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EFFECT OF WORKING FLUID ON THE PERFORMANCE OF A MINIATURE HEAT PIPE

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ABSTRACT
With the fast increase in power densities in electronic equipments, especially in personal computers and telecommunication field, application of miniature heat pipe (MHP) has been extended gradually. So investigation on MHP is indispensable for further development and improvement of its performance. An experimental study is performed to investigate the effect of working fluid on the performance of a MHP having diameter of 5 mm and a length of 150 mm. Experiments are conducted with ethanol, methanol and acetone. The major findings in the investigation are as follow. For all working fluids, at a particular heat input the wall temperature of the evaporator section is higher when the heat pipe is placed at a lower inclination angle. Wall temperatures of the evaporator section decrease with the increase of inclination angle. Overall heat transfer coefficient of the MHP is found maximum for ethanol working fluid.

Keywords: Miniature heat pipes, Working fluids, Inclination angle.

1. INTRODUCTION
On electronics equipment, market's demand for increasingly powerful product, in smaller and smaller packaging, creates a cooling problem. The integrated circuit (IC) lifetime, which is dependent upon its operating temperature, creates a trade off situation: either to enlarge the package to accept additional cooling, or to sacrifice IC lifetime. This is a great challenge in thermal design management. Among other cooling techniques heat pipes emerges as the most appropriate technology and cost effective thermal design solution due to its excellent heat transfer capability, high efficiency and its structural simplicity. Because of the phase change characteristics, heat pipe have a tremendous capacity for transferring heat, they are often referred to as the 'superconductors' of heat. Today heat pipes are widely used in computer, telecommunication and other various electronics equipment. Due to the space constraint in most of personal computers and telecommunications systems placed constraint on the size of heat pipes. Normally for these equipments miniature heat pipes of diameter 3 to 5 millimeter and length less than 400 millimeter are preferred. The MHP applications for cooling telecom boots and notebook computers were started in the last decade and now 80% 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 have been actively conducted by the American and Japanese enterprises specializing in the heat pipe recently [1- 3]. The present study is investigating the effect of working fluid on the performance of an MHP having diameter of 5 mm and a length of 150 mm. Experiment are conducted with ethanol, methanol and acetone at different inclination and coolant flow rate.

2. EXPERIMENTAL APPARATUS AND TEST PROCEDURE
The schematic diagram of the experimental apparatus is shown in Fig. 1. The test section consists of three parts: evaporator, adiabatic and condenser. Detailed dimensions of the MHP are shown in Fig. 2. The evaporator section of MHP is electrically heated by a DC power supply (Model: GPC-1850). Insulated Ni-Cr thermic wires having diameter of 0.28 mm (10 Ω/m) are wound around the evaporator wall at a constant interval of 1.5 mm. To minimize heat loss, the evaporator section is covered with glass fiber. The condenser section is cooled by constant temperature cooling water circulating in an annular space between the copper tube and the jacket.

The cooling water is supplied from an elevated water tank through a flow meter. The inlet and outlet water temperatures are recorded by digital thermometers.

Eleven calibrated K type (ф 0.18mm) thermocouples are glued to the wall of the MHP: five units at the evaporator section, one unit at the adiabatic section, and five units at the condenser section. A digital thermometer is used to measure temperature.

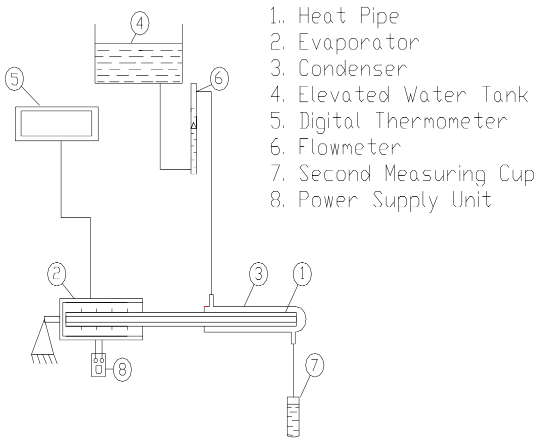

Fig 1. Experimental apparatus

Input power to the heater in the evaporator section is increased from 0.5 W to 5W by steps of 0.5W.

