



## **Effects of working fluids, working temperatures and inner diameters on internal pressure and heat transfer rate of a closed-loop oscillating heat-pipe with check valves (CLOHP/CV)**

S. Sangiamsuk<sup>1</sup>, B. Bubphachot<sup>1</sup>, O. Watanabe<sup>2</sup>, S. Rittidech<sup>\*1</sup>

<sup>1</sup>Heat-Pipe and Thermal Tools Design Research Unit (HTDR),  
Department of Mechanical Engineering, Faculty of Engineering,  
Mahasarakham University, Thailand

<sup>2</sup>Solid Mechanics and Material Science,  
Department of Engineering Mechanics and Energy, Faculty of Systems and Information Engineering,  
University of Tsukuba, Japan

\*Corresponding Author. E-mail: [s.rittidech@hotmail.com](mailto:s.rittidech@hotmail.com), <http://www.esan-htdr.com>, Tel: 043-754-316, Fax: 043-754-316.

### **Abstract**

Effects of working fluids, working temperatures and diameters on the internal pressure and heat transfer rate of a closed-loop oscillating heat-pipe with check valves (CLOHP/CV) were investigated in this research. The CLOHP/CV was made of a copper capillary tube with 1.77 and 2.03 mm ID. There were three working fluids (distilled water, ethanol and R123) and the temperatures in the evaporator were 100, 150 and 200°C with a filling ratio of 50%; the number of meandering turns was 40 and the number of check valves was 2. The lengths of the evaporator, adiabatic and condenser sections were 50 mm. The research reports the working fluids effects, inner diameters and working temperature were on internal pressure, heat transfer rate and thermal resistance. It was found that; the CLOHP/CV (R123, 2.03 mm ID and  $T_e$  200 °C) had the maximum internal pressure and heat transfer rate of 7.53 Mpa, 0.83 kW, respectively and the minimum thermal resistance was 2.51 °C-m<sup>2</sup>/kW. The increased working temperature varied directly with the internal pressure and heat transfer rate accordingly, but it reversed variation when thermal resistance was decreased.

**Keywords:** Closed-loop oscillating heat-pipe, Check valves, Heat transfer rate, Thermal resistance.

### **1. Introduction**

Nowadays, there is rapid development of practical engineering solutions of a multitude of heating problems. The generated heat in micro-devices was used in manufacturing and electronics special solutions.

The pulsating heat-pipe (PHP) or the oscillating heat-pipe (OHP) is one type of heat transfer devices that it is relatively young members in the heat pipes family. In 1990s, Akachi invented a new type of heat-pipe which made of a capillary tube [1,6] and it can be divided into 3 groups: (a) closed-end oscillating

heat-pipe (CEOHP); a capillary tube is bent to meandering turns and closed at both ends; (b) closed loop oscillating heat-pipe (CLOHP) a capillary tube is connected at both ends to form close-loop; (c) closed-loop oscillating heat-pipe with check valves (CLOHP/CV) which in the both ends of the capillary tube are connected to form a closed-loop. CLOHP/CV is installed with check valves to the center of heat pipe then the check valves will control the flowing working fluid direction within the pipe that flow in the same direction [4,5]. Each loop has one or more check valves. The CLOHP/CV is a new type of heat transfer device. It gives a high performance and several advantages. The CLOHP/CV is a very effective heat transfer device. Heat is transported from an evaporator to the condenser by the oscillation of a working fluid moving in an axial direction inside the tube. In this type of system, the inner diameter of the pipe is important. It must be small enough because operation conditions; liquid slugs and vapor plugs can be formed. While quite some research has been performed on the operational behavior, including various experimental studies [2,8-9]. However the CLOHP/CV can be considered as a standard cooling device.

The major of research focuses on heat-pipe systems which affect to working fluids, working temperatures and inner diameter in the system's operational performance. The closed-loop oscillating heat-pipe with check valves, under normal operating conditions, is capable controlling the flow direction of the working fluid. Previous research established a correlation that predicted the heat transfer performance of such

a system at vertical orientation (when the evaporator section is below). In this study, it will affect the internal pressure of CLOHP/CV and heat transfer rate.

CLOHP/CV is commonly favored in cooling electronic devices, humidity control air conditioning system, etc. Despite these common applications, limited reliable experimental research findings are available on the operation of closed loop oscillating heat pipe with check valves (CLOHP/CV) (see Fig. 1). In these reason, the lack of detailed data, working fluids effect, working temperatures and internal pressure diameters and heat transfer rate of a closed-loop oscillating heat-pipe with check valves (CLOHP/CV) so that this study focuses on determining the actual performance of such a system.

