นิพนธ์ต้นฉบับ

การถ่ายเทความร้อนของท่อความร้อนแบบสั่นวงรอบที่ติดตั้งวาล์วกันกลับชนิดมีครีบโดยใช้เงินนาโนเป็นสารทำงาน

Heat Transfer of Closed-loop Oscillating Heat Pipe with CV on fin by using Silver-nanofluid

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บทคัดย่อ

งานวิจัยนี้เพื่อหาการถ่ายเทความร้อนของท่อความร้อนแบบสั่นวงรอบที่ติดตั้งวาล์วกันกลับชนิดมีครีบโดยใช้เงินนาโนและน้ำดีไอเป็นสารทำงาน ในการศึกษานี้ท่อความร้อนทำจากทองแดงที่มีขนาดเส้นผ่านศูนย์กลางภายนอกท่อและและครีบ คือ 5 และ 16 มิลลิเมตร ตามลำดับ ความยาวของส่วนทำระเหย ส่วนกันความร้อน และส่วนควบแน่น คือ 200 100 และ 200 มิลลิเมตร ตามลำดับ ท่อความร้อนมี 24 ท่อ โดยใช้เงินนาโนและน้ำดีไอเป็นสารทำงาน ใช้อัตราเติมสาร 50% ของปริมาตรรวมท่อ ส่วนทำความร้อนให้ความร้อนด้วยลวดความร้อนหล่อเย็นส่วนควบแน่นด้วยอากาศ ควบคุมอุณหภูมิของอากาศร้อนที่ 60 องศาเซลเซียส ปรับเปลี่ยนความเร็วอากาศที่มารับความร้อน 3 ระดับ คือ 0.5 1.0 และ 1.5 เมตรต่อวินาที ในการทดสอบจะมุ่งเน้นที่การถ่ายเทความร้อนและประสิทธิผลทางความร้อนของท่อความร้อนแบบสั่นวงรอบที่ติดตั้งวาล์วกันกลับชนิดมีครีบโดยใช้เงินนาโนและน้ำดีไอเป็นสารทำงาน พบว่าเมื่อใช้เงินนาโนเป็นสารทำงาน ที่ความเร็ว 0.5 เมตรต่อวินาที ค่าการถ่ายเทความร้อนและประสิทธิผลทางความร้อนของท่อความร้อนจะมีค่าสูงที่สุด คือ 5,973.94 วัตต์ต่อตารางเมตร และ 0.33

คำสำคัญ: ท่อความร้อนแบบสั่นวงรอบ ที่ติดตั้งวาล์วกันกลับ การถ่ายเทความร้อน เงินนาโน

Abstract

This research determined heat transfer rate of a CLOHP/cv by using Silver-nanofluid and Di-water as the working fluids. The CLOHP/cv in this study was made of copper. The copper tube and fin had an outside diameter were 5, 16 mm, respectively. The length of the evaporator, adiabatic and condenser sections were 200, 100 and 200 mm, respectively. The CLOHP/cv had 24 tubes with Silver-nanofluid and Di-water as the working fluids, and a filling ratio 50% of total volume. The evaporator section was heated by a heater, while the condenser section was cooled by fresh air. The hot air was controlled to 60 °C, and the fresh air velocities were adjust to three levels: 0.5, 1.0 and 1.5 m/s. The test operation was focused on the heat transfer rate and thermal effectiveness of the CLOHP/cv when using Silver-nanofluid and Di-water as the working fluids. It was found that the maximum value were 5,973.94 W/m^2 and 0.33 of the heat transfer rate and thermal effectiveness occurred when the air velocity was 0.5 m/s and using the silver-nanofluid as the working fluid.