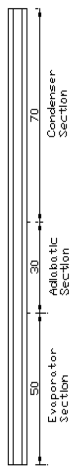

Fig 2. Detailed dimensions of the MHP

Experimental arrangement for the performance test of an MHP is summarized in table 1

Table 1: Experimental Parameters

Parameters	Condition
Diameter of pipe (mm)	5
Total length (mm)	150
Length of the evaporator section (mm)	50
Length of the adiabatic section (mm)	30
Length of the condenser section (mm)	70
Working fluid	Ethanol, Methanol
Charge ratio	0.90
Inclination angle (deg.)	30 ~ 90
Wick (SS)	200 mesh

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.

In the present study, the performance of an MHP is evaluated by measuring the thermal resistance, R (^{0}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

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

3. RESULTS AND DISCUSSION

Figure 3(a) to 3(f) show the axial wall temperature distribution for ethanol methanol and acetone working fluid of a miniature heat pipe having diameter of 5 mm, at various power inputs and inclination angles.

Figures indicate that at a particular heat input, the temperature of evaporator section is higher when the heat pipe is placed at a lower inclination angle. For all three working fluid, the temperature of the evaporator section decreases as the inclination angle of MHP increases. This result is consistent with the finding of Wel and Yuan [4] .In all cases the increase in wall temperature is not so large with increase in heat flux.

At the same power input, coolant flow rate and inclination angle, the wall temperature of the evaporator section of ethanol is lower than methanol and acetone.

Figure 4 shows the change in the thermal resistance according to the coolant flow rate in the condenser within the stable operational zone where no dryout occurs.

