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HEAT TRANSFER CHARACTERISTICS OF SQUARE MINIATURE HEAT PIPES

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ABSTRACT

Because of the high capacities and compactness of today's electronic equipments, the power density in the devices increases rapidly which causes overheating. To mitigate this overheating, uses of miniature heat pipes (MHP) have been extended quickly. So investigation on MHP is indispensable for further development and improvement of its performance. An experimental work is performed to investigate the effect of change in geometry of MHP in its performance. The experiment is conducted in a square MHP having a hydraulic diameter of 5 mm and a length of 150 mm with ethanol as working fluid and compare results over a circular MHP of same properties where in both cases water is used as coolant. The major findings in the investigation are as follows. For a constant heat flux and coolant flow rate, wall temperature of the square MHP is much lower then circular MHP. With the increase in both inclination angle and coolant flow rate, the rate of decrease in wall temperature of the evaporator section for square MHP is higher then that of circular MHP. At a constant heat flux, coolant flow rate and inclination angle, the thermal resistance for square MHP shows much lower value then the circular MHP. For square MHP, thermal resistance is almost independent with the increase of coolant flow rate. Overall heat transfer coefficient for square MHP is found maximum at vertical orientation.

Keywords: Miniature Heat Pipes, Geometry, Inclination angle, Coolant flow rate

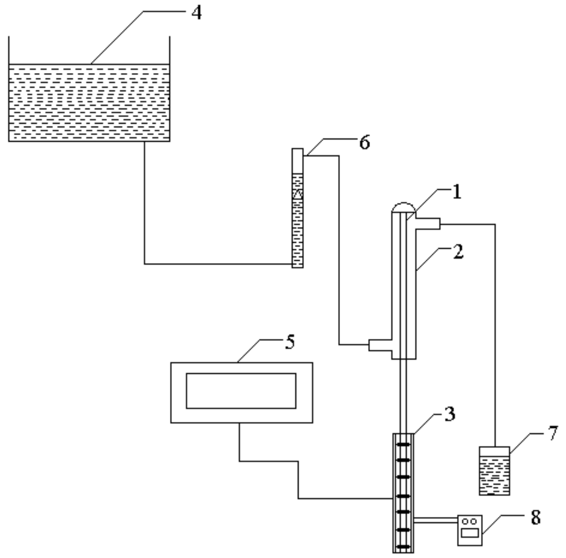
1. INTRODUCTION

With the advancement of micro and nano technologies, the power densities in the electronic equipments are increasing rapidly. Overheating of components, especially in personal computers, telecommunication equipments and microelectronic devices is a potential threat. Now it is a prime issue for the existence of high performance technologies to facilitate optimum cooling of the various components in the compact electronic devices because integrated circuit life time depends on it. Demand of powerful gadgets in smaller cabinets creates a trade off situation; either to enlarge the package to provide additional cooling or to forgo IC lifetime. Among various techniques meant for optimum cooling facilities in compact electronic devices, miniature heat pipe (MHP) emerges as the most appropriate technology and cost effective thermal design solution due to its excellent heat transfer capability, high efficiency and structural simplicity. So study on MHP should go onwards in style for its further development and improvement of performance.

Heat pipe can, even in its simplest form, provide a unique medium for the study of several aspects of fluid dynamics and heat transfer and it is growing in significance as a tool for use by the practicing engineer or physicist in applications ranging from heat recovery to precise control of laboratory experiments. Normally for these equipments MHPs of diameter 3 to 5 mm and length less than 400 mm are preferred [1]. Most preferable length is 150 mm [2]. The MHP applications for cooling telecom boots and notebook computers were started in the last decade and now 95% of notebooks PCs are using MHP. Studies on the application of MHP having the diameter of 3 or 4 mm for cooling of the notebook PC CPU has been actively conducted by the American and Japanese enterprises specializing in the heat pipe recently [3-5]. An experimental study is performed by Haque and Feroz [6] to investigate the effect of working fluid on the performance of a MHP having diameter of 5 mm and a length of 150 mm. Very few investigations have been conducted in MHPs with different geometries of same hydraulic diameter [7]. Therefore, the present study is to investigate the heat transfer characteristics of a square MHP having a hydraulic diameter of 5 mm and the length of 150 mm. The results are compared with a circular MHP of same properties. Experiments are conducted with ethanol as the working fluid at different inclination angles and coolant flow rates.

