Experimental Investigations on Thermal Performance of Small Closed End Heat Pipes with Special Vapor Chamber

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Abstract

This article presents a thermal performance of a small closed end heat pipe with special vapor chamber (SCEHP/SVC). This study has carried out the effect of parameters (such as pipe size, filling ratio, working fluids and incline angle etc.) on thermal performance. The SCEHP/SVCs consists of 2, 3 and 4.5 mm ID small closed end pipe and special vapor chamber were 14.5, 17.5 and 20.0 mm ID (at evaporator section). The number of meandering turns was 10. The lengths of the evaporator were 50, 100 and 150 mm (The length of evaporator, adiabatic and condenser sections were equal). R-134a, ethanol and water were used as working fluids with filling ratios of 30, 40 and 50%.The evaporator was heated by hot water to 60, 70 and 80°C, whereas the condenser was cooled with water at 20 °C. The inclination angles were 90, 60, 30, 0, -30, -60 and -90 degrees from horizontal plane. The temperatures at significant points (evaporator, adiabatic, condenser, inlet and outlet) were recorded every 10 minutes by data logger. As the result of the experiment, the boiling behaviors of SCEHP/SVCs, which has a small closed end of 2 mm acts like oscillating heat pipe, were like thermosyphon. As inclination angle increases, the heat flux increases. The best working fluid was R134a. The filling ratio, section length and small closed end size increased with decreasing heat flux. In addition, the heat transfer performances were excellent under the condition; the 2 mm of small closed end pipe, 17.5 mm vapor chamber pipe, R134a with filling ratio 30%, and also hot water at 80 °C with inclination angle of 90 degree.

Keywords: thermal performance, small closed end heat pipes, special vapor chamber

Introduction

In recent years, heat pipes have been widely employed as heat exchanger devices in many industries or other fields, owing to their excellent heat transfer performance, non complex structure and low heat input workability also[1]. It utilizes the liquid → vapor phase change of working fluid inside the pipe. Nowadays the oscillating heat pipe (OHP) has become popular as has been reported in many literatures.

The oscillating heat pipe can be classified into three types such as, closed end oscillating heat pipe (CEOHP), closed loop oscillating heat pipe (CLOHP) and closed loop oscillating heat pipe with check valves (CLOHP/CV)[2].

The advantages of this heat pipe for instance; easy to build, fast thermal response and capable of conducting in many positions etc.[3], but connot operate at higher temperature differences. However, we have invented a new OHP in order to overcome its limitation. The new OHP was called “a Small Closed End Heat Pipe with Special Vapor Chamber” or “SCEHP/SVC”. Its structure seems to be the OHP combined with thermosyphon as shown in (Figure 1).

The aim of this study is to investigate the thermal performance of SCEHP/SVCs. The experiments conducted are based on the important thermo-mechanical parameters namely, internal diameter, section length, working fluid, volumetric filling ratio, heat input, and

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tested orientation. The researcher hopes that the experimental results may bring about further information for design and develop the new heat pipe.

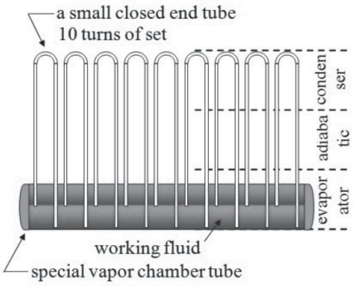

Figure 1 Shows the SCEHP/SVCs structure.

Materials and Methods

In order to built the tested SCEHP/SVCs (see in Figure 1), the upper part is called a small closed end (SCE) tube made of copper capillary tube of 2mm, 3mm and 4.5mm ID. It is bent into 10 meandering turns. At the lower part is a special vapor chamber (SVC) tube also made of copper tube in 14.5mm, 17.5mm and 20.0mm ID with 500mm of length. SCEHP/SVCs are fabricated by weld soldering. The evaporator, adiabatic and condenser sections were 50mm, 100mm and 150mm in equal length. The end of the capillary tube was inserted into the SVCs which can be seen in (Figure 1). Inclination angles were at -90, 60, 30, 0, 30, 60, 90 degree. The working fluids used were R134a, ethanol and water with filling ratios of 30%, 40% and 50% of the SVCs total volume. The working temperature were 60 °C, 70 °C and 80°C the condenser section was cooled by a cold bath at 20°C. The heating, cooling water jacket as well as adiabatic section were well wrapped with insulating sheet.