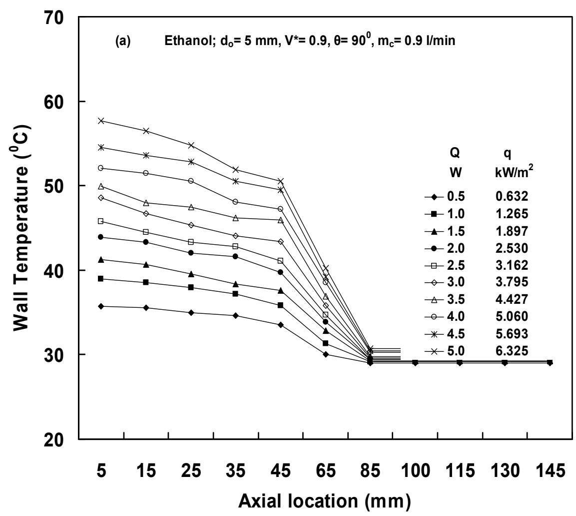

Fig 3(a). Axial temperature distributions of MHP for ethanol at 90^0 inclination

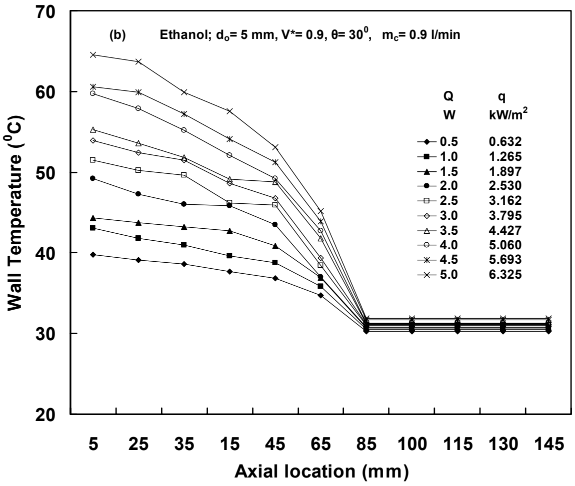

Fig 3(b). Axial temperature distributions of MHP for ethanol at 30^0 inclination

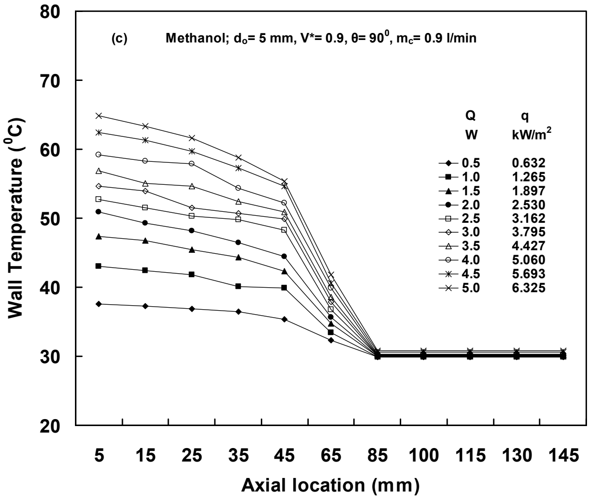

Fig 3(c). Axial temperature distributions of MHP for methanol at 90^0 inclination

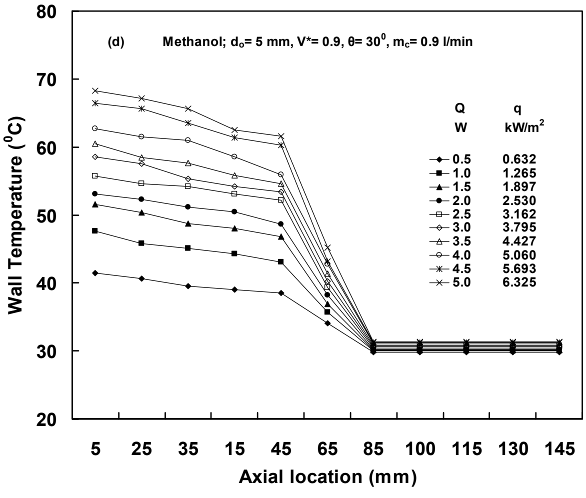

Fig 3(d). Axial temperature distributions of MHP for methanol at 30^0 inclination

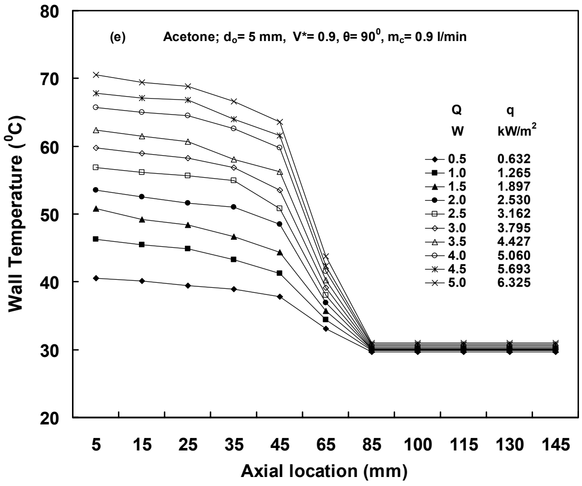

Fig 3(e). Axial temperature distributions of MHP for acetone at 90^0 inclination

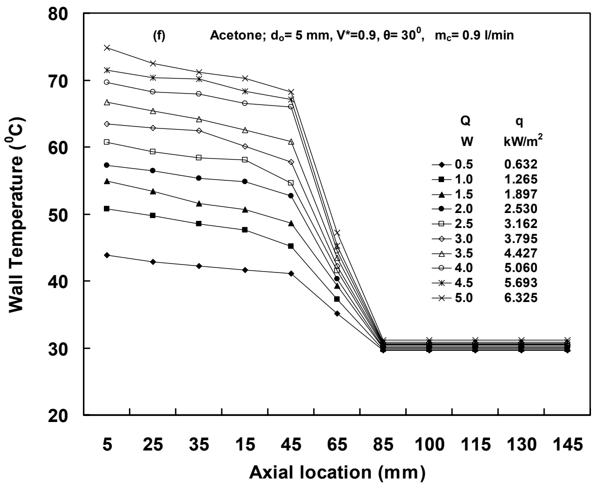

Fig 3(f). Axial temperature distributions of MHP for acetone at 30^0 inclination

It is evident that the thermal resistance is reduced as the coolant flow rate is increased.