Keywords: Oscillating heat pipe, Check valve, Heat transfer, silver-nanofluid

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Introduction

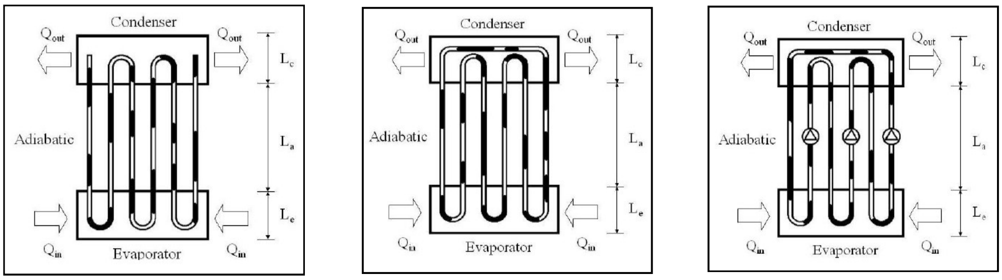
The heat pipe is a type of heat transfer equipment that has high performance and can operate even if the difference in temperature between the heat sources is less have been developed. The principle of the heat pipe was first proposed by RS Gaugler in 1942. Later experimental research and development continued until the heat pipe could be widely applied.[1-5] Their use includes the cooling of electronic equipment, retaining heat from the gases leaving the engine cooling system to breakdown snow and medical uses, etc. Heat transfer enhancement techniques have been applied to the heat exchanger equipment widely. In the design of heat exchangers, heat transfer efficiency must take into account the size, shape and proper use. Currently, when developing heat exchangers there are two methods used: active and passive. Most researchers are often interested in the passive method because it does not require external power to stimulate the increase of the surface area inside or outside the pipe. To help increase the efficiency of the heat pipe, the heat transfer must be better. For several years, many researchers have undertaken research on the thermal performance, until now.

Nomenclature			
A	Surface area, (m^2)	**Greek symbols**	
C_p	Specific heat capacity, (kJ/kg K)	μ	Viscosity, (Pa s)
d	Diameter, (m)	ρ	Density, (kg/m^3)
k	Thermal conductivity, (W/m K)	σ	Surface tension, (N/m)
L	Length (m)	ε	Effectiveness
L_d / d_i	Aspect ratio	η	Fin efficiency
$\dot{m}$	Mass flow rate (kg/s)	η_0	Surface efficiency
Q	Heat-transfer rate, (W)	**Subscripts**	
q	Heat-flux, (W/m^2)	a	Adiabatic
R_{cv}	Ratio of check valves	e	Evaporator
T	Temperature, (°C)	c	Condenser, cool air
T_{in}	Inlet temperature at condenser section, (°C)	f,	fin Fin
T_{out}	Outlet temperature at condenser section,(°C)	h	Hot air
V	Velocity, (m/s)	i	Inside
		l	Liquid
		o	Outside
		t	Fin thickness
		v	Vapor

Miyazaki et al.[6] studied an oscillating heat pipe including a check valve under normal operating conditions where the liquid and vapour are effectively separated. Charoensawan and Terdtoon.[7] investigated the thermal performance of a horizontal closed-loop oscillating heat pipe (HCLOHP) under normal operating conditions. The tested HCLOHPs were made out of copper capillary tubes with various inner diameters, evaporator lengths and number of turns. The working fluids were distilled water and absolute ethanol with various filling ratios. The thermal performance of the HCLOHP was demonstrated to improve with increasing evaporator temperature and decreasing ratio of the evaporator length to the effective length. The best performance of all the HCLOHPs occurred at the maximum number of 26 turns. Rittidech et al.[8] Investigated the thermal performance of various horizontal closed-loop oscillating heat pipe systems with check valves (HCLOHPs/CVs). The results showed that the heat-transfer performance of the HCLOHP/CV could be improved by decreasing the evaporator length. The highest performance of all the tested systems was obtained in the system with two check valves. The maximum specific heat flux occurred when a tube with an inner diameter of 2 mm was used, and R-123 was determined to be the most suitable working fluid. Rittidech et al.[9] studied the heat-transfer characteristics of the CLOHP/CV. The inclination of the CLOHP/CV used in the experiments was 90° to the horizontal line. The experimental results showed that the heat flux increases with an increase in the ratio of the check valve with a decrease in the aspect ratio *Le/d*. This study focuses on determining the heat transfer of a CLOHP/cv on fin by using Silver-nanofluid.

