Design and Fabrication of a Heat Pipe using Refrigerant R-134a as Working Fluid

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Abstract - *Heat pipe is a simple device of very high thermal conductance with no moving parts that can transfer a large amount of heat by absorbing and releasing latent heat by a phase changing working fluid. As heat pipe is advantageous in heat transfer application over ordinary process, it is a topic of interest by the researcher and is improving every day. In this experimental work, a simple heat pipe was designed and fabricated using refrigerant R-22 as working fluid. Then the performance of the heat pipe was compared with natural cooling. The comparison was also made between free and forced convection applying a constant power input of 3.825 watt. For forced convection air velocity of 3.4 m/s and 4.1 m/s was used. It is found that with the aid of a heat pipe cooling rate can be decreased by 47%. This percentage can be decreased further by forced convection even with a constant power input. It is also found that the overall thermal resistance decreases with time.*

Keywords - *Heat Pipe, Refrigerant R-134a, Heat transfer, Free convection, forced convection, Overall thermal resistance.*

I. INTRODUCTION

A heat pipe is a simple device of very high thermal conductivity with no moving parts that can transport large quantities of heat efficiently over large distances fundamentally at an invariable temperature without requiring any external electricity input. A heat pipe is essentially a conserved slender tube containing a wick structure lined on the inner surface and a small amount of fluid such as water at the saturated state [1]. Heat pipe is divided into three sections namely evaporator section, adiabatic section and condenser section. At evaporator section the working fluid takes heat and evaporated, then it goes to the condenser section through the adiabatic section where it rejects heat and becomes liquid. The liquid from the condenser section then moves back to the evaporator section by capillary action with the help of a wick structure or by gravity in case of thermosiphon. The heat source or evaporator section can be more than one and sometimes there may be absence of an adiabatic section. [2].

Using heat pipe in heat transfer application is advantageous over the other ordinary methods. It can have extremely high thermal conductance in a steady state operation. It also works on the basis of absorbing and rejecting the latent heat. Therefore, it can transfer a high amount of heat over a relatively long length with a comparatively small temperature difference. A heat pipe can also have thermal conductance much more than the best solid metallic conductor such as silver and copper. Moreover, the designing and manufacturing process of heat pipe is simple. So, it has become a popular device with unique characteristics in a wide range of heat transfer application [3].

The heat pipe has been, and currently is being, studied for a wide variety of applications, covering almost the complete spectrum of temperatures encountered in heat transfer processes. Some of the major application areas of heat pipe are: energy storage system, chemical reactor, aircraft and spacecraft, energy conservation and renewable energy, preservation of permafrost, melting and de-icing of snow, food industry [4].

Though the idea of heat pipe was suggested by Gaugler [5] in 1942, the significance of heat pipe was realized after its independent invention by Grover [6],[7]. Since then, a number of experimental studies have been carried out to provide data on heat pipe operation, set references for validation of theoretical models, and provide databases for design purposes. In addition, many theoretical analyses have incorporated empirical or semi-empirical correlations to simplify the models and the solution process [8].

In literature researches were conducted on heat pipe for different working fluids depending on the temperature range and application [9]-[14]. Refrigerant have a wide range of working temperature depending on the operational pressure. So, using refrigerant as working fluid will enhance and widen the range of working condition of a heat pipe.

It is well recognized that the quick destruction of the ozone layer in the earth atmosphere noted recently has been primarily related to the wide use of the chlorofluorocarbon "CFC" refrigerants which have been employed as the working fluids in many refrigeration air conditioning and heat pump systems or as cleansing fluids for processing microelectronic devices. Under the mandate of the Montreal Protocol the use of CFCs had been phased out and the use of

HCFCs will also be phased out in a short period of time. Therefore, we have to replace the CFCs by new alternative refrigerants. In order to properly use these new refrigerants detailed understanding is required [15].

In this experiment R-134a is used as the working fluid. R134a is a single hydrofluorocarbon or HFC compound with no chlorine content and ozone depletion potential. It has a modest global warming potential.

The specific objective of this study was to design, fabricate and analyse the performance of the heat pipe.

II. METHODOLOGY

In this experiment a simple heat pipe was designed and fabricated using a Copper tube. The detailed structural parameters of the fabricated heat pipe are given in Table 1. Hot water in a mug was used as the heat source.

TABLE 1. STRUCTURAL PARAMETERS OF HEAT PIPE

Diameter of pipe	25.4 mm
Wall Thickness	1 mm
Length of condenser	170 mm
Length of evaporator	140 mm
Length of Adiabatic Section	140 mm
Fin Dimension	(150 mm×70 mm)
Number of Fin	5
Working fluid	R-134a
Fill ratio	58%
Wick Type	Wire mesh
Insulator for adiabatic section	Glass wool

At first, the water was heated to 46℃ using a heater and then allowed to cool. The temperature of the hot water was measured by a mercury thermometer and recorded periodically. Then again the water was heated to 46℃ and the heat pipe was dipped in the mug. The temperature of the condenser section of the heat pipe was measured by a k-type thermocouple and recorded periodically. Then after heating the water to 45℃ a constant input of 3.825 watt was applied at the evaporator section. Three sets of data was recorded for free convection, forced convection (V_{air}=3.4 m/s), and forced convection (V_{air} =4.1 m/s). A table fan was used for forced convection and an anemometer was used to record the velocity of the fan. The experimental set up is shown in Fig. 1.