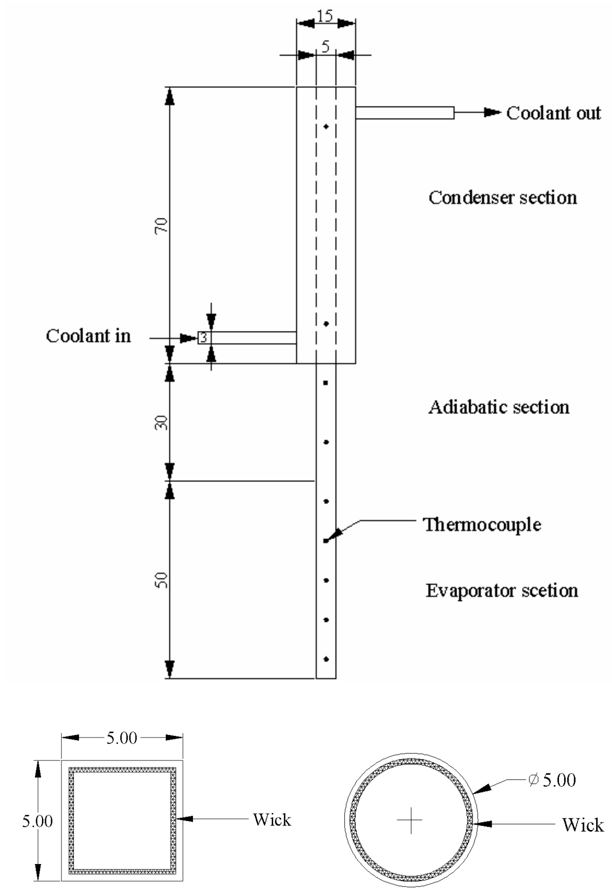
2. EXPERIMENTAL APPARATUS AND TEST PROCEDURE

A schematic diagram of the experimental apparatus is shown in the figure 1. The test sections consist of three parts: evaporator, adiabatic and condenser regions. In the present investigation two types of geometry, square and



1. Heat pipe
2. Condenser
3. Evaporator
4. Elevated water tank
5. Digital temperature indicator
6. Flow meter
7. Secondary measuring cup
8. Power supply unit

Fig 1: Experimental apparatus



Square MHP (d_h = 5 mm) Circular MHP (d_h = 5 mm)

(All dimensions are in mm)

Fig 2: Detail dimensions of the MHPs.

circular having same hydraulic diameters of 5 mm are used. The square section is made of copper sheet (0.5 mm thick). The circular section is made of copper tube of 5.0 mm ID and 6.0 mm OD. In both cases the length of the test section is 150 mm. Stainless steel wicks of 200 mesh are inserted in both sections. Dimensions of the test sections and the locations of the thermocouples are presented in figure 2.

The evaporator sections of MHPs are electrically heated by an AC power supply. A variac is used to apply different voltages and thus different power input to the heating coil. Insulated Ni-Cr thermic wires having width of 1.5 mm, thickness of 0.1 mm are wound around the evaporator walls at a constant interval of 1.5 mm. To minimize heat loss the evaporator, adiabatic and condenser sections are covered with glass fiber.

The condenser sections are cooled by a constant temperature water coolant circulating in an annular space between the copper tube and jacket. The water coolant is supplied from an elevated water tank and the flow is controlled by a flow meter.

Nine calibrated K-type (Φ = 0.18 mm) thermocouples are attached at the wall of each MHP using adhesive to measure the wall temperature: five units at the evaporator section, two units at the adiabatic section and two units at the condenser section. The inlet and outlet coolant water temperatures are also measured. All thermocouples are connected with a digital temperature indicator (kKk, made in China) through a 12 point selector switch to measure the wall temperatures.

