



เอกสารอ้างอิง

ประดิษฐ์ เทอดทูล *ท่อความร้อน* : ภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเชียงใหม่, 2536

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ภาคผนวก ก

บทความทางวิชาการเรื่อง Effect of Length Ratios on Heat Transfer Characteristics of Closed-Loop Oscillating Heat Pipe with Non-Uniform-Diameter วารสาร Energy Research Journal 1(2): 104-110 (ISSN 1949-0151), 2010

Effect of Length Ratios on Heat Transfer Characteristics of Closed-Loop Oscillating Heat Pipe with Non-Uniform Diameter

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Abstract: Problem statement: Closed-loop oscillating heat pipe is a high performance heat exchanger especially as this heat exchanger has one direction flow of working fluid inside tube. **Approach:** This research studies the effect of length ratios on heat transfer characteristic of Closed Loop Oscillating Heat Pipe with Non-Uniform Diameter (CLOHP/NUD). The 2.03 and 1.06 mm inner diameter of capillary tube were alternated connection and bent into 16 turns and both ends were connected to form of loop. Length ratio of 3, 1, 0.33 and 0.2 were studied. Evaporator, adiabatic and condenser length were 100 mm. R123, ethanol and water were used as the working fluid and filling ratio 50% by total inner volume of CLOHP/NUD was used. The evaporator and condenser temperatures were controlled at 100 and 20°C. CLOHP/NUD operated at vertical plane. **Results:** It was found that, the CLOHP/NUD transferred higher heat than the conventional Closed Loop Oscillating Heat Pipe (CLOHP) with the same heat transfer area because the working fluid flowed in only one direction. Working fluid moved to condenser section in larger inner diameter and returned to evaporator section in smaller inner diameter. The heat flux of the CLOHP/NUD with R123 as working fluid increased from 15.49-20.85 kW m⁻² when length ratio decreased from 1-0.2, respectively. This is due to the head loss from the sudden enlargement resulted in well circulation of working fluid. Furthermore, higher heat flux was obtained by using water as working fluid. **Conclusion:** The heat transfer performance of CLOHP/NUD can be improved if one directional circulation of working fluid can be induced.

Key words: Closed loop oscillating heat pipe, non-uniform diameter, length ratios, heat transfer characteristics

INTRODUCTION

Heat pipe is a high performance heat exchanger and useful device in engineering field such as a heat exchanger to recover waste heat energy, removing of local heat and heat in electronic device. The heat pipe has been accepted as a necessary part for sustainable well-being. Heat pipe has many advantages. One type of heat pipe is a Close-Loop Oscillating Heat Pipe (CLOHP) (Akachi *et al.*, 1996). CLOHP is small, light weight, simple structure, high efficiency, fast thermal responsibility, performing through low difference of temperature and it can be operate in all orientation. In many researches, CLOHP had shown its higher performance because inside working fluid flowed in one direction (Khandekar and Groll, 2004; Chareonsawan *et al.*, 2003). Close Loop Oscillating Heat Pipe with Check Valve (CLOHP/CV) has been proposed to controlled working fluid circulation in one direction, it had higher performance at higher

ratio of number of turns to number of check valve (Rittidech *et al.*, 2007). Moreover, the other type of close loop oscillating heat pipe with controlled flow direction is Closed Loop Oscillating Heat Pipe with Non-Uniform Diameter (CLOHP/NUD). CLOHP/NUD can control flow direction by their geometry. It has higher performance than CLOHP (Liu *et al.*, 2007; Tharawadee *et al.*, 2008). However, few previous researchers studied only effect of diameter ratio. In this research, thus, the structure was changed by changing length of connected tube in order to study of effects of length ratio (length of 2.03 mm tube by length of 1.06 mm tube) and working fluid to heat transfer characteristics of CLOHP/NUD operated at vertical position.

MATERIALS AND METHODS

Experimental setups and procedure: The CLOHP/NUD set-up used in this study was made of

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2.03 and 1.06 mm inner diameter of copper capillary tube alternated connection and bent into 16 turns. Both ends were connected in a form of loop. Evaporator, adiabatic and condenser length were 100 mm. Length ratio of 3, 1, 0.33 and 0.2 were studied. The shorter tube length was control as 300 mm as shown in Fig. 1.

CLOHP/NUD was evacuated and then working fluid was filled with the filling ratio of 50% by total inner volume. R123, ethanol and water were used as the working fluid. The experimental set-up is shown in Fig. 2. The heating silicone oil from a hot bath (HAAKE, 8N3-B and $\pm 0.5^\circ\text{C}$ accuracy) was circulated and maintained the inlet temperature at 100°C .