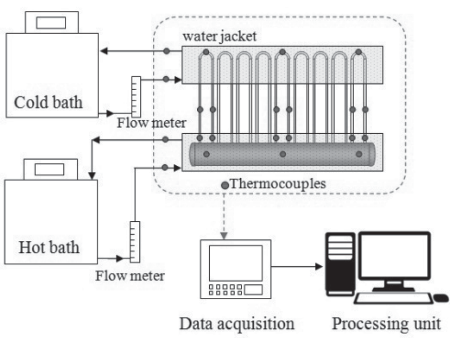

Figure 2 Schematic of experiment

(Figure 2) shows the experimental set up, the tested heat pipe was monitored and recorded by a Yogokawa MV1000 data acquisition with ±0.7°C accuracy, it was used with type-K thermocouple ±0.5°C accuracy (22 points attached). Thermo Fisher Scientific EX-35 hot bath (±0.01°C) was used to suppy hot water to the evaporator section with controlled 0.014705 kg/s of flow rate. Moreover, the EYELA CA-112CE cold bath (±2°C) used to pump cool water to condenser section with 0.004643 kg/s of flow rate. All tested parameters are shown in (Table 1)

Table 1 Specifications and experimental conditions

Controlled parameter	**Value**
Turns	10 turns
Cold bath	20°C
Evaporator flow rate	0.014705 kg/s
Condenser flow rate	0.004643 kg/s
Variable parameters	**Values**
Small closed end tube	2, 3 and 4.5 mm ID
Vapor chamber tube	14.5, 17.5 and 20mm ID
Section length	50, 100 and 150mm
Working fluid	R134a, ethanol, water
Filling ratio	30%, 40% and 50%
Tested orientation	-90, 60, 30, 0, 30, 60, 90
Working temperature	60, 70 and 80°C

For the experiment procedure, The hot bath and cold bath were maintained at operating temperature steadily. When steady state was reached, the temperatures were recorded in 10 minute intervals by data acquisition. Those recorded values are used to calculate the thermal performance, is obtained by;[4]

$$Q_c = \dot{m}_c Cp_c \Delta T_c \quad (1)$$

$$\dot{q}_c = \frac{Q_c}{2\pi D_o L_c N} \quad (2)$$

Where Q_c is heat flux of condenser (W), $\dot{m}_c$ is cooling water mass flow rate (kg/s), Cp_c is specific heat of cooling water (J/kg.°C), ΔT_c is difference temperature of cooling water between inlet and outlet (°C), $\dot{q}_c$ is the condenser heat flux (kW/m^2), D_o is the outer diameter of small copper tube (mm), L_c is the condenser length (mm) and N is number of turn.

$$Q_e = \dot{m}_e Cp_e \Delta T_e \quad (3)$$

$$\dot{q}_e = \frac{Q_c}{\pi D_{ve} L_e + N\left[2\pi D_o\left(L_e - D_{ve}\right) - 2\pi\left(\frac{D_o}{2}\right)^2\right]} \quad (4)$$

In where Q_e is heat flux of evaporator (W), $\dot{m}_e$ is hot water mass flow rate (kg/s), Cp_e is specific heat of hot water (J/kg. °C), ΔT_e is difference temperature of cooling water between inlet and outlet at evaporator (°C), D_{ve} is an outer diameter of SVC (mm), L_e is an evaporator length (mm) and $\dot{q}_e$ is the evaporator heat flux (kW/m^2).

Results and Discussion

The results of the experiment presented the effects of thermo-mechanical parameters, i.e. geometric dimensions, working fluid, volumetric filling ratio, heat input, and tested orientation.

1. Effect of inner diameter of the SCE

(Figure 3), shows the SCEs tube size affected at variations of inclination angle. The heat flux of SCEHP/SVCs which used SCEs tube of 2 mm ID reached the maximum value at 39.68 kW/m^2 in 90° orientation.