The measurements are made under a steady state condition at each input power. To understand the effects of inclination as well as the change of coolant flow rate in the condenser, the same procedure is followed for each set of inclination angle and coolant flow rate. Ethanol is used as the working fluid. The experimental parameters and their ranges are indicated in Table 1.

Table 1: Experimental parameter and their ranges

Parameters	Type / Condition
Geometry	Square, Circular
Hydraulic diameter (mm)	5.0
Total length (mm)	150
Length of evaporator section (mm)	50
Length of adiabatic section (mm)	30
Length of condenser section (mm)	70
Working fluid	Ethanol
Heat flux (kW/m^2)	6.72 ~ 12.86
Coolant flow rate (*l*/min)	0.3 ~ 1.0
Inclination angle (degree)	0 ~ 90
Charge ratio	0.9
Wick (SS)	200 mesh

In the present study, the performance of a MHP is evaluated by measuring the thermal resistance, R (^{o}C/W), which is defined in Equation (1)

$$R = \frac{T_e - T_c}{Q} \tag{1}$$

The overall heat transfer coefficient, U_t is obtained from Equation (2) as follows

$$U_t = \frac{Q}{A_e(T_e - T_c)} \quad (2)$$

3. RESULTS AND DISCUSSION

Figures 3(a) to 3(c) show the axial wall temperature distribution for square and circular MHPs having the same hydraulic diameter of 5 mm and length of 150 mm, at various power inputs, coolant flow rates and inclination angles. Ethanol is used as the working fluid.

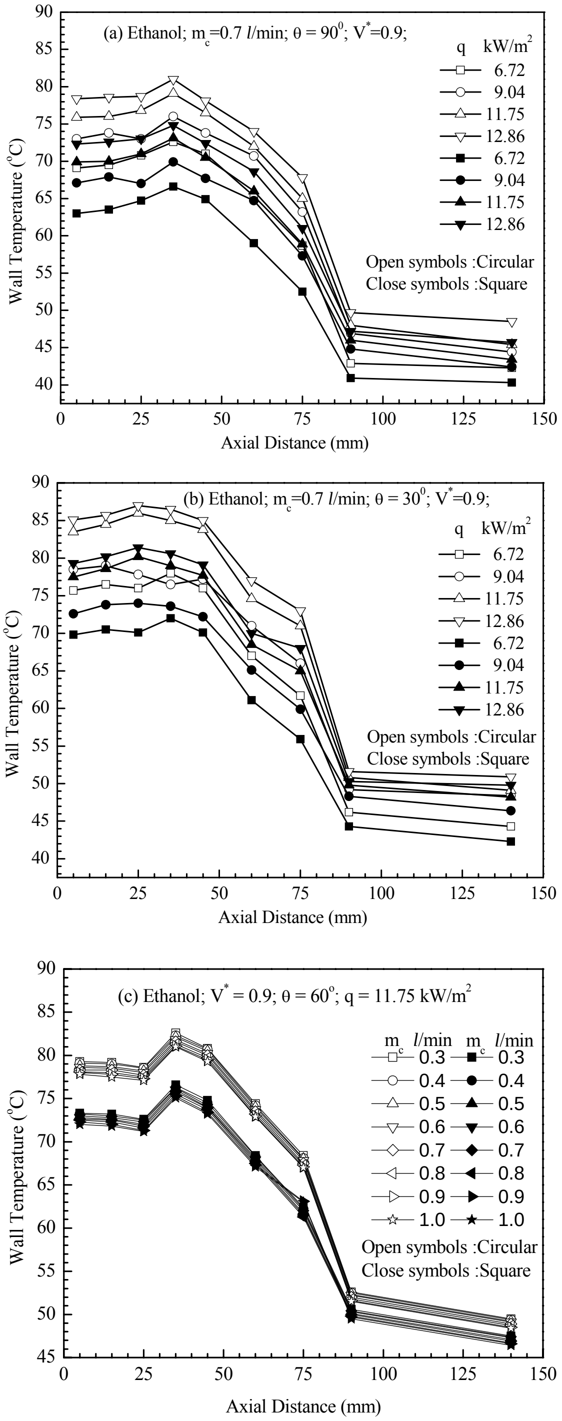


Fig 3: Axial wall temperature distribution of MHPs.