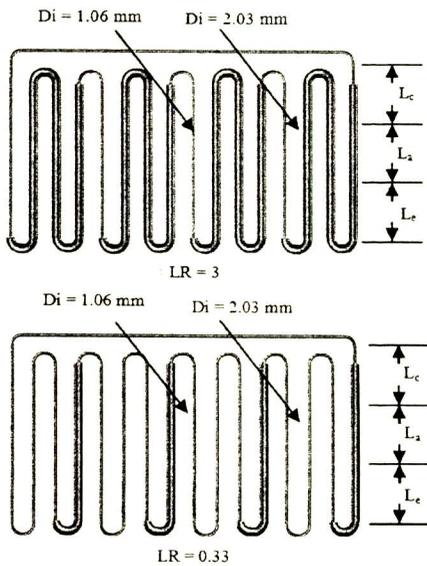


Fig. 1: CLOHP/NUD

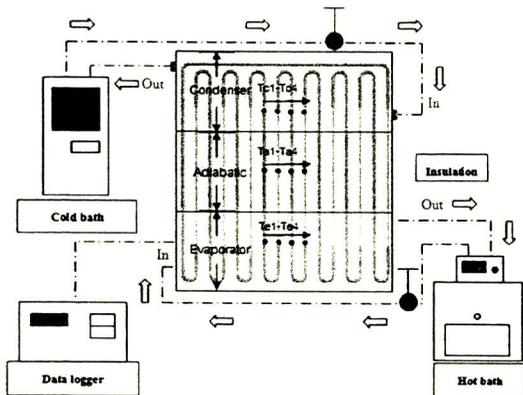


Fig. 2: Details of the experimental set-up

The cooling water from a cold bath (BITZER, D7032 and $\pm 1^\circ\text{C}$ accuracy) was circulated and maintained the inlet temperature at 20°C . The mass flow rate of cooling water was measured by a balance (Computer electronic scale ± 0.005 kg). The temperature at specified points was monitored by a data logger (Brainchild, VR18, accuracy $\pm 0.1^\circ\text{C}$). Chromel-alumel thermocouples (Omega-type 'K') were used to measure the temperature of the cooling water, by two probes were installed at the inlet and outlet cooling water of the condenser. The heat transfer was calculated by calorimetric method at condenser section. In addition, the 12 thermocouples were employed to measure the temperature at 4 points in evaporator section, 4 points at adiabatic section and 4 points in condenser section. All test sets were well-insulated with foam insulation (Armaflex, 3/8 inch thickness).

The inlet temperature of the hot baths and cold baths were controlled at 100 and 20°C , respectively. The hot and cold fluids were supplied to the jackets of both the evaporator and condenser sections, respectively. After a quasi-steady state was reached, the temperature and flow rate were recorded and then the heat throughput was determined. Each experiment was repeated for three times. Finally, the influenced parameters were varied according to the required objectives.

RESULTS

The measured temperature of CLOHP/NUD operating at normal state (length ratios 0.33, $L_c = L_a = L_e = 100$ mm, alternative of 2.03 and 1.06 mm inner diameter of CLOHP/NUD, 16 turns, filling ratio 50%, vertical orientation) using R123, ethanol and water as working fluid are shown in Fig. 3-5, respectively.

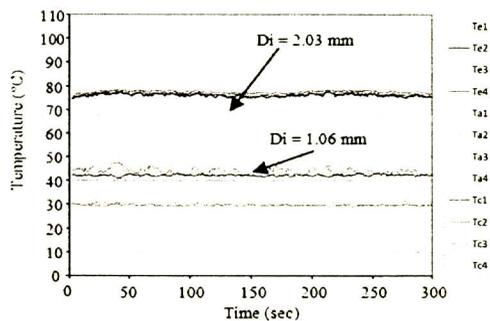


Fig. 3: The measured temperature of CLOHP/NUD (LR of 0.33 and R123 as working fluid)

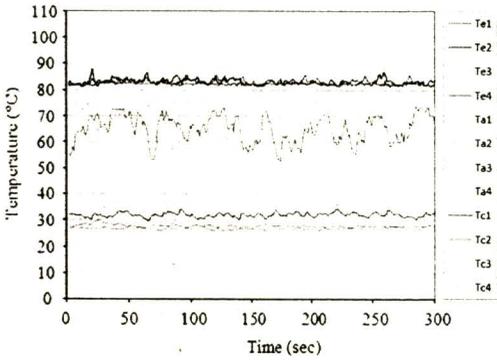


Fig. 4: The measured temperature of CLOHP/NUD (LR of 0.33 and ethanol as working fluid)

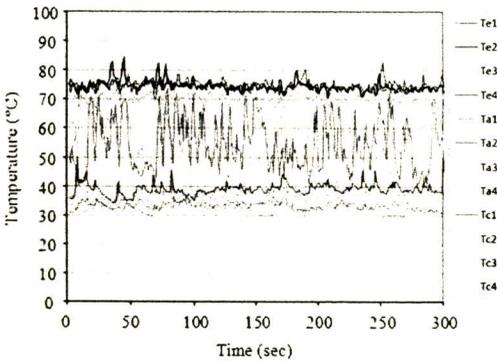


Fig. 5: The measured temperature of CLOHP/NUD (LR of 0.33 and water as working fluid)

Figure 6 shows the heat flux of CLOHP/NUD with R123, ethanol and water as working fluid at the condition of length ratios 0.33, $L_c = L_a = L_c = 100$ mm, alternative of 2.03 and 1.06 mm inner diameter of CLOHP/NUD, 16 turns, filling ratio 50%, vertical orientation. The highest heat flux is obtained at 21.79 kW m^{-2} when using water as working fluid while R123 and ethanol provide the heat flux at 20.16 and 14.14 kW m^{-2} , respectively.

Figure 7 and 8 show the relationship of heat flux of CLOHP/NUD ($L_c = L_a = L_c = 100$ mm, alternative of 2.03 and 1.06 mm inner diameter of CLOHP/NUD, 16 turns, filling ratio 50%, vertical orientation) and length ratios, when R123 and water were use as working fluid, respectively. In Fig. 7, R123 was use as working fluid at vertical plane, the highest heat flux of CLOHP/NUD with 0.2 length ratio is 20.85 kW m^{-2} . Which it was higher than CLOHP/NUD with length ratio of 1 about 34.60%

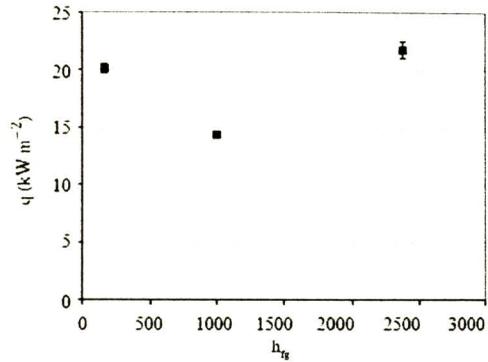


Fig. 6: Effect of working fluids on heat transfers characteristic of CLOHP/NUD (LR of 0.33)