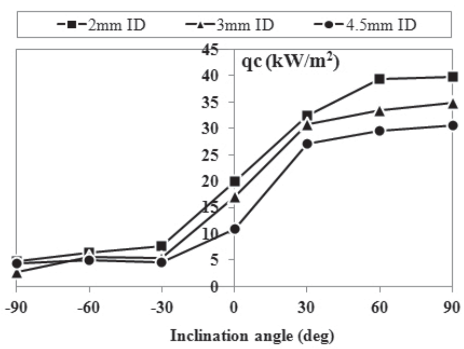

Figure 3 Heat flux with variations of inclination angle for various SCEs sizes. (SVC: 17.5mm ID, R-134a, 30% Fill ratio, section length: 50mm, working temp.: 80°C)

Furthermore, the effect of SCEs size on boiling behavior could observed in (Figure 4). The thermal oscillations on the outer tube wall relates to the vapor plug and liquid the slug periodically flushing inside heat pipe[5]. The SCEs size of 2mm ID had short amplitude of temperature fluctuations than others, also acts like a oscillating heat pipe.

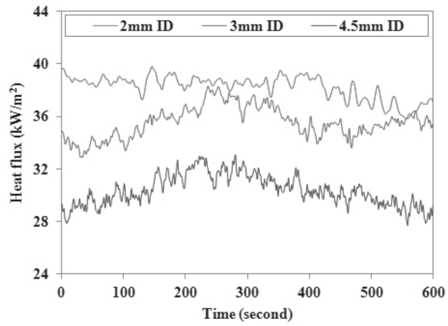

Figure 4 Heat flux fluctuation with time series for various SCEs sizes. (SVC: 17.5mm ID, R-134a, 30% Fill ratio, section length: 50mm, working temp.: 80°C)

2. Effect of inner diameter of the SVC

The SVCs diameters used were 14.5, 17.5 and 20.0mm ID. The effect of SVCs size on the heat flux at varying inclined angle, it found that the heat flux of 17.5 mm of SVCs ID was higher than 14.5 and 20.0 mm. The low heat flux achieved on 20.0mm ID is caused by a few spaces for supplied hot water, while on a 14.5 mm ID is due to smallest heat transfer area.

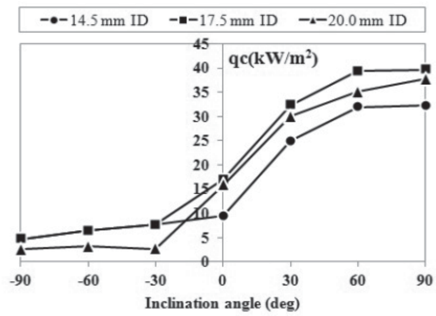

Figure 5 Heat flux with variations of inclination angle for various SVCs sizes. (SCE: 2mm ID, R-134a, 30% Fill ratio, section length: 50mm, working temp.: 80°C)

3. Effect of section length

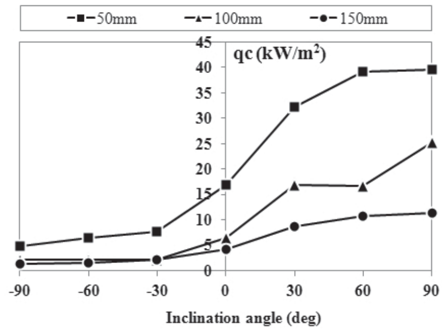

Figure 6 Heat flux with variations of inclination angle for various section lengths. (SCE: 2mm ID, SVC: 17.5mm ID, R-134a, 30% Fill ratio, working temp.: 80°C)

It is clear that the heat flux of the tested heat pipe with 50 mm section length was higher than the other length on every inclination angle. (Figure 6)

4. Effect of working fluid

(Figure 7) presents the relationship between heat flux and inclination angle at different working fluids. The result indicated that the R-134a was an excellent medium when compared with ethanol and water at every oriented angle, owing to R-134a haveing good properties, nomely, low boiling point and a low melting point.

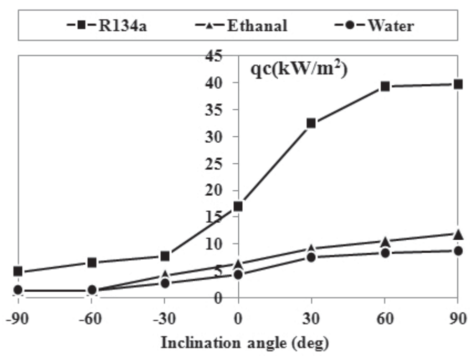

Figure 7 Heat flux with variations of inclination angle for various working fluid types. (SCE: 2mm ID, SVC: 17.5mm ID, section length: 50mm, 30% Fill ratio, working temp.: 80°C)