The figures indicate that, at a particular heat input, coolant flow rate and inclination angle, the wall temperature of evaporator section of square MHP shows the lower value than the circular one. For both geometries of MHPs, the wall temperature of the evaporator section decreases with the increase of inclination angle and the rate of decrease is also higher for square MHP. This result is consistent with the finding of Well and Yuan [8]. At the same power input and inclination angle, the wall temperature of the evaporator section of square MHP is lower than the circular MHP. In both cases the decrease in wall temperature with the increase of coolant flow rate is not significant as shown in figure 3(c).

Figures 4(a) and 4(b) show the change in the thermal resistance with the change of the coolant flow rate in the condenser section within the stable operational zone where no dryout occurs. The figures present the fact that the thermal resistance of square MHP is less compared to that of circular MHP. With the increase of coolant flow rate, the thermal resistance remains fairly constant for both the square and circular MHPs. The result is very similar to the prediction of Kim, K.S., et al. [9]. This small optimum range of the flow rate of cooling water of MHPs is rather favorable to reduce pumping power.

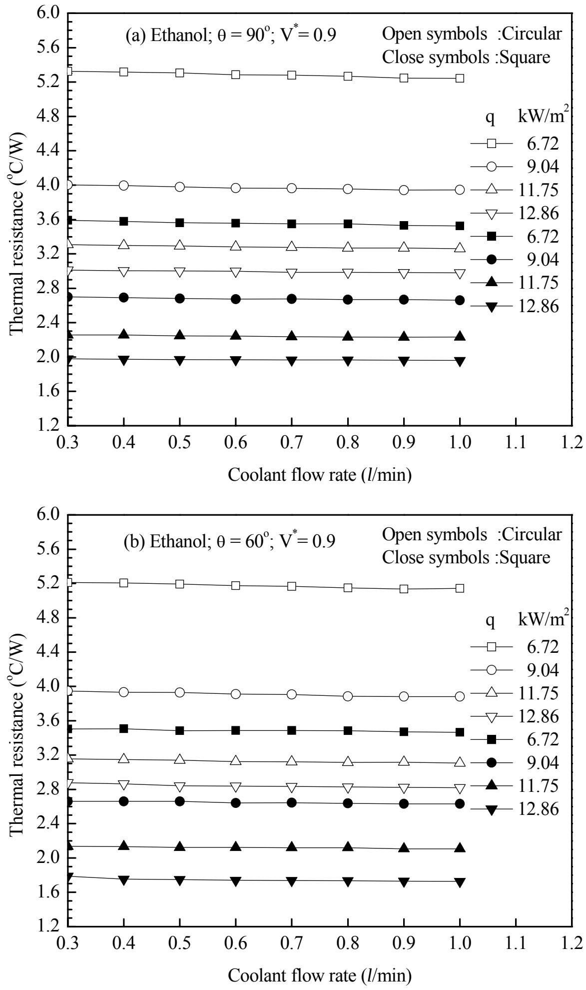


Fig 4: Effect of coolant flow rate and inclination angle on thermal resistance for various heat input.

From various research, it is found that the thermal resistance of an MHP is not so affected by the installed inclination angle of the MHP [8][9]. The present study also gives similar result with small variation as shown in figure 5. For square MHP, more flattened thermal resistance curve is found than circular MHP. This implies that the flow resistance by the gravity is sufficiently overcome by the capillary pressure driving the working fluid through a wick within the stable operational zone where no dryout occurs.