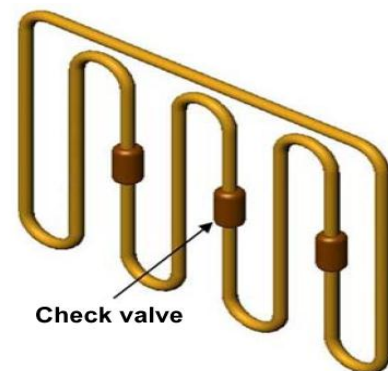


Fig. 1 Closed-loop oscillating heat-pipe with check valve (CLOHP/CV)

## 2. Experimental setup and procedure

The experimental setup was set with the test rig as shown in Fig. 2 and a real experimental setup as shown in Fig. 3 they were consist of the CLOHP/CV test, a power filled input source connected to a temperature



controller, a fan connected to a speed motor controller, a temperature recorder and a personal computer. The evaporator sections of the CLOHP/CV were heated by electric plate heaters. The CLOHP/CV was made of a copper capillary tube. The evaporator, adiabatic and condenser sections were arranged to be equal lengths. The evaporator sections of the CLOHP/CV were heated by electric plate heaters. The heaters were placed on the outer surface of the tube walls and connected to the AC power input source and temperature controller (Linking PID LT400 series). The evaporator temperature of the CLOHP/CV was varied by adjusting the temperature controller. The heat was removed from the condenser sections by the forced convective heat transfer of ambient air that was blown through these sections. The air flow velocity was controlled by the AC motor controller which was maintained at 0.6 m/s and the temperature of the air conditioner was kept at 25 °C. The adiabatic sections were insulated well by using foam insulators (Aero flex). The thermocouples (OMEGA type K) were used to measure the temperature of the evaporators, adiabatic and condenser sections of the CLOHP/CV. The ambient air temperature at the inlet and outlet of the condenser parts and the internal pressure were taken by the temperature working fluid inside the tube and then convert to average pressure. All temperature data were recorded by the data logger (Yokogawa DX200 with  $\pm 0.1^\circ\text{C}$  accuracy) and connected to a PC for collecting the data every 1 hour. The air velocity was detected by the humidity and anemometer

measurement (A testo 445 with  $\pm 0.05\%$  accuracy) that it was pitot tube probe types. First, the CLOHP/CV were evacuated by a high performance vacuum pump (Makashi, 50 l/min, 1/4 hp) and then filled required a working fluid ratio in the A CLOHP/CV which was set into a test rig that tilted to vertical operation modes (the evaporator, adiabatic and condenser sections is equal lengths). The evaporator temperature was set until the desired value and the AC electricity was supplied to the strip heaters. Simultaneously, the ambient air with a 25 °C temperature and 0.6 m/s velocity were blown through the condenser section. After a quasi steady state was reached, all temperatures were recorded. Then the experimental parameters were varied according to the required conditions. The thermal performance of the CLOHP/CV was evaluated by calculating the heat transfer rate to the ambient air at the condenser part and applying the heat transfer rate for a heating process, which is shown as equation (1).

$$Q = \dot{m}C_p(T_{out} - T_{in}) \quad (1)$$

Where  $Q$  is the heat transfer rate of a CLOHP/CV,  $C_p$  is the specific heat capacity of dry air and  $T_{out}$  and  $T_{in}$  are the temperature of dry air at the exit and the inlet of the condenser section,  $\dot{m}$  is the mass flow rate of dry air can be calculated by the following equation (2).

$$\dot{m} = \rho v A \quad (2)$$

Where  $\rho$  is the dry air density,  $v$  is the dry air velocity and  $A$  is the cross sectional air flowing area. In this experiment, the heat flux can be calculated by the following equation (3).

$$q = \frac{Q}{A_c} \quad (3)$$

When  $Q = \dot{m}C_p(T_{out} - T_{in})$ ,  $A_c$  is the all outer surface area of tube in condenser section,  $q$  is the heat flux. The CLOHP/CV thermal resistance ( $R$ ) would be equal to temperature difference between condenser section and evaporator section to the heat flux that can be calculated by equation (4).

$$R = \frac{T_e - T_c}{q} \quad (4)$$

Where  $T_e$  and  $T_c$  are the wall temperatures of the evaporator section and the condenser section, respectively. The measurement error of the recording instruments and the axial heat conduction of the copper capillary tube were also considered. The complete experimental parameters are summarized as follows:

The controlled parameters:

- Evaporator length ( $L_e$ ): 50 mm
- Number of turns: 40 turns
- Number of check valves 2
- Filling ratio (FR): 50% of total internal tube volume
- Inclination angle:  $90^\circ$
- Air inlet of 0.6 m/s

The variable parameters:

- Working fluid: distilled water, ethanol and R123

- Working temperature ( $T_e$ ): 100, 150 and 200 °C
- Tube inner diameter ( $D_i$ ): 1.77 and 2.03 mm

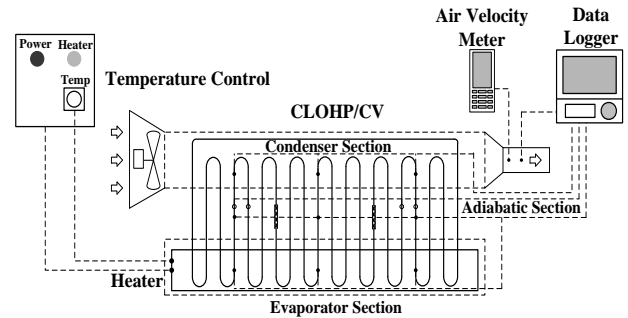


Fig. 2 Details of experimental setup

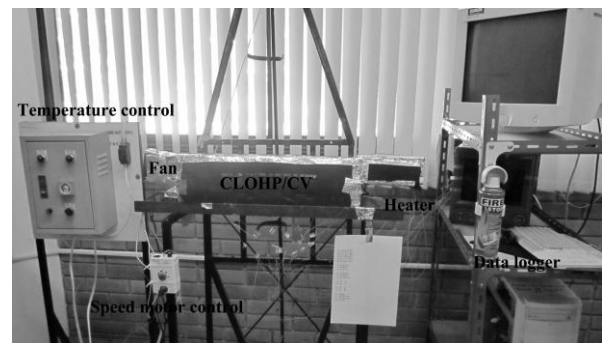


Fig. 3 Real experimental setup

### 3. Results and Discussion

#### 3.1 Result of working fluids on internal pressure and heat transfer rate:

The results showed that the working fluid that affected to the internal pressure increase. R123 was as the working fluid which gave the most internal pressure effect and heat transfer rate. R123, which has highest thermal conductivity and lowest latent heat of vaporization, this major property caused a great effect on the liquid slugs motion and vapor bubbles in the tube. It causes the heat transfer to the evaporator so well that it affects to the

heat receiving in more and the working fluid boiling. It can be concluded that the CLOHP/CV with R123 as the working fluids, an inner diameter 2.03 mm and the working temperature of 200°C caused the highest internal pressure of 7.53 MPa, as shown in Fig. 4. Therefore the working fluid oscillations transport heat from the evaporator to the condenser efficiently. If the heat transfer rate increases, both the evaporator temperature and the fluid temperature will increase gradually so they cause surface tension decreasing and latent heat (Higher surface tensions will increase to the maximum allowable diameter and also the pressure drop in the tube. Larger diameter would allow improved performance, but an pressure drop in high because it require greater bubble pumping and thus a higher heat will input to maintain pulsating flow), (A low latent heat will cause the liquid to evaporate more quickly at a given temperature and a higher vapor pressure; the liquid slug oscillating velocities will be increased and the heat transfer performance of the PHP will be improved) [10] thus more vapors generated that caused faster vapor flow. As a result, R123 as the working fluid had highest heat transfer rate of 0.83 kW and the lowest thermal resistance was 2.51 °C-m<sup>2</sup>/kW showed as in fig. 5-6.

### 3.2 Result of working temperature on internal pressure and heat transfer rate:

Fig. 4 show the relationship between working temperature versus internal pressure for the CLOHP/CV with working fluids (distilled water, ethanol and R123) and inner diameter (1.77 and 2.03 mm). The result was found that

the working temperature increased from 100 until 200 °C, the internal pressure clearly increased. When the working temperature increases, it directly varied with the internal pressure. And it affects to the increasing of the heat transfer rate accordingly. The CLOHP/CV, with R123 as working fluids, an inner diameter was 2.03 mm and the working temperature of 200°C result the highest internal pressure of 7.53 MPa. At higher temperature, it has a low boiling point and higher internal pressure than ethanol and distilled water as working fluid, respectively. Because of the heat input in high, it caused high internal pressure in the evaporator section. It is the energy source which provides the driving force in the direction of motion within the tube that causes fluid flow to the condenser section [3,7]. When the heat at the condenser exchanges, the working fluid within the CLOHP / CV is restoring force and returns to evaporator section.

