Analysis of a Vertical Heat Pipe for Free and Forced Convection using Refrigerant R-22 as Working Fluid

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***Abstract*— The heat pipe is a highly effective heat transmitting device that allows transferring a large amount of heat over a considerable distances with minimal temperature difference. As heat pipe can transmit a large amount of heat by the virtue of latent heat of vaporization and condensation by using a two phase fluid as working fluid and it requires no external power source, it has become one of the heavily investigated approaches to the researcher in the field of heat transfer. This paper illustrates an experimental work for a simple vertical heat pipe using refrigerant R-22 with a view to analyzing the performance for free and forced convection with and without the application of a constant power input. The overall thermal contact resistance was also calculated and compared for free and forced convection. During the experiment the air velocities of 2.4 and 3.2 m/s was used for forced convection and a constant power input of 7.84 watt was applied. It has been observed that forced convection require 67% to 70% less time than free convection. The overall thermal resistance was also found to be higher in forced convection than free convection.**

Keywords—Vertical Heat Pipe, Refrigerant R-22, Overall Thermal Resistance, Free convection, Forced Convection.

I. INTRODUCTION

The heat pipe is a highly effective heat transmitting device that allows transferring a large amount of heat over considerable distances with minimal temperature difference. Heat pipe also come with simple construction, and easy control, and it does not require external pumping power.

In 1942 the idea of the heat pipe was suggested by Gaugler [1]. However, the remarkable properties of the heat pipe became appreciated and serious development work took place after its independent invention by Grover [2, 3] in the early 1960s. A simple heat pipe has three major components: a sealed container, working fluid and wick structure. The heat pipe can be divided into three sections: evaporator section, adiabatic section and condenser section. The working fluid in the evaporator section becomes vapor absorbing the heat from heat source that goes to the condenser section through the adiabatic or transport section and becomes liquid releasing a vast amount of latent heat to heat sink at condenser section. The wick structure helps the liquid to return back to the evaporator section by capillary action. A heat pipe may have single or multiple heat source or heat sink [4]. Heat pipe can transport a large amount of heat without the aid of any external power source. As a result it has become popular for various heat transfer equipment and numerous study has been carried out since its first application in aerospace. There are many heat pipe configurations like two phase closed thermo-syphon, capillary driven heat pipe, vapor chamber heat pipe, rotating heat pipe, loop heat pipe, pulsating heat pipe, micro and miniature heat pipe that have been built for different applications including in heat exchangers, waste heat recovery, cooling of electric equipment, storage facility, renewable energy etc. [5-10].

To get the best performance from a heat pipe it is very important to select the wick structure and working fluid for a certain application. A particular working fluid can only be a functional at certain temperature ranges. The choice of working fluid should also incorporate the fluid's interactions with the heat pipe container and wick [11]. There are a number of researches found in the literature for various wick structure [12-14] and working fluid [15-21]. In this study wire mesh was used as the wick structure and refrigerant R-22 was used as the working fluid. R-22 or chlorodifluoromethane is a hydrochlorofluorocarbon (HCFC) which is a colorless gas and commonly used as a propellant and refrigerant. R-22 is often used as an alternative to the highly ozone-depleting CFC-11 and CFC-12 [12]. Since the HCFCs were firstly invented by Thomas Midgley and Albert Henne in 1930, they have become the dominant types of refrigerants and R-22 has been predominantly used, in the past few decades, in domestic air-conditioners and heat pumps due to its preferable characteristics [23].

In this research a simple vertical heat pipe was designed and fabricated and the performance of the refrigerant R-22 as working fluid was analyzed for both free convection and forced convection.

II. METHODOLOGY

A schematic diagram of the experimental setup is shown in Fig. 1. It consists of a mug full of hot water in which the evaporator section of the heat pipe was dipped in, a heater, one k-type thermocouple, one mercury thermometer, and a fan. The heat pipe was constructed using a copper tube. The diameter and length of the tube was 25.4mm and 450mm respectively. Wire mesh was used as the wick structure. The length of the evaporator section, adiabatic section and condenser section was 170mm, 140mm and 140mm in respectively. The adiabatic section was insulated using glass wool and tape. Five (15cm×7cm) rectangular fins made of tin were integrated on the condenser section. It was assumed that the temperature of the evaporator was equal to the temperature of water. A mercury thermometer was used to measure the hot water temperature which that is temperature of the evaporator and k-type thermocouple was used to measure the condenser temperature. A fan was used for forced convection. The velocity of the fan was measured using a digital anemometer. Data was recorded giving interval for four different set of