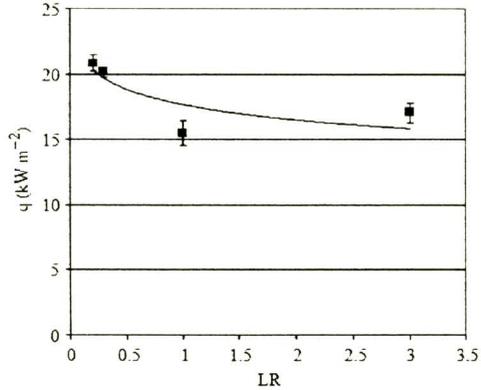


Fig. 7: Effect of length ratios on heat transfers characteristic of CLOHP/NUD (R123 as working fluid)

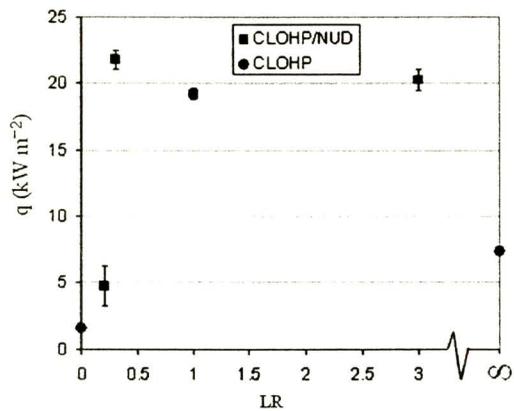


Fig. 8: Effect of length ratios on heat transfers characteristic of CLOHP/NUD (water as working fluid)

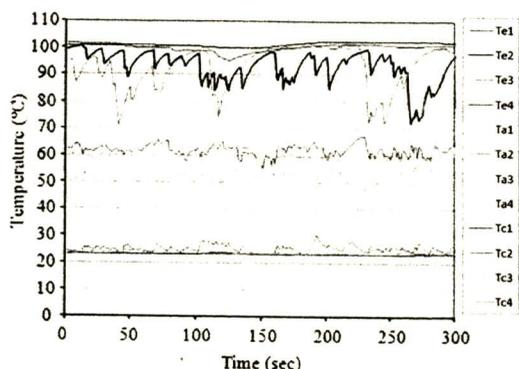


Fig. 9: The measured temperature of CLOHP/NUD (LR of 0.2 and water as working fluid)

Figure 9 shows temperature of CLOHP/NUD operating at critical state (length ratios of 0.2, $L_c = L_a = L_c = 100$ mm, 2.03 and 1.06 mm inner diameter of CLOHP/NUD, water was use as working fluid, 16 turns, filling ratio 50%, vertical orientation

DISCUSSION

CLOHP/NUD operation: The measured temperatures are shown in Fig. 3-5, it was implied that temperature at adiabatic section of larger diameter tube is higher than that of smaller diameter tube. CLOHP/NUD is heated at evaporator section, resulting in the vapor is easily circulated inside the larger diameter tube. After that, the working fluid flows throughout adiabatic section resulting in the temperature of adiabatic section with larger diameter was higher. This high temperature tube will be called “hot tube” afterward. Then, the working fluid flows inside condenser section and condenses. The condensate flows inside smaller diameter tube and flows throughout adiabatic section, resulting in the temperature of adiabatic section of smaller diameter tube was lower than temperature in larger diameter tube. This will designated as “cold tube”. The working fluid returns into evaporators to complete it circulation in one direction.

Effect of working fluids: Figure 3-5 show that adiabatic section of 2.03 mm tube (Ta1, Ta3) with R123 and ethanol as working fluid have higher temperature and nearly constant, compare with 1.06 mm (Ta2, Ta4). This implies that the working fluid in vapor phase flows out from larger diameter tube in evaporator section. Nevertheless, adiabatic section of 2.03 mm tube with water as working fluid has higher temperature and severely fluctuate compare with 1.06 mm tube. The

latent heat of evaporation (h_{fg}) of water is higher than R123 and ethanol that result in lower evaporation. Moreover, the average temperature difference of adiabatic and evaporator section is about $4 \pm 1.5^\circ\text{C}$. This value is smaller than those of ethanol and R123 as working fluid, which are 7 ± 0.5 and $10 \pm 0.9^\circ\text{C}$, respectively. Water has higher surface tension and dynamic viscosity than ethanol and R123 resulting in water is difficult to circulate. Thus, higher vapor pressure is required for circulation. This causes the temperature of adiabatic section is higher. In case that it is difficult for the water to circulate, there appears the vapor flowing in opposite direction in some part of 1.06 mm diameter tube, it can be observed from high temperature (Ta2, Ta4) oscillation and has nearly temperature of 2.03 mm tube in adiabatic section. Macroscopically, CLOHP/NUD still has one direction circulation because it has no liquid flowed in 2.03 mm tube. Therefore, the temperature drop at this tube cannot be observed.

Effect of working fluids is shown in Fig. 6. This tendency occurs in all experiments at normal operation and this is in agreement with results from constant 2.03 mm inner diameter CLOHP, filling ratio 50% of total inner volume, 16 turns, 80°C of evaporator temperature, 20°C of condenser temperature and operated at vertical plan (Chareonsawan *et al.*, 2003). The highest heat flux is obtained when using water as working. Due to its surface tension, $(dp/dt)_{\text{sat}}$, sensible heat, latent heat and viscosity, were suitable for this operation. Although water cannot easily circulate, but latent heat and sensible heat of water is much higher than that of R123 and ethanol. Thus R123 can be easier evaporated in evaporator section result in more driving force of circulation and then more heat flux is obtained than using ethanol or water as working fluid.

