Experimental Investigation on the Thermal Resistance of Straight Heat Pipes with Double-Ended Cooling and Middle-Heating at Different Tilt Angles

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ABSTRACT: An experimental study has been investigated on the thermal resistance of straight heat pipes with double-ended cooling and middle heating at different tilt angles. Two cooling blocks installed on both ends of heat pipes and a coil heater placed in the middle as the condenser and evaporator sections respectively. The experiments were conducted at inclinations 0° to 90° for heat inputs 20 to 80 W. The effects of heat input variation, cooling water flow rate and tilt angle on the thermal resistance of heat pipes were studied. The obtained results compared with the conventional heat pipes. The results showed that by using the new cooling approach, the thermal resistance of the heat pipes can be reduced significantly. Also, in low heat inputs, increasing the cooling water flow rate increases the thermal performance of the heat pipes. The experimental results indicated that the tilt angle has a significant effect on the thermal resistance of the heat pipes. The minimum thermal resistance and the maximum effective thermal conductivity coefficient values are 0.2533 °C/W and 14072.65 W/m°C respectively, and they were observed at the tilt angle equal to 60° and for heat input of 60 W.

1. INTRODUCTION

Heat pipe is a very convenient and efficient heat transfer device designed based on the principles of thermal conductivity and fluid phase change. The retaining chamber, wick structure, and the working fluid can be referred to as the three main components of the heat pipe. The structure of a heat pipe in terms of performance is divided into three sections: evaporator, insulation and condenser. At the evaporator section, the water liquid vaporizes by absorbing the heat power inserted to the wall surface of the retaining chamber. The produced vapor moves from the evaporator to the condenser through the insulation section due to the pressure difference between the condenser and the evaporator. In the condenser section, the vapor converts to the fluid phase again by losing its latent heat to the heat sink. Then the wick structure moves the condensed water from the condenser to the evaporator due to the capillary force.

Today, In many practical applications, such as the space industry [1], energy storage and recycling systems [2], electronic cooling and etc., most of the heat pipes are installed in non-horizontal conditions. In such cases, the cooling and reliability of the heat pipe's efficiency during their operation is very important. So the tilt angle is one of the effective parameters in the thermal efficiency of the heat pipes, which is very important for the cooling of the electronic equipment and plays an essential and important role in the thermal resistance of the heat pipes. The thermal resistance has a huge impact on heat loss and the performance of the cooling system. Many studies have been done so far on the inclined heat pipes that Vassilev [3] and Kamotani [4] can be considered as the first persons in this regard. In this research, the effect of heat input, tilt angle and the volumetric flow rate of the cooling water on the thermal resistance of the Double-ended Cooling and Middle Heating (DCMH) heat pipes has been studied. The results compared with conventional heat pipes at a positive tilt angle (Single Heating Upper Cooling (SHUC)) and conventional heat pipes at a negative tilt angle (Single Heating Bottom Cooling (SHBC)).

2. METHODOLOGY

2.1. Description of the heat pipe

The heat pipes used in this study were made from a free-oxygen copper tube with 10 mm, 9.5 mm and 280 mm as outer diameter, inner diameter, and total length respectively. All the heat pipes had an equal evaporator, adiabatic and condenser length which was 70 mm, 110 mm and 100 mm respectively. Two cooling blocks installed on both ends of the heat pipes and a coil heater placed in the middle as the condenser and evaporator sections respectively.

2.2. Experimental setup and procedure

The schematic of the experimental setup used to evaluate the heat pipe's thermal resistance is shown in Fig. 1. The

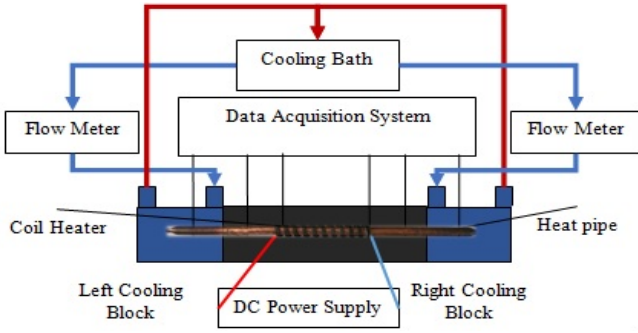*Corresponding author's email: spooshan@kashanu.ac.ir

Fig. 1. schematic of the experimental setup

experiments were proposed and evaluated at different tilt angles (0° to 90° with incrimination of 10°). The testing heat input range was between 20 W to 80 W by increments of 20 W.