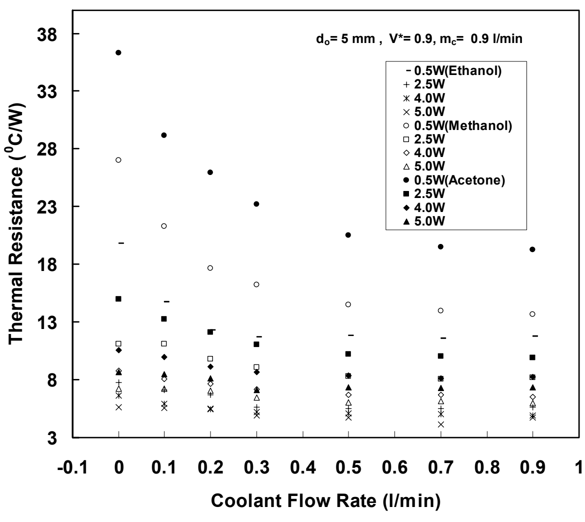

Fig 4. Thermal resistance vs. coolant flow rate

Figure 4 presents the fact that the thermal resistance of ethanol is less compare to that of methanol and acetone. It is also shown that the thermal resistance is high when cooling water flow rate is zero. With the increase of cooling water flow rate, the thermal resistance reduces significantly due to forced convection cooling. This trend continues up to a flow rate of 0.3 l/min, beyond which the thermal resistance remains fairly constant. The result is very similar to the prediction of Kim, K.S., *et al.* [5]. This small optimum range of the flow rate of cooling water of MHPs is rather favorable to reduce pumping power.

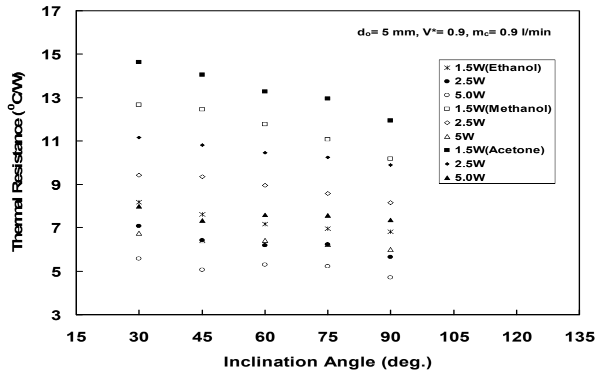

Fig 5. Effect of inclination angle on thermal resistance within the range of no dryout

It has been reported that the thermal resistance of an MHP is not affected by the installed inclination angle of the MHP [5][6]. The present study also gives similar result. Figure 5 shows that the thermal resistance is almost independent of inclination angle for all three working fluids. This implies that the flow resistance by the gravity is sufficiently overcome by the capillary pressure driving of working fluid through a wick within the stable operational zone where no dryout occurs.

Figure 6 shows the thermal resistance of MHP as a function of thermal load. The thermal resistance exhibited a decreasing trend as the thermal load is increased. The result is consistent with the result found by Joon H. B. , *et. al.*[7] and the lowest values are observed for ethanol at 90^0 inclination angle within the present experimental range.