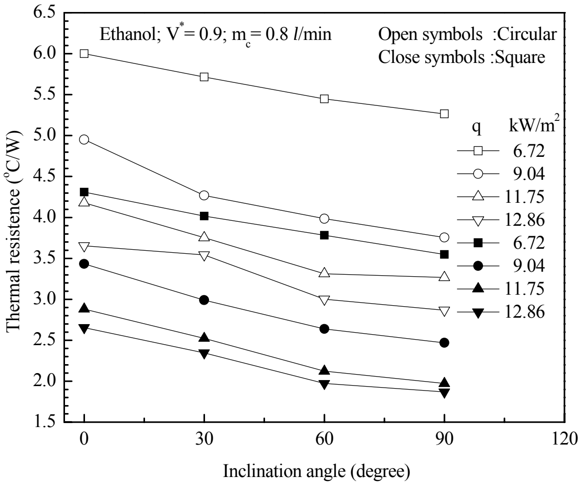


Fig 5: Thermal resistance vs. inclination angle.

Figure 6 shows the thermal resistance of MHPs as a function of thermal load. At a constant coolant flow rate the thermal resistance exhibited a decreasing trend as the thermal load is increased. For a particular inclination angle, the range of variation of thermal resistance with heat input is smaller for square MHP. Part of the result is consistent with the result found by Joon H. B., et. al.[10] and the lowest values are observed for square MHP at 90° inclination angle.

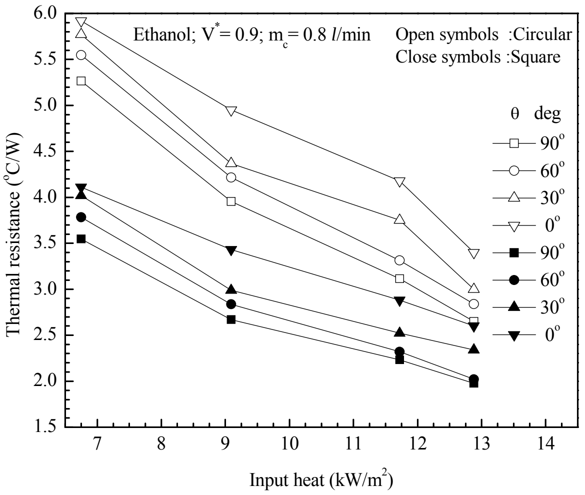


Fig 6: Thermal resistance as a function of input heat

Figures 7(a) and 7(b) depicts the overall heat transfer coefficient variation with the coolant flow rate. With the increase of coolant flow rate, maximum overall heat transfer coefficient is found for square MHP with an increasing trend. For both MHPs, overall heat transfer coefficient increases with the increase of inclination angle and the rate of increase is higher for square MHP.

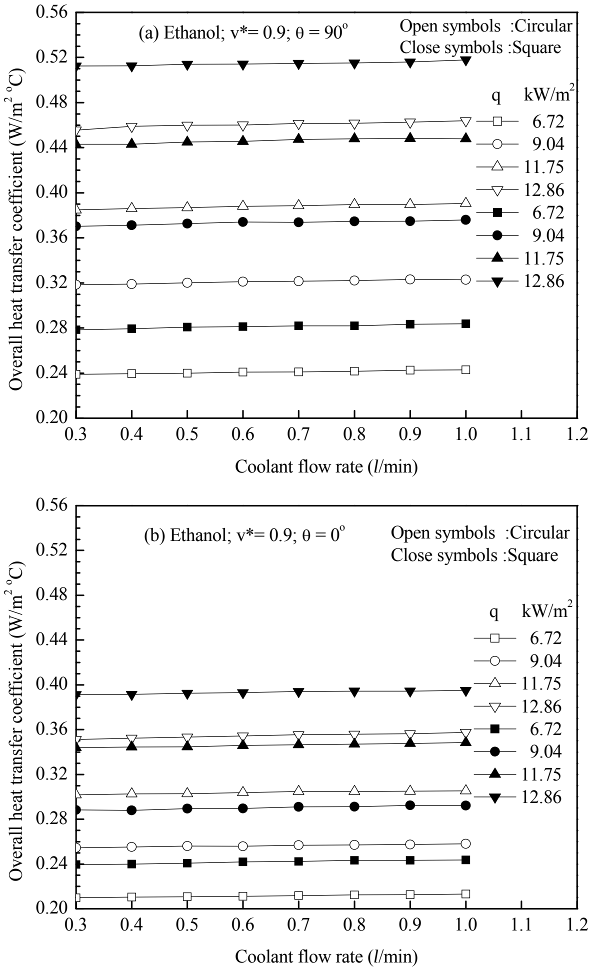


Fig 7: Effect of coolant flow rate on overall heat transfer coefficient

Figure 8 represents the overall heat transfer coefficient variation with input power. The overall heat transfer rate increases with the increase of input power. The figure also shows that the overall heat transfer coefficient of square MHP is maximum where as circular MHP has the minimum value.