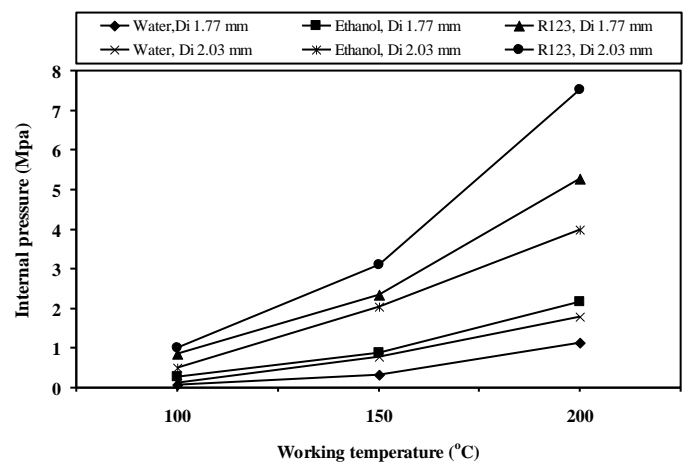


Fig. 4 Relationship between working temperature versus internal pressure

Fig. 5 show the relationship between working temperature versus heat transfer rate for

the CLOHP/CV with working fluids (distilled water, ethanol and R123) and inner diameter (1.77 and 2.03 mm). The result was found that the working temperature increased from 100 until 200 °C and the heat transfer rate increased. Because of the working temperature is higher when receiving the heat, R123 caused boiling in the pipe and the thermal conductivity of the base fluid increasing. The CLOHP/CV affected to the surface area and the heat capacity of the base fluid would be increase. Moreover; the temperature affected to the heat transfer rate of the CLOHP/CV because boundary force decreased when the temperature increased. It transferred the heat better than using distilled water or ethanol as working fluids respectively. So the working temperature of 200 °C using R123 as the working fluid and an inner diameter was 2.03 mm gave highest heat transfer rate of 0.83 kW. The inner diameter of 1.77 mm gave the heat transfer rate of 0.54 kW.

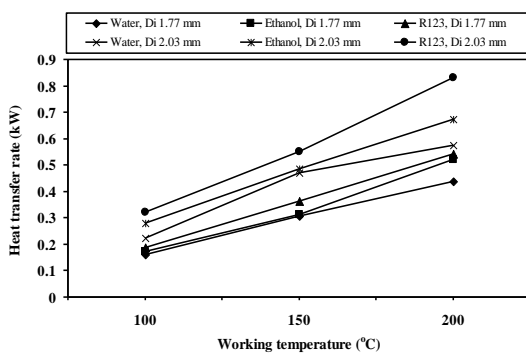


Fig. 5 Relationship between working temperature versus heat transfer rate

Figs. 6 show the relationship between working temperature versus thermal resistance for the CLOHP/CV with working fluids (distilled water, ethanol and R123) and inner diameter

(1.77 and 2.03 mm); the results showed that while the working temperature was increasing from 100 until 200 °C, the thermal resistance decreased. The CLOHP/CV, with R123 as working fluids, the working temperature was 200°C and inner diameter was 1.77 and 2.03 mm caused the highest working temperature of 200°C. The affected thermal resistance would be minimal 6.63°C-m<sup>2</sup>/kW and 2.51°C-m<sup>2</sup>/kW, respectively. So the CLOHP/CV with R123 as the working fluid with the working temperature of 200 °C and an inner diameter of 2.03 mm was able to obtain a thermal resistance lower than ethanol and distilled water as the working fluid. The working temperature increased, which affected increased heat transfer, and that caused low thermal resistance. In conclusion, the working temperature was inversely related to thermal resistance which accorded to heat transfer rate increasing.