Effect of length ratios: It was found from the experiments that, working fluid inside CLOHP/NUD still circulates in one direction. In Fig. 7 shows all of CLOHP/NUD operated at normal state, it can be concluded that, the heat flux increases when length ratio decrease. The decreasing in the length ratio means reducing the connection points, result in decreasing in pressure drop of sudden contraction. Thus, the working fluid circulates easily and continuously flows. Furthermore, length ratio lower than 1 presents that most of CLOHP/NUD is made of smaller diameter tube. In addition, the larger diameter tube not only supports working fluid to flow in one direction, also reduces flow friction of changing inner diameter of tubes. On the other hand, length ratio higher than 1 presents that most of CLOHP/NUD is made of larger

diameter tube. Addition smaller diameter tube result in working fluid flows in one direction, flow friction increases in system.

Figure 8 shows that, heat flux tends to increase to its maximum and approach to heat flux of CLOHP (at very low length ratio). At 0.2 length ratio of CLOHP/NUD, critical state is occurred as shown in Fig. 9. The evaporator temperature is 100°C which equals to silicone oil temperature, it was implied that the dryout occurs. The CLOHP/NUD with 0.2 length ratio obtains heat transfer at 4.76 kW m⁻² which it is lower than those of 0.33 length ratio, which has the highest heat transfer at 21.79 kW m⁻². Previously research of CLOHP (inner diameter = 1.06 mm, L_c = L_a = L_e = 100 mm, 15 turns, filling ratio 50%, WF = Water, vertical orientation) showed that, the highest heat flux of CLOHP is 1.6 kW m⁻² (Sakulchangsattajai *et al.*, 2007). This shows that, CLOHP/NUD with length ratio closed to zero was the same in heat flux and phenomena as CLOHP. In contrast, heat flux decreases when length ratio increases as shown in Fig. 8. Heat flux of CLOHP/NUD with 3 length ratio is not different compare with that of CLOHP/NUD with length ratio of 1, but still higher than CLOHP (inner diameter = 2.03 mm, L_c = L_a = L_e = 100 mm, 15 turns, filling ratio 50%, WF = water, vertical orientation). This can be concluded that, heat flux of CLOHP/NUD is higher than heat flux of CLOHP as also found in previous researches (Liu *et al.*, 2007; Tharawadee *et al.*, 2008).

CONCLUSION

The effects of length ratios and working fluids on the heat performance of CLOHP/NUD have been experimentally investigated. The following main conclusions can be drawn from the study:

- The working fluid of the CLOHP/NUD with length ratio of 3, 1, 0.33 and 0.2 flows in one direction. The heat flux is increased when the length ratio decreases
- Type of working fluid affects its circulation direction. Heat flux of CLOHP/NUD with water as working fluid reaches the highest at 21.79 kW m⁻² at vertical orientation. The CLOHP/NUD with R123 as working fluid obtains the heat flux at 20.85 kW m⁻² with length ratio of 0.2 at vertical orientation. The CLOHP/NUD with ethanol as working fluid obtains the heat flux of 14.41 kW m⁻² with length ratio of 0.33 at vertical orientation

The heat transfer performance of CLOHP/NUD can be improved if one directional circulation of working fluid can be controlled.

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ภาคผนวก ข

บทความทางวิชาการเรื่อง Heat Transfer Characteristics of a Closed-Loop Pulsating Heat Pipe with Non-Uniform Diameter at Normal Operating Condition คาดว่าจะตีพิมพ์ในวารสาร Heat Transfer Engineering (เฉพาะบทคัดย่อของบทความ)

Heat Transfer Characteristics of a Closed-Loop Pulsating Heat Pipe with Non-Uniform Diameter at Normal Operating Condition

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Abstract

The objective of this study is to experimentally investigate the heat transfer characteristics of a closed-loop pulsating heat pipe with non-uniform diameter (CLPHP/NUD) at normal operating condition. The tested CLPHP/NUDs were made of copper capillary tubes with various two-inner diameters size along the pipe, working fluid types, filling ratios, evaporator lengths, evaporator temperatures and number of turns. The evaporator section of the CLPHP/NUDs was heated by silicone oil. The heat was removed from the condenser section by a mixture of water and ethylene glycol. The adiabatic section was well insulated by insulator material. The outer surface temperature of evaporator, adiabatic and condenser section were recorded in order to observe the direction of working fluid inside the heat pipe. The inlet and outlet temperature and the flow rate of the cooling substance were recorded in order to calculate the heat transfer rate of the CLPHP/NUDs by calorific method after the system reached the steady state. It was found from all the experimental results that the heat transfer rate of CLPHP/NUDs depends on the evaporator temperature that is related to the number of turns. The critical number of turns depends on the evaporator temperature and the inner diameter of the tube. The thermal performance of a HCLPHP improves by increasing the evaporator temperature and decreasing the evaporator/effective length. The best performance of all the CLPHP/NUDs occurred at the maximum number of 26 turns. The proper filling ratio for a HCLPHP with a 150 mm Le is 30% and for a 50 mm Le is both 30% and 50%. The proper working fluid for a CLPHP/NUDs with a 2 mm inner diameter is water, but for those with a 1 mm inner diameter both water and ethanol are appropriate. The performance of CLPHP/NUD is strongly dependent on the flow pattern existing inside the tubes.