Using the heat input, condenser temperature and evaporator temperature, the overall thermal resistance of the heat pipe was calculated. The overall thermal resistance of a heat pipe is defined by the following expression,

$$R = \frac{T_E - T_C}{Q} \dots\dots\dots (1)$$

Where, R is the overall thermal resistance in ℃/W, T_E and T_C are the temperature of Evaporator section and condenser section respectively. The temperature of the hot water inside mug was assumed as the temperature of evaporator. The reduction in cooling time was calculated using the following formula,

$$\%\text{ of reduction in cooling time} = \frac{\Delta T}{T_{free}} \times 100\% \dots\dots\dots (2)$$

Where, ΔT represents the difference in time between free and forced convection to cool down to a certain temperature, and T_{free} represents the time required for free convection to reach at reference temperature.

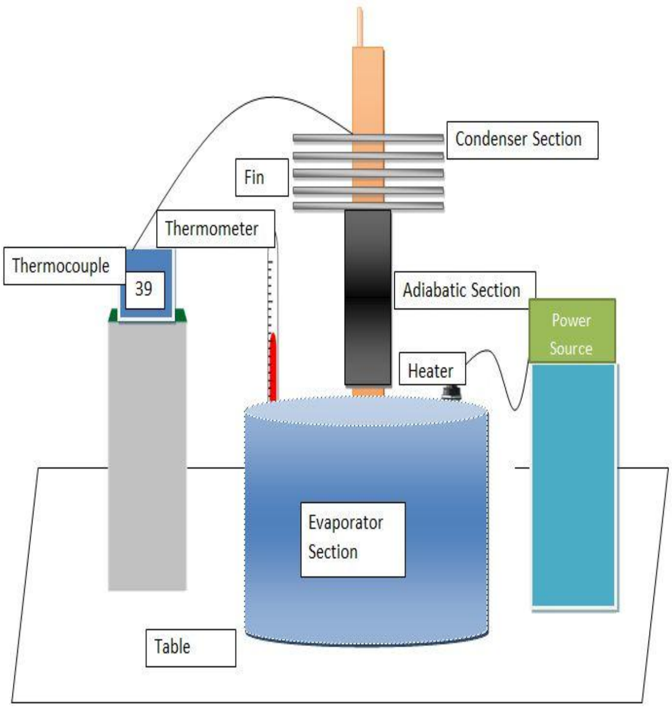

Fig. 1 Experimental setup

III. RESULT AND DISCUSSION

Fig. 2 presents the temperature of hot water against time with and without the application of heat pipe.

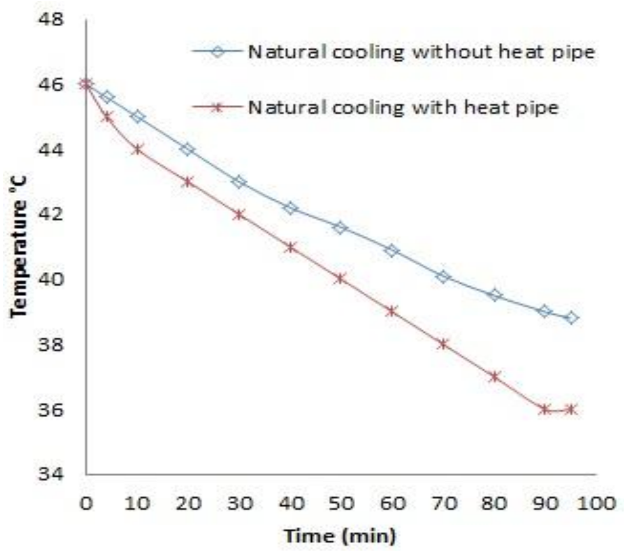

Fig.2 Temperature of hot water with and without the application of heat pipe against time.

Here, it is seen that after 95 minutes hot water cooled down from 46 to 40℃ whereas using heat pipe the temperature reduced to 36℃ . With heat pipe, hot water cooled down to 40 ℃ after 50 minutes. So it can be concluded that application of heat pipe reduce the cooling time by 47.4%.

Fig. 3 and 4 represents the temperature of evaporator section and condenser section respectively with respect to time for three different conditions. The conditions are free convection, forced convection for an air velocity of 3.4 m/s and 4.1 m/s respectively. It is seen from fig. 3 that after 95 minutes the evaporator section has the lowest temperature of 37.5℃ for forced convection with an air velocity of 4.1 m/s.

