at 70% fill ratio.

7. 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 (Fe_2O_3) 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.

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