From the study, it was found that when the internal diameter and number of meandering turns increased, the maximum heat flux increased. However, when the evaporator section length increased, the maximum heat flux decreased. The maximum heat flux of a CLPHP occurs due to

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บทความทางวิชาการเรื่อง Effect of Diameter Ratio on Heat Transfer Characteristic of Non-Uniform Diameter Closed Loop Oscillating Heat Pipe นำเสนอในงานประชุม Proceedings of the 9th International Heat Pipe Symposium, Malaysia, 2008.

Effect of Diameter Ratio on Heat Transfer Characteristic of Non-Uniform Diameter Closed Loop Oscillating Heat Pipe

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Abstract

The objective is to study the effect of improved configuration on closed-loop oscillating heat pipe (CLOHP) by varied inside diameter. This variation causes the working fluid to circulate in just one direction. The CLOHP was made of a long copper capillary tube and bent into 15 turns. Then, both ends were connected to form the loop with is the diameter ratio (ratio of greater inner diameter to the smaller inner diameter), 2.85 (2.03, 0.71 mm), 1.91 (2.03, 1.06 mm), 1.49 (1.06, 0.71 mm). The evaporator section length was 50 mm. The adiabatic and condenser section length were equaled to the evaporator length. R123, ethanol and water was used as the working fluid. Filling ratio is 30, 50 and 70 percent by total volume. CLOHP operated at the horizontal and vertical plane. The evaporator and adiabatic temperature was controlled at 80 and 20 °C respectively. It is found that, The highest heat flux are obtained by using R123 ethanol and water respectively, The best filling ratio is 70 percent. Moreover, The lower diameter ratio is conducted, the higher heat flux is obtained. And the heat transfer performance increases comparing to the conventional CLOHP from 4,270 to 14,178w/m². On account of the operational mechanism and the asymmetry can propel the working fluid to flow in one direction, thus, result the efficiency increases.

Key Words: non-uniform diameter closed loop oscillating heat pipe, diameter ratio, heat transfer characteristics, filling ratio.

1. INTRODUCTION

Nowadays, new technology consist of small size electronic parts and the more efficiency have to be increased. Moreover heat is also much more accumulate. At the same time, area of removed heat is become smaller. Regard to this limit, the appropriated heat transfer device should be conducted, therefore, the Oscillating Heat Pipe (OHP) is used with electrical circuit for removing the heat. There are three main OHP: Closed-end oscillating heat pipe (CEOHP), Closed-loop oscillating heat pipe (CLOHP) and Closed-loop oscillating heat pipe with check valve (CLOHP/CV) [1]. These different configurations, effect to the operational characteristic of the working fluid, oscillation and circulation. As the previous relate research, the study of effects of various parameters to normal oscillating heat pipe have been proposed[5-7]

OHP have a good and continual heat transfers efficiency, when the working fluid flow in one direction [2]. For this reason then improve oscillating heat pipe is made by adding a check valve [7], which cause the OHP to be asymmetry and non-uniform inside diameter is applied. These changed force the working fluid to circulate in one direction and the mathematical model also have a good agreement [3]. It was found that when add check valve in oscillating heat pipe, the higher

heat transfer is obtained but expensive and inconvenience to setup. The recent research has mentioned that CLOHP with non-uniform inside diameter makes the working fluid can be circulated into one direction and heat resistant become lower which express the increased heat transfer rate too [4]. However the above researches only investigate on the qualitative aspect of the the CLOHP with non-uniform inside diameter. Obviously, there is no study on heat transfer characteristic of this type. Thus, this study investigate on the quantitative aspect of effect of diameter ratio (ratio of greater inner diameter to the smaller inner diameter), working fluid and filling ratio on heat transfer characteristic of CLOHP with non-uniform inside diameter operates at the horizontal and vertical plane.

2. Experimental setups and procedure

Regards to the experiment, the performance testing method is as follow. The evaporator temperature was always maintained at 80 °C by using hot bath (HAAKE, 8N3-B, and ± 0.5 °C accuracy) for the condenser ,an aqueous solution of ethylene glycol (50% by volume) from a cold bath (BITZER,D7032, and ± 1 °C accuracy) was circulated maintained the inlet temperature at 20 °C. Essential three

parameters were varied at the outset : (a) diameter ratio and tube connection is shown in Fig. 1, with various 3 valves 2.86 (2.03, 0.71 mm) 1.91 (2.03, 1.06 mm) and 1.49 (1.06, 0.71 mm) respectively. (b) Filling ratio (FR) : 30%, 50%, 70% of total internal tube volume. (c) The CLOHP was tested in vertical and horizontal orientation. The experimental set-up is shown in fig. 2. It consisted of tested CLOHPs were made of copper capillary tube. Both ends of the tube were connected together to form a closed loop structure, hot bath , cooling bath , data logger (BRANCHILD,VR18, overall accuracy $\pm 0.1^\circ\text{C}$) and a flow meter (Platon, PGB411, and ± 0.1 l/min accuracy) was used to measure the flow rate of the coolant solution. Chrom-alumel thermocouples (OMEGA-TYPE 'K') were used to measure the temperature of the solution, two each at the inlet and outlet sections of the condenser. The heat throughput was thus measured by calorimetric method applied to the condenser-cooling jacket. In addition, the 12 thermocouples were employed to measure the temperature: 4 on the evaporator section, 4 on the adiabatic section and 4 on the condenser section. All test sets were well-insulated with foam insulation (Armaflex, 3/8 inch thickness). The experimental procedure is described as below.

First, the CLOHP was evacuated and then working fluid was filled. The inlet temperature of the hot and cold baths were set at the fixed values and the hot and cold fluids were supplied to the jackets of both the evaporator and condenser sections. After a quasi-steady-state was reached, the temperature and flow rate were recorded. Thus for a given configuration the heat throughput was evacuated. Then the influence parameters were varied according to the required conditions.