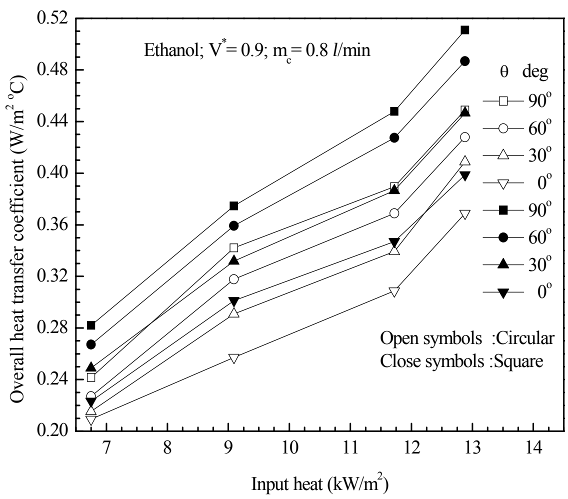


Fig 8: Effect of input heat on overall heat transfer coefficient for various inclination angle.

Figure 9 shows the effects of inclination angles on overall heat transfer coefficient for square and circular MHPs. It is evident that the overall heat transfer rate increases slightly with the increase of the inclination angles. In this case also, the rate of increase of overall heat transfer is higher for square MHP then the circular MHP.

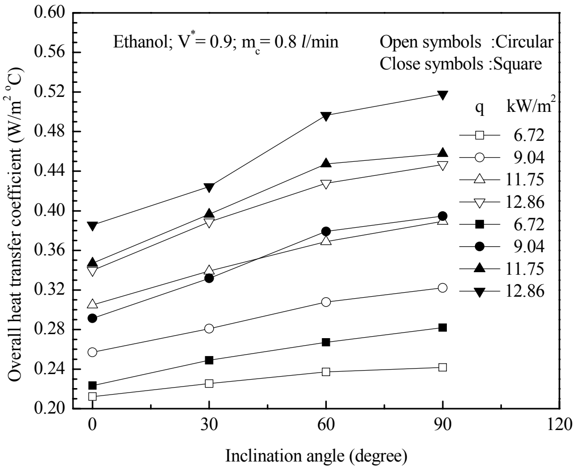


Fig 9: Effect of inclination angle on overall heat transfer coefficient

4. CONCLUSIONS

The following conclusions can be drawn for the heat transfer characteristics of a square MHPs over a circular MHPs having the same hydraulic diameter of 5 mm and length of 150 mm:

1. For ethanol as the working fluid, at a particular heat input, coolant flow rate and inclination angle, the wall temperature of the evaporator section of square MHP is lower than that of circular MHP. The wall temperature decreases with the increase of inclination angle and the rate of decrease is higher for square MHP.
2. For the same experimental condition, the minimum thermal resistance is found for square MHP. Thermal resistance is almost independent on the coolant flow rate for square and circular MHP.
3. Overall heat transfer coefficient is found maximum for square MHP and it increases with the increase of coolant flow rate and inclination angle.

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6. NOMENCLATURE

Symbol	Meaning	Unit
q	Heat flux	(kW/m^2)
R	Thermal Resistance	(°C/W)
U_t	Overall Transfer Coefficient	(kW/m^2 °C)
A_e	Surface Area of Evaporator	(m^2)
T_e	Average Wall Temperature of Evaporator	(°C)
T_c	Average Wall Temperature of Condenser	(°C)
m_c	Coolant Flow Rate	(l/min)
θ	Inclination Angle	(degree)
V^*	Charge Ratio	