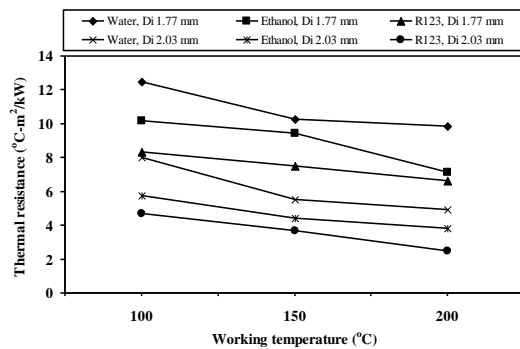


Fig. 6 Relationship between working temperature versus thermal resistance

### 3.3 Result of inner diameter on internal pressure and heat transfer rate:

Fig. 7 show the relationship between inner diameter versus internal pressure of the CLOHP/CV with working fluids (distilled water,

ethanol and R123) and working temperature are begin from 100 until 200 °C. The result was found that when the inner diameter increased from 1.77 to 2.03 mm, the working temperatures were 100 and 150 °C which slightly affected to the pressure. But, comparing with working temperature of 200 °C, the internal pressure was high so that the inner diameter was 1.77 mm that it affected to the working fluid movement in the tube; it was difficulty movement because of high tension and the internal pressure in the heat pipe dropped if the internal diameter increased, the working fluid boiled and moved rapidly. Because of the working fluid properties, the temperature increased, the density of working fluid would drop that causing the surface tension and shear force to also drop but the driving tension increased. As a result, the heat transfer performance increased also the heat transfer rate would increase when the internal pressure increased as well. It can be concluded that CLOHP/CV for R123 as the working fluid, working temperature at 200 °C and inner diameter was 2.03 mm, gave the highest internal pressure; this value was 7.53 MPa.

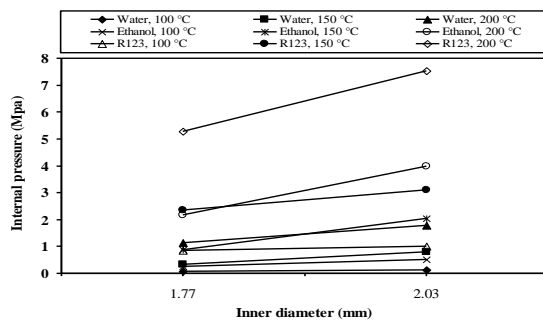


Fig. 7 Relationship between inner diameters versus internal pressure

Fig. 8 shows the relationship between inner diameter versus heat transfer rate of the CLOHP/CV with working fluids (distilled water, ethanol and R123) and working temperature from 100 until 200 °C. The result was found that as increasing the inner diameter from 1.77 to 2.03 mm, the heat transfer rate increased and changing it from 1.77 to 2.03 mm, the heat transfer rate increased from 0.54 kW to 0.83 kW, respectively. For both arrangements, the experimental results of the heat transfer rate were similar. The highest heat transfer was attained at the maximum with inner diameter of 2.03 mm. The small inner diameter leads to an increased frictional pressure drop and flow resistance. In conclusion, when the inner diameter increased, the heat transfer rate would slightly increase too.

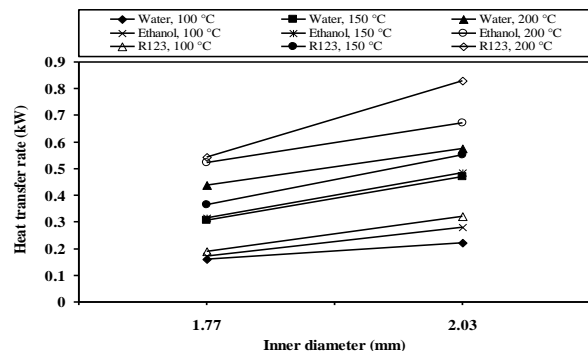


Fig. 8 Relationship between inner diameters versus heat transfer rate

Fig. 9 show the relationship between inner diameter versus thermal resistance of the CLOHP/CV with working fluids (distilled water, ethanol and R123) and working temperatures from 100 until 200 °C. The result was found that increasing the inner diameter from 1.77 to 2.03 mm, the thermal resistance decreased because

of the inner diameter decreased; the effect of operational orientation becomes relatively small or insignificant with decreasing inner diameter. Finally, because surface tension dominates the fluid flow in the smaller tube that getting these results. Vapor bubbles cannot move to the condenser section easily. It was seen that heat could be transferred of CLOHP/CV with a 2.03 mm inner diameter for all working fluids tested. Because of the Maezawa et al. hypothesis [6] was used to estimate the maximum inner the CLOHP/CV diameter, it might have been thought that the vapor slug filled the cross section area within the tube. But in reality, the internal wall of the tube was covered by a liquid film. Therefore, the inner diameter of the tube can be slightly larger than the finding value. In conclusion, the heat decreased as a result the thermal resistance decreased, at the view point that CLOHP/CV with R123 as working fluid, working temperature at 200 °C and inner diameter was 2.03 mm; this value was 2.51 °C-m<sup>2</sup>/kW.