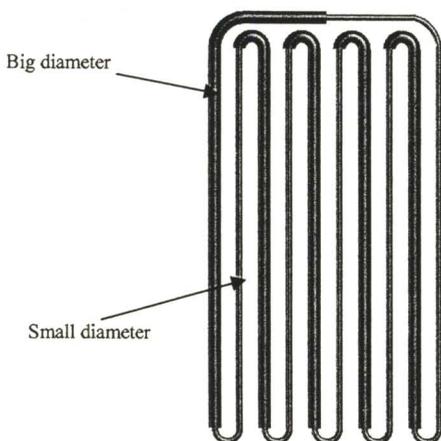


Fig. 1 CLOHP With Non-Uniform Inner Diameter

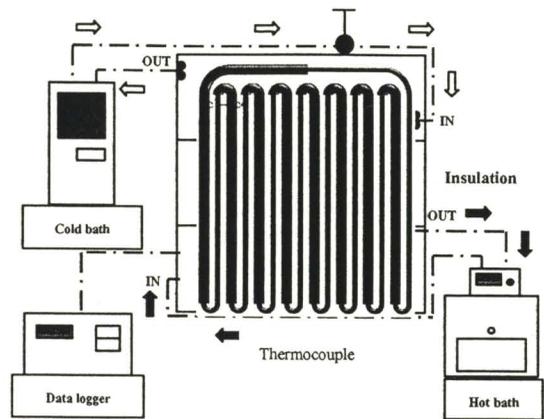


Fig. 2 Details of the experimental set-up

3. Results and discussion

3.1 Data accuracy

Since the heat transfer rate of the CLOHPs is calculated by measuring the volume flow rate and the inlet and outlet temperatures of the coolant flowing through the condenser section, the accuracy of each recorded data is inspected. After carrying out a detailed error analysis with respective accuracy of individual measurements and thermal losses is shown in Equation 1.

$$dq = \left[\left(\frac{\partial q}{\partial \dot{m}_c} d\dot{m}_c \right)^2 + \left(\frac{\partial q}{\partial C_{pc}} dC_{pc} \right)^2 + \left(\frac{\partial q}{\partial T_{c,out}} dT_{c,out} \right)^2 + \left(\frac{\partial q}{\partial T_{c,in}} dT_{c,in} \right)^2 \right]^{1/2} \quad (1)$$

All points of data in this research is passed error of instrument, But error bars as shown in every graphs are calculated from Standard deviation of experimental repetition.

3.2 Compare performance of heat transfer

Fig. 3 shows the comparison of thermal performance between normal CLOHP and CLOHP with non-uniform inside diameter. It was found that, maximum heat flux of CLOHP with inside diameter 0.71 mm and 1.06 mm (with the exception of L_e 50 mm, 15 turns and R123 as working fluid) is 4270 and 9590 kW/m² respectively. Comparing to the CLOHP with non-uniform inside diameter of 1.06,0.71 mm, the maximum heat flux is 14178 kW/m². The heat flux of CLOHP with non-uniform inside diameter is more than that in normal diameter CLOHP in vertical and horizontal orientation. Due to physical configuration of tube which allows the working fluid circulate in only one direction as describe in next chapter.

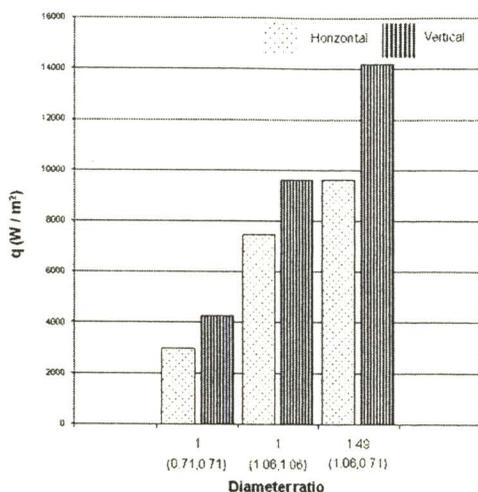


Fig. 3 Comparison of heat flux between normal diameter CLOHP and CLOHP with non-uniform inside diameter

3.3 Effect of diameter ratio

Fig. 4 shows the effect of diameter ratio on heat flux (with the exception of L_e 50 mm, 15 turns and R123 as working fluid, vertical orientation) the Standard deviation is shown on each data point. It was found that, diameter ratio of 1.49 (1.06 mm, 0.71 mm) is the highest heat flux, follow with 1.92 (2.03 mm, 1.06 mm) and 2.86 (2.03 mm, 0.71 mm). Because of the low diameter ratio shows a small difference between greater and smaller diameter. It effects the working fluid to flow with lower pressure drop which cause good heat transfer is occurred. In the other hand, the higher diameter ratio shows the large different between greater and smaller diameter, then the pressure drop increased. Which enforce the working fluid difficulty moves and the circulated velocity becomes lower, hence the amount of Fluid for transferring the heat and performance of the CLOHPs are decreased.