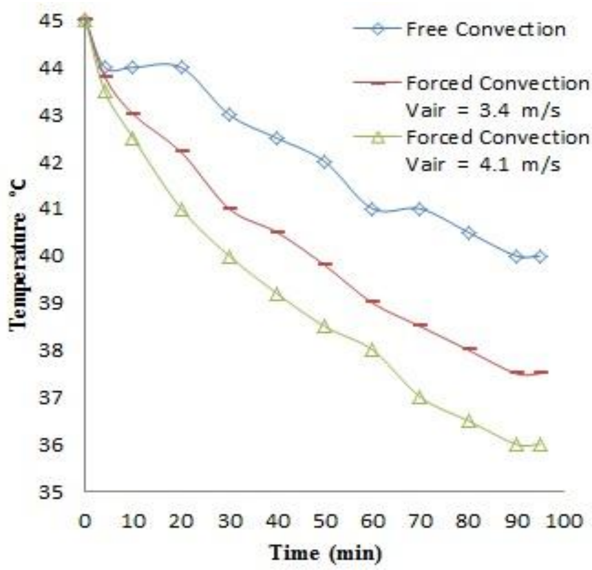

Fig. 3 Change in evaporator section temperature with time

After 95 minutes, evaporator section has a temperature of 37.5 and 40℃ for Forced convection with an air velocity of 3.4 m/s and free convection. For cooling of the evaporator from 45 to 40℃, forced convection reduce the cooling time by 68.4% and 49.4% for with air velocity of 4.1 m/s and 3.4 m/s respectively. Again, cooling time is reduced by 73.3% and 66.7% by forced convection with air velocity of 4.1 m/s and 3.4 m/s respectively compared to free convection to cool down from 45 to 43℃. The percentage of saving time decreases as time passes because the temperature difference between the evaporator section and condenser section decreases over time shown in fig.3 and fig.4. It is also seen from fig. 4 that free convection takes more time than forced convection to become steady.

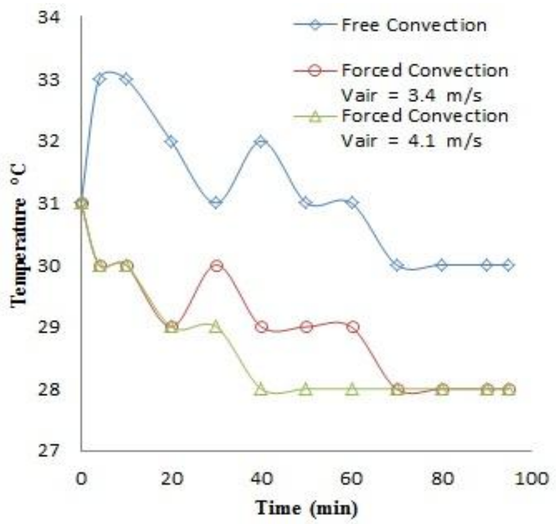

Fig. 4 Change in temperature of condenser section with time.

Fig. 5 shows the change of overall thermal resistance over time for free and forced convection with air velocity of 4.1 and 3.4 m/s respectively with constant power input of 3.825 watt

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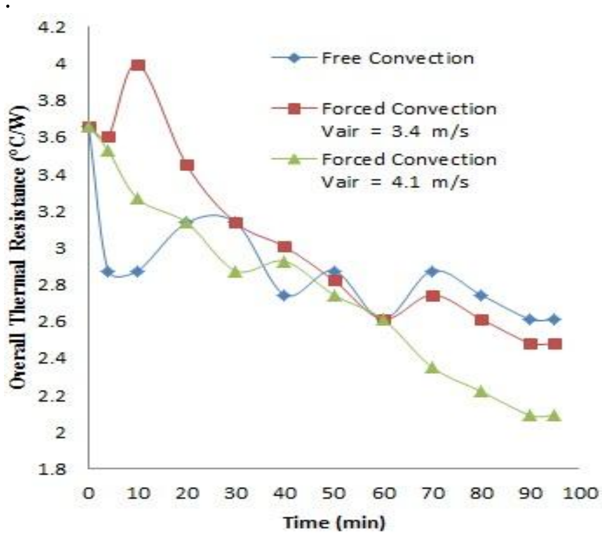

Fig. 5 Change in overall thermal resistance with time.

It is seen that the overall thermal resistance is decreases over time as it depends on the temperature difference between the condenser and evaporator. The higher the temperature difference the higher the overall thermal resistance. Among the three curves, forced convection (V_{air}=4.1 m/s) shows the most smooth curve. This is due to the fact that in forced convection with higher velocity condenser temperature becomes steady within a short period of time as shown in Fig. 4.

IV. CONCLUSIONS

From the experimental result it is clear that using refrigerant R-134a as the working fluid in a heat pipe hot body can be cooled down faster than natural cooling. This also works with a constant power input. And the rate can be further increased by forced convection with air. The cooling rate increases with air velocity. Cooling rate decreases over time for any process, as the temperature gradient decreases with time. Heat pipe is preferred device for various heat transfer application. The performance of the heat pipe can be increased by using refrigerant and can be applied for wide range of temperature varying the working pressure of the refrigerant. Refrigerant R-134a is a replacement for various ozone depleting gases. The data found in this experiment can be further used as a reference for the application of R-134a in any heat transfer process.

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