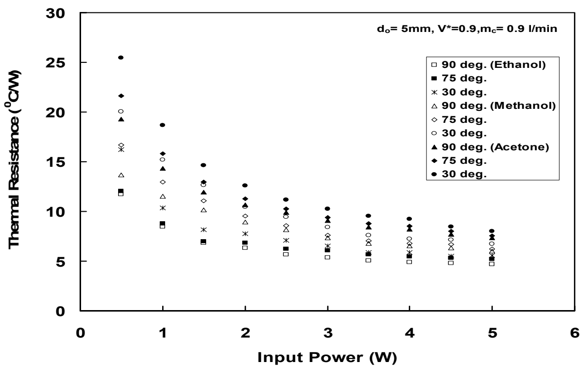

Fig 6. Thermal resistance as a function of thermal load

Figure 7 depicts 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 ethanol working fluid is maximum whereas acetone has the minimum value.

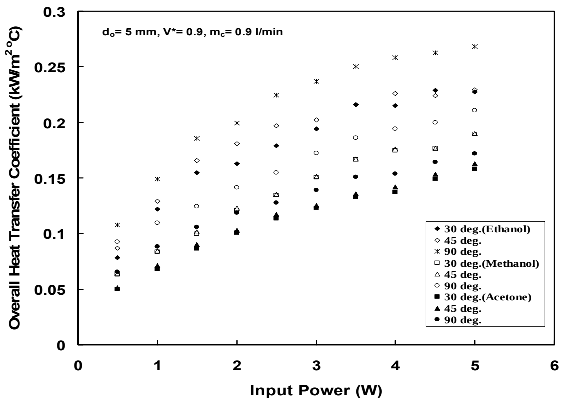

Fig 7. Effect of input power on overall heat transfer Coefficient for various inclination angle

Figure 8 shows the effects of inclination angles on overall heat transfer coefficient for ethanol, methanol and acetone. It is evident that the overall heat transfer rate increases slightly with the increase of the inclination angles. Therefore the effect of the inclination angle seems not to be much significant.

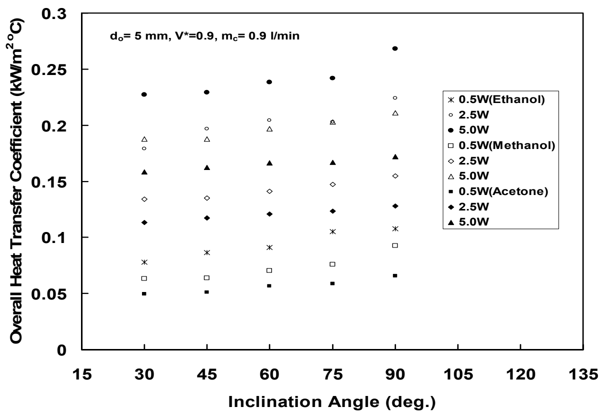

Fig 8. Effect of inclination angle on overall heat transfer coefficient

4. CONCLUSIONS

The following conclusions may be drawn from the performance test for the MHP with woven wired wick and having diameter 5 mm:

i. For all three working fluids, at a particular heat input the wall temperature of the evaporator section is higher when the heat pipe is placed at a lower inclination angle and the wall temperature of the evaporator section decreases as the inclination angle increases. This is implies that the action of gravity, which serves to speed up the flow of liquid from condenser to evaporator increases with the increase of inclination angle.

ii. The thermal resistance decreases with the increase of cooling water flow rate up to 0.3 l/min. Beyond this flow rate, the thermal resistance becomes practically a constant. It is almost independent of inclination angle.

iii. Overall heat transfer coefficient of ethanol is higher than methanol and acetone working fluid used in the present experimental study. There is no significant effect of inclination angle on overall heat transfer coefficient.

5. REFERENCES

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6. NOMENCLATURE

Symbol	Meaning	Unit
Q	Input Power	(W)
R	Thermal Resistance	($^oC/W$)
U_t	Overall Transfer Coefficient	($kW/m^2\,^oC$)
A_e	Surface Area of Evaporator	(m^2)
T_e	Average Wall Temperature of evaporator	(^oC)
T_c	Average Wall Temperature of Condenser	(^oC)
m_c	Coolant Flow Rate	(l/min)
θ	Inclination Angle	(deg.)
V*	Charge Ratio	