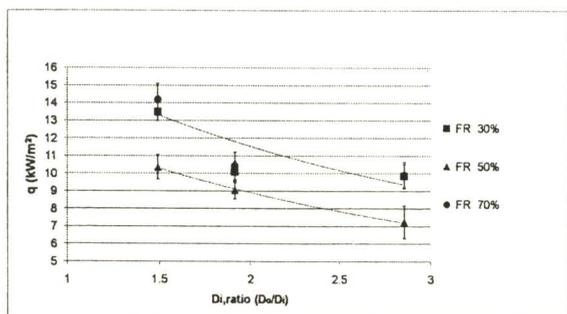


Fig. 4 Effect of diameter ratio (L_e 50 mm N15 R123)

Moreover, CLOHP with non-uniform inside diameter compels the working fluid circulation flows in one direction and transferred

heat from evaporator section to condenser section is increased. Flow of working fluid is separated clearly to be higher temperature tube and lower temperature tube as shown in Fig. 5 (diameter ratio 2.86 (2.03 mm, 0.71 mm), L_e 50 mm, 15 turns, R123 as working fluid, filling ratio 30%, vertical orientation). At steady state of CLOHP, working fluid receive heat and vaporize up to the big diameter tube. Because of the hot vapor is flow up, and it can flow easier in big diameter tube than the small one, results the higher temperature appear, so the big one is called 'Hot Tube'. Due to inertia force, working fluid are condensed and flow down to small diameter tube and then back to evaporator section again makes the inside is completely filled with fluid, result tube temperature become lower, so this tube is called 'Cold Tube' as shown in Fig. 6. There by cause heat transfer is increased. Which is resemble to the experimental data of [4]. However, one directional circulation of working fluid can be found only using R123. This because of R123 have a low latent heat of vaporization which cause the better boiling than using water and ethanol as a working fluid, working fluid is not circulate but only oscillated. Clearly, regards to improve configuration of CLOHP to have higher performance, the effect of diameter ratio of CLOHP must be considered the diameter ratio implies to the difference between greater and small diameter tube is that cause CLOHP with improve configuration have the higher heat flux

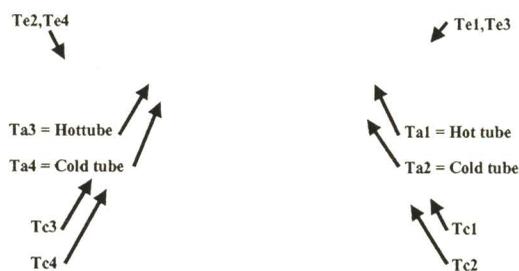


Fig. 5 shows the measured temperature of the working fluid in the adiabatic section

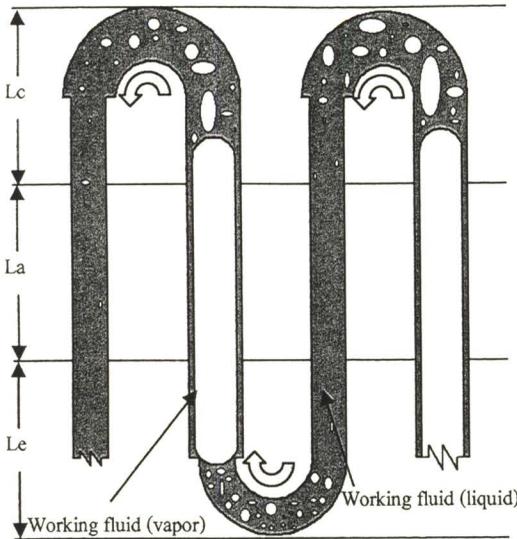


Fig.6 Character of working fluid circulation inside CLOHP with varied diameter

As the conclusion is diameter ratio of 1.49 (1.06 mm, 0.71 mm) provides the highest heat flux follows by 1.92 (2.03 mm, 1.06 mm) and 2.86 (2.03 mm, 0.71 mm) respectively

3.4 Effect of working fluids

Fig. 7 show the effect of working fluids on heat flux at diameter ratio of 1.49 (1.06 mm, 0.71 mm) (L_e 50 mm, 15 turns, filling ratio 70%, vertical orientation). It was found that, R123 as working fluid provides the highest heat flux of 14.18 kW/m², follows by ethanol and water of 7.10 kW/m², 5.91 kW/m² respectively. Due to a very high surface tension, low $(dP/dT)_{sat}$ and high specific heat of water, so the dynamic viscosity also extremely high, including the highest latent heat of vaporization (h_{fg}) of 2381.92 kJ/kg then relatively to ethanol (1000.40 kJ/kg) and R123 (160.5 kJ/kg) but its heat transfer is low. Apparently, the lower h_{fg} is, the easier working fluid vaporize. Thus, when working fluid has a low h_{fg} then heat transfer is higher. With application to the CLOHP with non-uniform inside diameter, the inside flow phenomena is separated into hot tube and cold tube make the working fluid circulates in one direction heat transfer performance is higher.

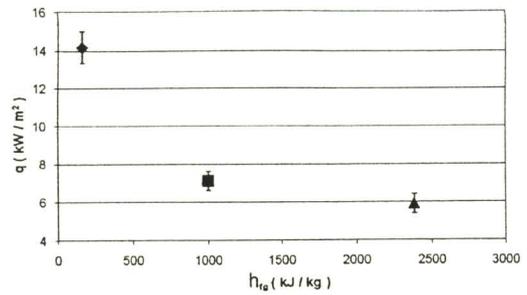


Fig.7 Effect of working fluids (1.06,0.71 mm L_e 50 mm N15 R123 70% β 90)

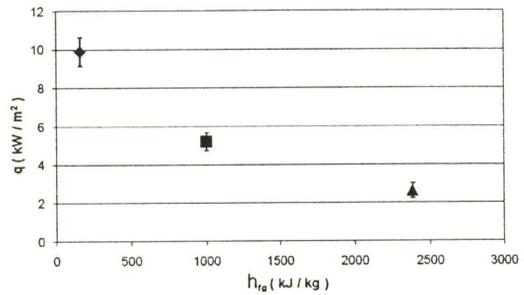


Fig.8 Effect of working fluids (2.03,0.71 mm L_e 50 mm N15 R123 70% β 90)