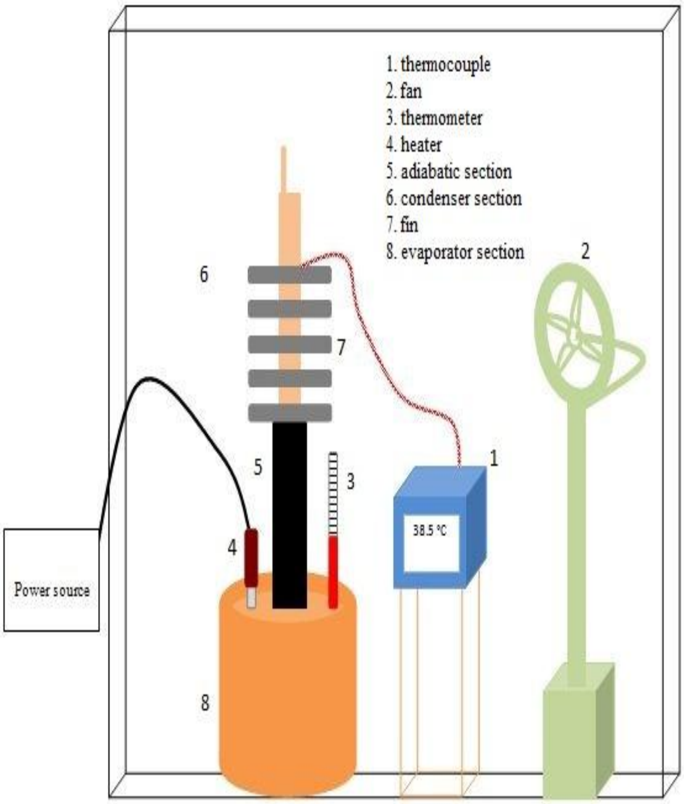

Fig. 1 Schematic diagram of the test apparatus.

condition: i) natural convection heat transfer without applying any power input, ii) natural convection and with a constant power input of 7.48 watt, iii) forced convection with an air velocity of 2.4 m/s and constant power input of 7.48 watt, and iv) forced convection with an air velocity of 3.2 m/s constant power input of 7.48 watt. Initially the water was heated to 56˚C. Then the temperature of the evaporator section and condenser section was recorded periodically for 110 minutes. Constant power input of 7.84 watt was applied after taking first set of data and heating again the water to 56˚C. Then second set of data was recorded. For third and fourth set of data same was done using a fan for an air velocity of 2.4 ms^{-1} and 3.2 ms^{-1} respectively. Then the recorded data was plotted to compare cooling time for free and forced convection. The overall thermal resistance of the heat pipe defined by the following equation [24] was used to compare the performance for free and forced convection with a constant power input.

$$R = (T_E - T_C)/Q \quad (1)$$

Where, R is the overall thermal resistance of the heat pipe in ˚C/W, T_E and T_C are the temperature of the evaporator and condenser respectively in ˚C and Q is the constant power input in W.

III. RESULT AND DISCUSSION

Fig. 2 and Fig. 3 shows the Time vs. Evaporator temperature and Time vs. Condenser temperature respectively for four different set of conditions. It is seen from the Fig. 2 that the cooling rate of the evaporator section initially is higher for each condition. It is because higher temperature gradient between the evaporator and condenser as shown in Fig. 2 and 3.

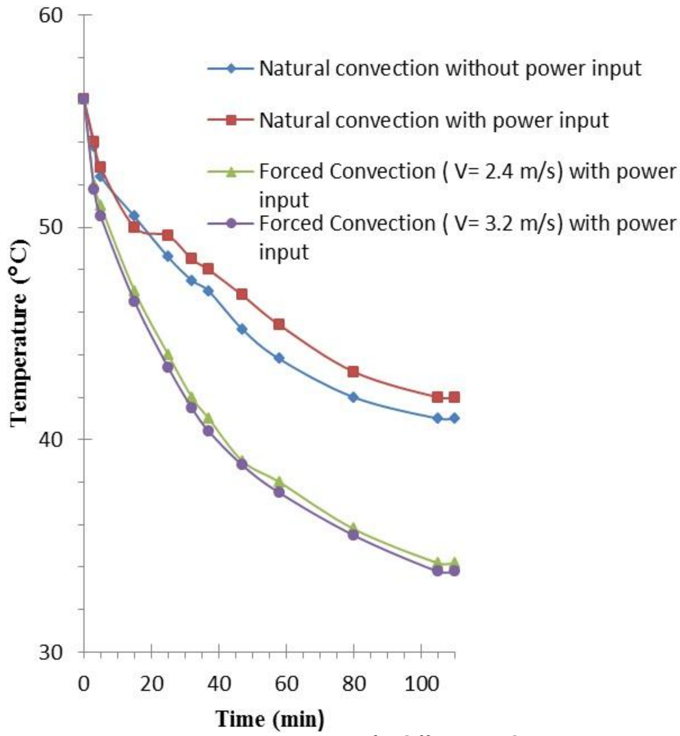

Fig. 2 Time vs. Evaporator Temperature for different conditions.