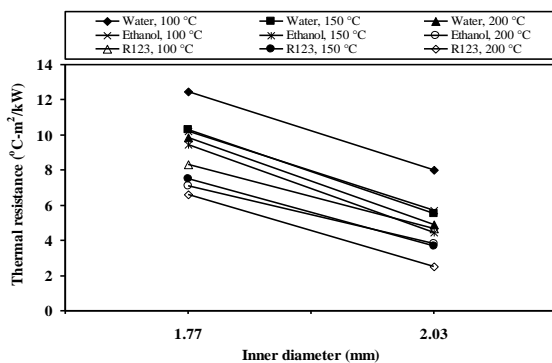


Fig. 9 Relationship between inner diameters versus thermal resistance

#### 4. Conclusions

It can be summarized that: The working fluid, working temperature and inner diameter affected to the internal pressure and heat transfer rate of

the CLOHP/CV. The CLOHP/CV using R123 as working fluid, working temperature of 200 °C and inner diameter of 2.03 mm caused the internal pressure and the heat transfer rate to be higher moreover; the thermal resistance was lower than when using distilled water and ethanol as working fluid.

#### 5. Nomenclature

$Q$	heat transfer rate (W)
$A_c$	all outer surface area of tube in condenser section (m <sup>2</sup> )
$q$	heat flux (W/m <sup>2</sup> )
$\dot{m}$	mass flow rate (kg/s)
$C_p$	specific heat capacity constant pressure (J/kg°C)
$T_c$	tube wall temperatures of the condenser section (°C)
$T_e$	tube wall temperatures of the evaporator section (°C)
$T_{in}$	temperature inlet of the condenser section (°C)
$T_{out}$	temperature of dry air at the exit (°C)
$R$	thermal resistance (°C-m <sup>2</sup> /W)

#### 6. Acknowledgement

The researcher has been supported generously by the Heat Pipe and Thermal Tools Design Research Unit (HTDR), Faculty of Engineering Mahasarakham University, Thailand and Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No.PHD/0002/2553).

#### 7. References



- [1] Akachi, H., Polasek, F. and Stulc, P. Pulsating heat pipe, *Proc. of the 5<sup>th</sup> International Heat Pipe Symposium*, Australia. (1996), pp. 208–217.
- [2] Charoensawan, P. and Terdtoon, P. Thermal performance of horizontal closed-loop oscillating heat pipes, *Applied Thermal Engineering*, vol. 28 (5-6) (2008), pp. 460-466.
- [3] Dobson, R.T. Theoretical and experimental modeling of an open oscillatory heat pipe including gravity, *Thermal science*, vol. 43 (2004), pp. 113-119.
- [4] Rittidech, S., Pipatpaiboon, N. and Thongdaeng, S. Thermal performance of horizontal closed-loop oscillating heat-pipe systems with check valves (HCLOHPs/CVs), *J. Mech. Sci. Technol*, vol. 24 (2) (2010), pp. 545-550.
- [5] Rittidech, S., Pipatpaiboon, N. and Terdtoon, P. Heat transfer characteristics of a closed loop oscillating heat pipe with check valves, *Applied Energy*, vol. 84 (2007), pp. 565–577.
- [6] Maezawa, S., Gi, K.Y., Minamisawa, A. and Akachi, H. Thermal Performance of Capillary Tube Thermosyphon, *Proc. of the 9th International heat-pipe conference*, USA, (1996). pp. 791-795.
- [7] Tong, B.Y., Wong, T.N. and Ooi, K.T. Closed-loop pulsating heat pipe, *Applied Thermal Engineering*, vol. 21 (2001), pp. 1845-1862.
- [8] Qu, W., Ma, T., Miao, J. and Wang, J. Effects of radius and heat transfer on the profile of evaporating thin liquid film and meniscus in capillary tubes, *Heat and Mass Transfer*, vol. 45 (2002), pp. 1879-1887.
- [9] Yang, H., Khandekar, S. and Groll, M. Operation limit of closed loop pulsating heat pipe, *Applied Thermal Engineering*, vol. 28 (2008), pp. 49-59.
- [10] Zhang, Y and Faghri, A. Advances and unsolved issues in pulsating heat pipes, *Heat Transfer Engineering*, vol. 29(1) (2008), pp. 20–44.