Experimental Study on Thermal Behavior of a Stainless Steel-Di Water Flat Plate Heat Pipe

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Abstract: Thermal performance of a stainless steel-DI water flat plate heat pipe (FPHP) is investigated experimentally. The heat pipe walls are made of stainless steel plate. Also DI-water and stainless steel mesh screen are utilized as working fluid and wick structure respectively. Experiments are conducted with various input heat fluxes in order to study thermal performance of the FPHP. The results show that thermal resistance increases with time and stays constant at the steady state condition. Furthermore, it is found that time of reaching to the steady-state condition decreases by increasing the heat flux. Moreover, it has been concluded that temperature distribution on the FPHP walls is rather uniform.

Key words: Experimental study · Stainless steel · DI water · Flat plate heat pipe

INTRODUCTION

Flat-plate heat pipes (FPHPs) are effective heat transfer devices in many industrial applications. They are special types of heat pipes which can usually transfer higher amounts of heat fluxes with respect to cylindrical heat pipes. A FPHP consist of three main part namely, container, working fluid and wick structure which is a porous media. For more information about porous media an interested reader can refer to [1-5]. As FPHPs have suitable thermal characteristics, flat-plate heat pipes are used in many applications including cooling of high power semiconductor chips and cooling of electronic equipments, spacecraft radiator segments and thermal management in the irradiation facility for Boron Neutron Capture Therapy (BNCT) [6-14]. They can also be used as a constant temperature surface along with a heater in some specific applications such as chemical heat treatment processes in wood industries.

A comprehensive experimental study has been performed by Vafai et al. [15] on a copper- D,O flat plate heat pipe. The heat pipe was 190.50 mm in length (L), 139.70 mm in width and thickness of 34.93 mm. They concluded that the temperature along the heat pipe wall surfaces is quite uniform and also indicated that the porous wick of the evaporator section creates the main thermal resistance resulting in the largest temperature drop, that affects the performance of the heat pipe. Furthermore, they obtained an empirical correlation for the time constant in terms of input heat flux (q). In their work a correlation for the maximum temperature rise and maximum temperature difference within the FPHP are also investigated.

Kikuchi et al. [16] had performed experiments on an electro hydrodynamic flat plate heat pipe. The heat pipe was 100 cm in length and 10 cm in width. Two Freon 111 and 113 were used as working fluid. Their results showed that Freon 11 was superior to Freon 113 from the point of view of thermal transport.

Basiulis et al. [6] carried out experiments to find out the performance of flat plate heat pipes for cooling printed wiring boards. Thomson et al. [4] investigated the application of FPHPs in the cooling of high power amplifiers for communication satellites.

Boukhanouf et al. [12] experimentally investigated the performance of a flat-plate heat pipe using an IR thermal imaging camera. Steady-state and transient temperature distribution of the evaporator surface of the FPHP have been measured using a single heat source with varied heat flux inputs.
For performance comparison, the experimental measurements have also been carried out on an identical flat plate heat pipe with a defect and on a solid copper block of similar dimensions. It has been shown that temperature excursion on the surface of the fully functioning flat plate heat pipe is less than 3°C for operating temperatures up to 90 °C and heat flux inputs ranging from 4 to 40 W/cm². Furthermore, the thermal spreading resistance of the flat plate heat pipe has been found to be about 40 times smaller than that of the solid copper block and flat plate heat pipe with a defect. Xuan et al. [13] examined the transient behavior of flat plate heat pipes with applied heat flux ranging from about 10 W/cm² to 16 W/cm² and achieved operating temperatures of about 63°C. Chien et al. [14] studied evaporation resistance on porous surfaces in flat heat pipes. Koito et al. [15] performed an experimental and numerical analysis of heat transfer in FPHPs with a single axisymmetric heat source.

In the present work, an experimental investigation is conducted to describe the thermal treatment of a stainless steel-DI water flat plate heat pipe in different heat fluxes.

**Experimental Set Up:** Flat plate heat pipe which is studied in this work is 200 mm in length, 200 mm in width with thickness of 30 mm. The heat pipe walls were made of 2 mm thick stainless steel plate. DI-water was selected as working fluid. Also stainless steel Mesh screen (900 pores per inch) utilized for wick structure. The wick thickness is 1.7 mm, with porosity of 0.73. A flexible heater with length of 100 mm and width of 200 mm was used as a unit heat source. The heater was attached on the centre of top outside surface of the heat pipe. In addition the other side of the heater was insulated with asbestos to prevent heat loss. Input power was controlled by an Ac power supply and its value was measured by a Lutron DW-6060 wattmeter. An insulate frame was used to cover around of FPHP and prevent heat loss through the edges. A table has also employed for installation of heat pipe on four rods to a certain height so as not to affect the free air convection over the condenser surface. Fourteen PT-100 thermocouples with accuracy ±0°C were attached to measure temperature of outside surface of the evaporator and condenser sections, as shown in Figure 1. It must be noticed that the thermocouple at L=0 is attached at the edge and does not show the temperature of the surface under the heater while displays the temperature of the wall edge across the heater.

**RESULTS AND DISCUSSION**

The results consist of three parts. First the transient thermal behaviour of the heat pipe is investigated. Then, the effect of input heat flux on the time of reaching to the steady-state condition is described. Afterwards, the wall temperature distribution for different values of time in different heat fluxes is studied.

Figure 2 shows the transient temperature response for different values of heat flux. It can be seen that temperature difference between the condenser sections and the surfaces next to the evaporator increases with time. Also it is clear form the Figure that, with increasing time thermal resistance increases and become constant at the steady state condition. Furthermore, the figure exemplifies that increasing the heat flux increases the wall temperature.

Figure 3 demonstrates the effect of input heat flux value on time to reach the steady-state condition. It is obvious that with increasing the heat flux the steady-state condition is achieved faster. It is due to increasing the rate of liquid evaporation and vapor condensation in the heat pipe.
Fig. 2: Transient temperature response of the heat pipe

Fig. 3: Influence of heat flux on time of reaching to steady-state condition
In Figure 4 the wall temperature distribution is illustrated for different times. It is shown that the temperature distribution is rather uniform in the surfaces of the heat pipe. Thus, it can be concluded that the evaporation of liquid, condensation in vapor region and liquid pumping to evaporator section by the wick structure is good.

CONCLUSION

An experimental study is conducted to investigate the thermal performance of the stainless steel-DI water FPHP. The experiments are done in three different heat fluxes and Transient temperature response of the heat pipe is obtained. Base on the results of this study, the following conclusion can be drawn:

- Thermal resistance increase with increasing the time and becomes constant at the steady state condition.
- The time of reaching to the steady-state condition decreases with increasing input heat flux.
- Temperature distribution is rather uniform and maximum temperature differences between condenser sections and surfaces next to the evaporator in heat fluxes 912.5, 6850 and 11800 w/m² are: 3, 6.1 and 14.9 °C respectively.

REFERENCES