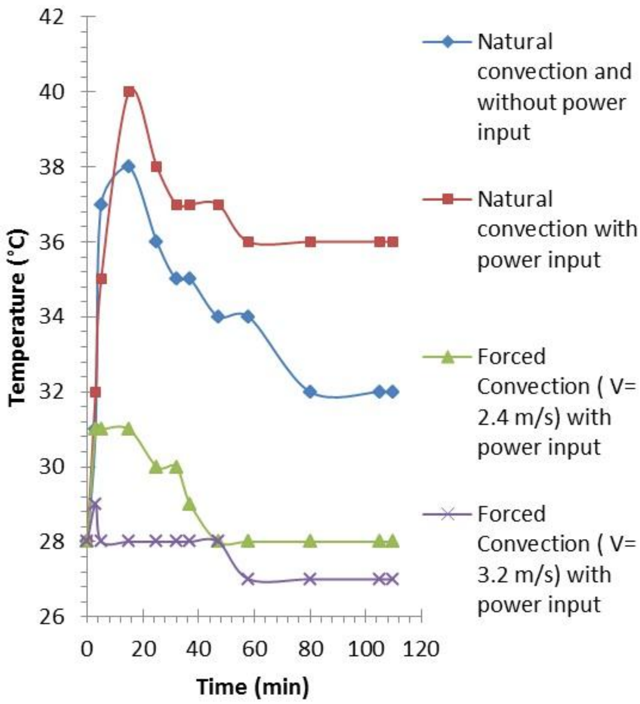

Fig. 3 Time vs. Condenser Temperature for different conditions

As time goes the cooling rate decreases as the temperature gradient decreases. Among the four conditions, forced convection with an air velocity of 3.2 m/s has the highest cooling rate, followed by the forced convection for an air velocity of 2.4 m/s, natural convection without power input and natural convection with power input respectively

The natural convection with power input has the lowest cooling rate as there is constant power input and there is no air to reduce the condenser temperature. It is also seen from Fig.2 that natural convection with constant power input require 110 minutes to reach 42˚C, but forced convection with power input requires only 32 and 31 minutes respectively for an air velocity of 2.4 m/s and 3.2 m/s respectively. Thus after 110 minutes Forced Convection with an air velocity of 2.4 m/s and 3.2 m/s takes 71% and 72 % less time. Again for cooling the evaporator section from 56 to 46˚C, the percentage of reduction time becomes 66% and 67% for forced convection with an air velocity of 2.4 m/s and 3.2 m/s. Fig. 3 also shows that free convection takes more time to become steady than forced convection.

Fig. 4 shows the variation of overall thermal resistance of the heat pipe for free and forced convection over time. Here it is seen that the overall thermal resistance is higher at the beginning and gradually decreases over time for all three conditions. As the power input is fixed and the temperature gradient between the condenser and evaporator decreases over time, overall thermal resistance also decreases.

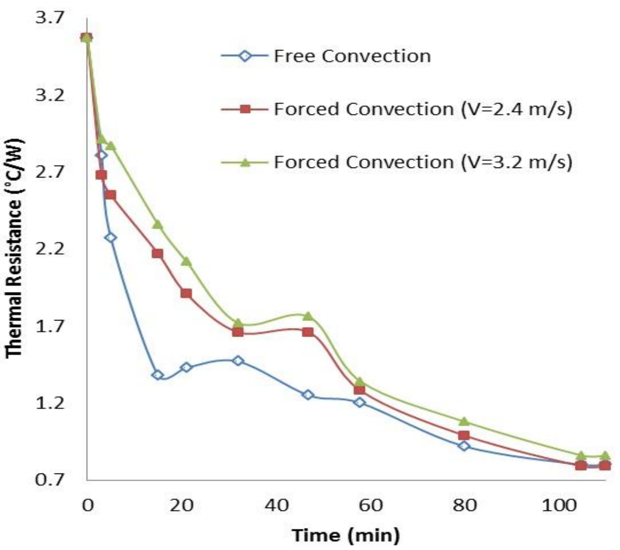

Fig. 4 Time vs. Overall Thermal Resistance for different conditions

IV. CONCLUSION

From the result obtained from this experiment it is evident that a heat pipe for forced convection performs higher than free convection reducing the cooling time 60% to 70%. The overall thermal resistance in forced convection is also higher than the free convection as it depends on the temperature gradient and forced convection maintain a higher temperature gradient than free convection. As the boiling temperature of the refrigerant is dependent on its pressure, different temperature range for specific operation can be obtained by maintaining that certain pressure. This experimental data presented here for refrigerant R-22 can be further used as a standard.

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