5. Effect of filled ratio

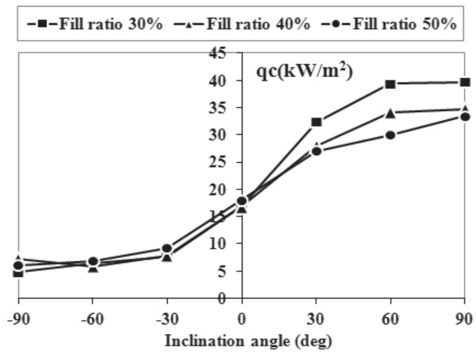

Figure 8 Heat flux with variations of inclination angle for various filling ratio. (SCE: 2mm ID, SVC: 17.5mm ID, section length: 50mm, R-134a, working temp.: 80°C)

As shown in (Figure 8), the 30% of filling ratio by SVCs volume obtained a heat flux more than 40% and 50%. Because, at the 50% filling ratio, the short leg of the capillary tube was touched with working fluid. It might cause a dynamic viscosity of bubble. In case of 40% have found same problem but less.

6. Effect of inclination angle

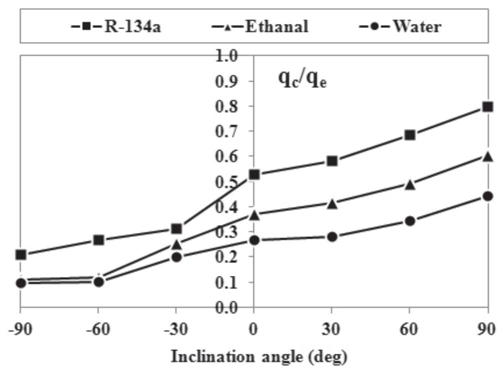

Figure 9 Heat transfer efficiency with variations of inclination angle for various working ratio. (SCE: 2mm ID, SVC: 17.5mm ID, section length: 50mm, filling ratio: 30%, working temp.: 80°C)

According to previous results, the tested heat pipe inclined 90 degree as it obtained maximum heat flux, because of the assisted gravity force and minimum friction to counter the bubble movement. By increasing inclination angle transfer efficiency increased. The highest its efficiency is about 0.80 in the vertical position shown in (Figure 9).

7. Effect of working temperature

In (Figure 10) illustrated the effect of the operating temperature which circulates hot water by hot bath at various temperatures i.e. 60, 70 and 80 °C. It can be concluded that the heat flux is dependant on the heat input. The heat flux increased as increasing of heat input at inclined orientation range 0-90 degree.

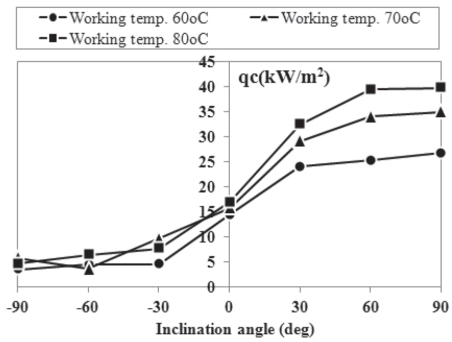

Figure 10 Heat flux with variations of inclination angle for various working temperature. (SCE: 2mm ID, SVC: 17.5mm ID, section length: 50mm, R-134a, filling ratio: 30%)

Conclusions

The conclusions for thermal performance of SCEHP/SVC which affects from parameters (e.g. pipe size, filling ratio, working fluid and inclination angle etc.) can be summarized as;

1. The increasing of the SCEs tube ID goes to remarkably decreasing heat flux. Because of the 2mm ID, the boiling behavior observed as heat flux fluctuations, act like a pulsating heat pipe while 3mm and 4.5 look like thermosyphon.

2. The 17.5 mm of SVCs tube was suited for this experiment.

3. Decreased heat flux when increasing section length, 50 mm is better.

4. The heat flux increases according to working fluid as R-134a, ethanol and water respectively.

5. Filling ratio of 30% by SVCs volume is appropriate in this experiment.

6. Inclination angle and working temperature increasing leads to heat performance increased.

7. The maximum heat flux of this heat pipe was achieved at 39.69 kW/m^2 on condition as; SCE: 2 mm ID, SVC: 17.5 mm ID, R-134a with filling ratio 30%, working temperature: 80 °C and tested in vertical position.

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