2.3. Data reduction

Thermal resistance is a decisive parameter used to investigate and compare the different heat pipes thermal performance in different modes and calculated as [5]:

$$R_{tot} = \frac{\Delta T}{Q_e} \tag{1}$$

In which ΔT and Q_e are the temperature difference between the evaporator and condenser and heat input applied to the evaporator surface of the heat pipe respectively and can be calculated from the following equations:

$$\Delta T = T_e - T_c \tag{2}$$

$$Q_e = V \times I \tag{3}$$

Where V is the voltage and I is the electric current and T_e and T_c are the surface average temperatures of the evaporator and condenser respectively.

3. RESULTS AND DISCUSSION

Fig. 2 shows the surface temperature axial distribution of the double-ended cooling and middle heating heat pipes at the horizontal position for different volume flow rates of cooling water. It is clear that by increasing the flow rate of the cooling water the surface temperature of the heat pipes decreases significantly. This decreasing in the surface temperature of the heat pipes can be justified by the fact that by increasing the flow rate of the cooling water, the amount of heat dissipated in the condenser increases and increases the amount of condensed water reaching to the evaporator, which decreases its surface temperature.

Fig. 3 shows the variation of total thermal resistance of heat pipes for different tilt angles at 80 W heat input. It is shown that with increasing the tilt angle up to the 60°, the thermal resistance of the heat pipes decreases, which can be attributed to the effect of gravity force. Because by increasing the tilt angle, in addition to the capillary force, gravity also helps to
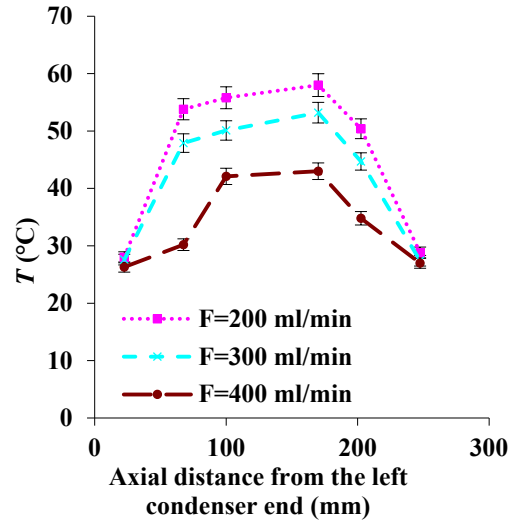

Fig. 2. Surface temperature axial distribution of the double-ended cooling and middle heating heat pipe at a horizontal position for different volume flow rates of cooling water at 40 W heat input
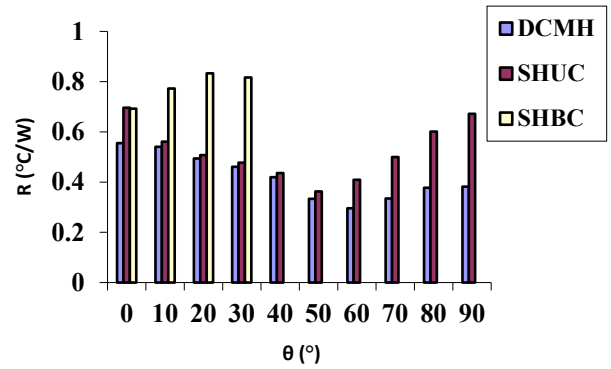

Fig. 3. The thermal resistance of the heat pipes at 80 W heat input and for different tilt angles

return the liquid to the evaporator and causes that working fluid reaches the evaporator more rapidly and decreases the thermal resistance. With an increasing tilt angle of more than 60°, the thermal resistance of the heat pipes increases again because the right condenser of the heat pipe is placed at the bottom of the evaporator. Therefore, the condensed fluid in the right condenser must move in the opposite direction to the gravitational force and upward, which is carried out only by the capillary effect of the wick. The minimum thermal resistance for double-ended cooling and middle heating heat pipe was obtained at 60° bending angle for 60 W heat input, which has decreased by 49.58% relative to the conventional heat pipe at positive tilt angles. It should be noted that for all tilt angles the thermal resistance of double-ended cooling and middle heating heat pipes is lower than conventional heat pipes for all heat inputs.

4. CONCLUSIONS

An experimental study was proposed and evaluated on the thermal resistance of the double-ended cooling and middle

heating straight heat pipes at different tilt angles. Results showed that with increasing the flow rate of the cooling water the evaporator surface temperature of the heat pipes reduced. The results indicated that for the double-ended cooling and middle heating heat pipes the total thermal resistance decreases with increasing the tilt angle up to 60°, then increases again with increasing tilt angle more than 60°.

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