Journal of Advances in Science and Technology
Vol. 13, Issue No. 1, (Special Issue) March-2017, ISSN 2230-9659

Analysis of Heat Transfer Coefficient in Heat Pipe

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Abstract – The heat pipe is similar in construction to that of a thermo siphon but in this case, a wick constructed from a few layers of wire gauge, is fixed to the inner surface and capillary forces return condensate to the evaporator. In the heat pipe evaporator position is not restricted and it may be used in any orientation. In this paper 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.

Keywords- Heat Pipe, Evaporator, Thermo Siphon, Capillary Force, Capacity

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INTRODUCTION

Heat pipes rely on a temperature difference between the ends of the pipe, and cannot lower temperatures at either end beyond the ambient temperature. When one end of the heat pipe is heated the working fluid inside the pipe at that end evaporates and increases the vapour pressure inside the cavity of the heat pipe. The latent heat of evaporation absorbed by the vaporization of the working fluid reduces the temperature at the hot end of the pipe. The vapour pressure over the hot liquid working fluid at the hot end of the pipe is higher than the equilibrium vapour pressure over the condensing working fluid at the cooler end of the pipe, and this pressure difference drives a rapid mass transfer to the condensing end where the excess vapour condenses, releases its latent heat, and warms up the cold end of the pipe. Non-condensing gases (caused by contamination for instance) in the vapour impede the gas flow and reduce the effectiveness of the heat pipe, particularly at low temperatures, where vapour pressures are low. The speed of molecules in a gas is approximately the speed of sound, and in the absence of non condensing gases (i.e., if there is only a gas phase present) this is the upper limit to the velocity with which they could travel in the heat pipe. In practice, the speed of the vapour through the heat pipe is limited by the rate of condensation at the cold end and far lower than the molecular speed [3].The condensed working fluid then flows back to the hot end of the pipe. In the case of vertically oriented heat pipes the fluid may be moved by the force of gravity. In the case of heat pipes containing wicks, the fluid is returned by action. When making heat pipes, there is no need to create a vacuum in the pipe. One simply boils the working fluid in the heat pipe until the resulting vapour has purged the non-condensing gases from the pipe, and then seals the end. An interesting property of heat pipes is the temperature range over which they are effective. Initially, it might be suspected that a water-charged heat pipe only works when the hot end reaches the boiling point (100 °C, 212 °F) and steam is transferred to the cold end. However, the boiling point of water depends on the absolute pressure inside the pipe. In an evacuated pipe, water vaporizes from its melting point (0 °C, 32 °F) to its critical point (374 °C; 705 °F), as long as the heat pipe contains both liquid and vapor. Thus a heat pipe can operate at hot-end temperatures as low as just slightly warmer as the melting point of the working fluid, although the maximum power is low at temperatures below 25 °C (77 °F). Similarly, a heat pipe with water as a working fluid can work well above the boiling point (100 °C, 212 °F). The maximum temperature for long term water heat pipes is 270 °C (518 °F), with heat pipes operating up to 300 °C (572 °F) for short term tests [4].

The main reason for the effectiveness of heat pipes is the evaporation and condensation of the working fluid. The heat of vaporization greatly exceeds the sensible heat capacity. Using water as an example, the energy needed to evaporate one gram of water is 540 times the amount of energy needed to raise the temperature of that same one gram of water by 1 °C. Almost all of that energy is rapidly transferred to the "cold" end when the fluid condenses there, making a very effective heat transfer system with no moving parts [5].

COMPACTIBILITY OF WORKING FLUID

The working fluid plays vital role in the heat transfer of any heat pipe. The heat transfer rate of any heat pipe is governed by the working fluid used. Each heat pipe application has a particular temperature range in which the heat pipe needs to operate. Therefore, the design of the heat pipe must account for the intended temperature range by specifying the proper working fluid. As a rule of thumb, the useful range extends from the point where the saturation pressure is greater than 0.1 atm and less than 20 atm. below 0.1 atm, the vapour pressure limit may be approached. Above 20 atm, the container thickness must increase to the point where the heat pipe becomes limited by the thermal resistance through the container. Longevity of a heat pipe can be assured by selecting a container, a wick and welding materials that are compatible with one another and with the working fluid of interest. Performance can be degraded and failures can occur in the container wall if any of the parts (including the working fluid) are not compatible. For instance, the parts can react chemically or set up a galvanic cell within the heat pipe. Additionally, the container material may be soluble in the working fluid or may catalyse the decomposition of the working fluid at the expected operating temperature. The working-fluid inventory of a heat pipe is the sum of the masses of the vapour and liquid phases, assuming the wick is full of liquid. This criterion is slightly over the optimum requirement because the meniscus recedes into the evaporator wick during normal operation. However, this situation is more advantageous than under filling the heat pipe, which may significantly reduce the maximum heat transfer. With extreme overfill, however, any excess fluid might collect as liquid in the condenser section and increase the thermal resistance, thereby decreasing the heat transport capability of the heat pipe.