According to these experiment, it has the same trend as the others, as shown is Fig. 8 (effect of working fluid on heat flux at diameter ratio 2.86 (2.03 mm, 0.71 mm) , L_e 50 mm, 15 turns, filling ratio 70%, vertical orientation)

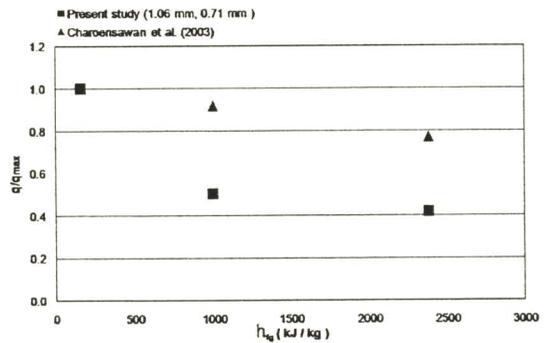


Fig.9 The comparison of the trend of the working fluid.

The effect of working fluid in the present is compared to that in the conventional CLOHP study, [5], as shown in Figure 8. The normalized data is presented to compare the effect of working fluid, that is, they have the same trend since the higher h_{fg} it is, the lower heat flux is obtained.

3.5 Effect of filling ratio

Effect of filling ratio is studied. The highest heat transfer for CLOHP with non-uniform inside diameter at the filling ratio of 70 % by total

volume follows with 30 and 50 percent respectively, as shown in Fig. 10 to 12

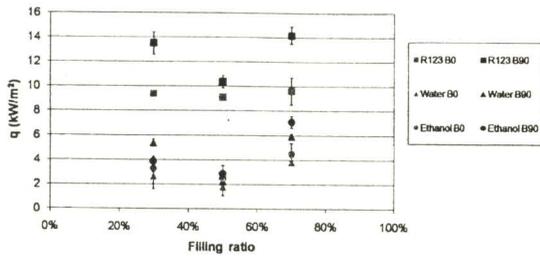


Fig.10 Effect of filling ratio

1.49 (1.06 mm, 0.71 mm)

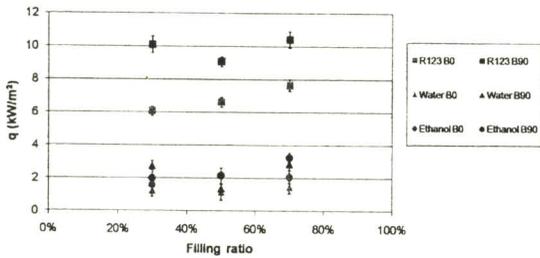


Fig.11 Effect of filling ratio

1.92 (2.03 mm, 1.06 mm)

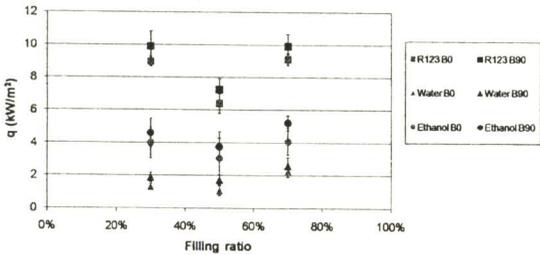


Fig.12 Effect of filling ratio

2.86 (2.03 mm, 0.71 mm)

As shown in the result, tendency of working fluid for CLOHP with non-uniform inside diameter is different from the normal CLOHP (best heat transfer is approximate 40-60 percent). The reason is physical configuration of CLOHP, the two sizes of inner diameter were designed to vary alternately between big and small tube diameter. Regards to the previous research [8], the highest heat transfer is obtained at inner diameter of 1.18 mm and filling ratio of 70 percent, including to the [9], copper tube inner diameter is 2 mm was used, the lower heat transfer resistant is found at 30 percent filling ratio. Therefore the different inner diameter also affects to filling ratio and heat transfer of CLOHP.

At a small inner diameter, there is a low heat transfer but at filling ratio 70 percent is gives the best heat transfer because of the sufficient working fluid can transfer the heat from evaporator to condenser section. Furthermore,

consider the asymmetry configuration of CLOHP with non-uniform inside diameter, small tube diameter affect to the velocity of working fluid more than the big tube diameter, Since the small tube diameter result in the inner high pressure comparing to with big tube diameter, as shown at 70 percent filling ratio is the best due to small tube effect. Effect of big tube diameter to heat transfer of CLOHP, however is remain as shows at 30 percent filling ratio which give the lower heat transfer then cause 50 percent filling ratio has the poorest heat transfer.

As the conclusion is the highest heat flux is obtained at 70 percent filling ratio by total volume and follows by 30 and 50 percent, respectively due to its asymmetry configuration.

4. Summary and conclusions

In this present has been experimentally investigated to the effects of various influence parameters to the heat performance of CLOHP: diameter ratio, working fluids and filling ratio. The following main conclusions can be drawn from the study:

- Diameter ratio of 1.49 (1.06 mm, 0.71 mm) provides the highest heat flux follows by 1.92 (2.03 mm, 1.06 mm) and 2.86 (2.03 mm, 0.71 mm) respectively. This parameter makes the circulation flow into one direction only using R123 as a working fluid, contrarily to water and ethanol which the oscillation are appeared.
- By using R123 as a working fluid, the highest heat flux is 14.18 kW/m^2 , follows by ethanol and water, 7.10 kW/m^2 , 5.91 kW/m^2 respectively
- The highest heat flux is obtained at 70 percent filling ratio by total volume and follows by 30 and 50 percent, respectively due to its asymmetry configuration.

From this research can be conclude that a CLOHP with asymmetry configuration or CLOHP with non-uniform diameter can be improved heat transfer performance and one directional circulation of working fluid is induced.

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