About Iron Oxide (Fe_2O_3)

In this study the iron oxide mixed with DI water is used as working fluid. Iron oxide is a chemical compound made up of oxygen and iron. It is commonly known as hematite. Most of the times, it occurs naturally. This iron oxide with proportionate quantity is taken for mixing with DI water; Fig.1 shows the Nano particles of iron oxide.

Fig.1 Iron Oxide Nano particles

Preparation of Nano Fluid

The performance of the heat pipe is quantified with use of iron oxide nanofluid mixed with DI water. The amount of liquid filled is varied and the variation of the performance for different concentration is observed. The nanofluid is prepared with different concentration by considering the total volume evaporator section. The iron oxide particle are added into DI water and it is stirrer still all particles are settled. The following are the composition of nano fluid by its weight.

i) *For 30 % filling Ratio*

Iron Oxide - 75 mgm DI Water-10 ml

ii) *For 50 % filling Ratio*

Iron Oxide -1 gm DI Water-15 ml

iii) *For 70 % filling Ratio*

Iron Oxide -1.5 gm DI Water-20 ml

iv) *For 100 % Filling Ratio*

Iron Oxide -2 gm DI Water-30 ml

EXPERIMENTAL PROCEDURE

The experiments are conducted using heat pipe which is manufactured as per mentioned dimensions as shown in fig.2. 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 was equipped with the band heater. Power to the heater was provided from line supply through a variance. Fins were attached at the condenser section and a fan was directed towards the fins for forced convection to occur at this section. 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 a distance 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 variance. 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.

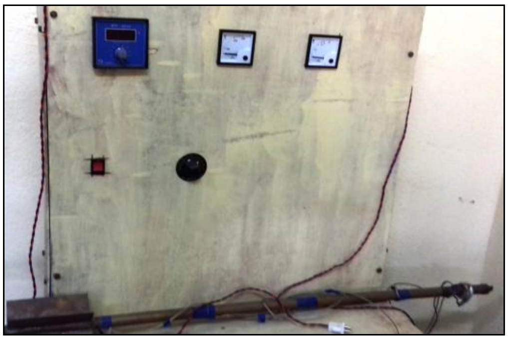

Fig.2. Experimental Set up

RESULT

However with DI water as working medium, it is constant with heat input. Heat pipe with nanofluid as working fluid shows very high heat transfer co-efficient. However, this monotonous trend of increasing value of heat transfer coefficient with increased load is limited by the burn out at highest heat input. As explained earlier, at this state the rate of condensate return will be lesser than the rate of evaporation, leading to "starving" at the evaporator section as shown in fig.3 and Table1.

Table: 1 Heat Transfer Coefficient along Heat Pipe with DI water mixed with Nanofluid as working fluid at different fill ratios

Power Input	2W	4W	6W	8W	10W
Heat Transfer Coefficient (h)					
Dry Run	220.6	189	224	255	237
35 % DI Water + Nanofluid	354.92	480	583.0	583	566.8
55 % DI Water + Nanofluid	326.53	510	583.0	572	530
85 % DI Water + Nanofluid	371.05	907	680.2	604.6	530.0
100 % DI Water + Nanofluid	1024.4	680	765.3	640.2	600.2

Fig. 3 Variations of heat Transfer Coefficient with different heat inputs for different fill ratio and DI water mixed with Nanofluid as working fluids

CONCLUSION

With Nano fluid mixed with DI water, the temperature difference across evaporator and condenser continues to drop down with an increase in the fill ratio. With Nano fluid mixed with DI water as the working fluid, 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser. Fill ratios of working fluid greater than 70% of volume of evaporator show better results in terms of increased heat transfer coefficient, decreased thermal resistance and reduced temperature difference across the evaporator and condenser.

FUTURE SCOPE

To find the effect on overall heat transfer coefficient and Heat transfer rate with variation in base Fluid of Hybrid Nanofluid in connection with Heat Pipe. To find the thermal Performance of heat pipe for different angle of Inclination.

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