Theoretical consideration

The Oscillating Heat Pipe (OHP), by Akachi et al.[10], was invented as a new type of heat-pipe made from capillary tube that has been applied to cool small electronic devices. This new type of heat-pipe is called an oscillating heat-pipe (OHP), and has the same basic operational principle as the oscillating movement of the fluid and phase change phenomena. The first type is a closed-end oscillating heat pipe (CEOHP). In this type, a capillary tube is bent into many meandering turns and closed at both ends. The second type is a closed loop oscillating heat-pipe (CLOHP), in which the capillary tube is connected at both ends to form close-loop. The third type is a closed-loop oscillating heat-pipe with check valves (CLOHP/CV). This type is a closed-loop oscillating heat-pipe, in which both ends of the capillary tube are connected to form a closed-loop. The loop has one or more check valves[11], see Figure 1.



(a) (b) (c)

Figure 1 Type of Oscillating Heat Pipes: (a) CEOHP, (b) CLOHP, (c) CLOHP/CV[12]

Heat transfer characteristics of the CLOHP/CV

Determination of the heat transfer to the condenser section is calculated by the calorific method. By measuring the temperature of the inlet and outlet of the heating fluid, the condenser values can be calculated using the following equation:

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

Where Q is the heat transfer (W), $\dot{m}$ is the mass flow rate (kg/s), C_p is the specific heat (J/kg-°C), T_{in} is the inlet temperature (°C) and T_{out} is the outlet temperature (°C).

The mass flow rate is given by the following equation:

$$\dot{m} = \rho V A \tag{2}$$

Where ρ is the density (kg/m^3), V is the velocity (m/s) and A is the area (m^2).

The heat transfer rate can be determined from the following equation:

$$q = \frac{Q}{A_c} = \frac{Q}{\pi D_o L_c N} \tag{3}$$

Where q is the heat flux (W/m^2), D_o is the outside diameter of the tube (mm), L_c is the length of condenser section (mm) and N is the number of rods in the heat pipe condenser section.

Fin efficiency, η_f performance of the fin is the ratio between the heat transfer surface of the cooling fins. The actual ratio of the heat transfer surface intermediates, but not the fin thermal performance of the fins (Fins efficiency), can be obtained from the following equation:

$$\eta_{fin} = \frac{Q_{fin}}{Q_{\max}} \tag{4}$$

The heat transfer rate of fin efficiency is given by the following equation:

$$Q_{\max} = A_{fin}\left(T_{out} - T_{in}\right) \tag{5}$$

The heat transfer rate of the fins is given by the following equation:

$$Q_{fin} = n\eta_{fin}h\left(T_b - T_a\right) \tag{6}$$

Fin surface area exposed to the fluid is obtained from:

$$A_{fin} = \left[2\pi\left(r_0^2 - r_i^2\right) + 2\pi r_o t\right] \tag{7}$$

When η_{fin} is the fin efficiency, Q_{fin} is the heat transfer rate at the fin surface (W), $Q_{\max}$ is the heat transfer rate at the maximum surface of the fins (W), A_{fin} is the fin surface area exposed to the fluid (m^2), h is the coefficient of heat transfer (W/m^2-K), T_b and T_a are the temperature of the pipe surface and ambient temperature, respectively (^{o}C), r_i is the internal radial of the fin (mm), r_o is the external radius of the fin (mm), t is the thickness of the fin (mm) and n is the number of fins. Gardner, analyzed the performance of a circular copper fin, then analyzed it in the form of graphs for ease of use, as shown in Figure 2.

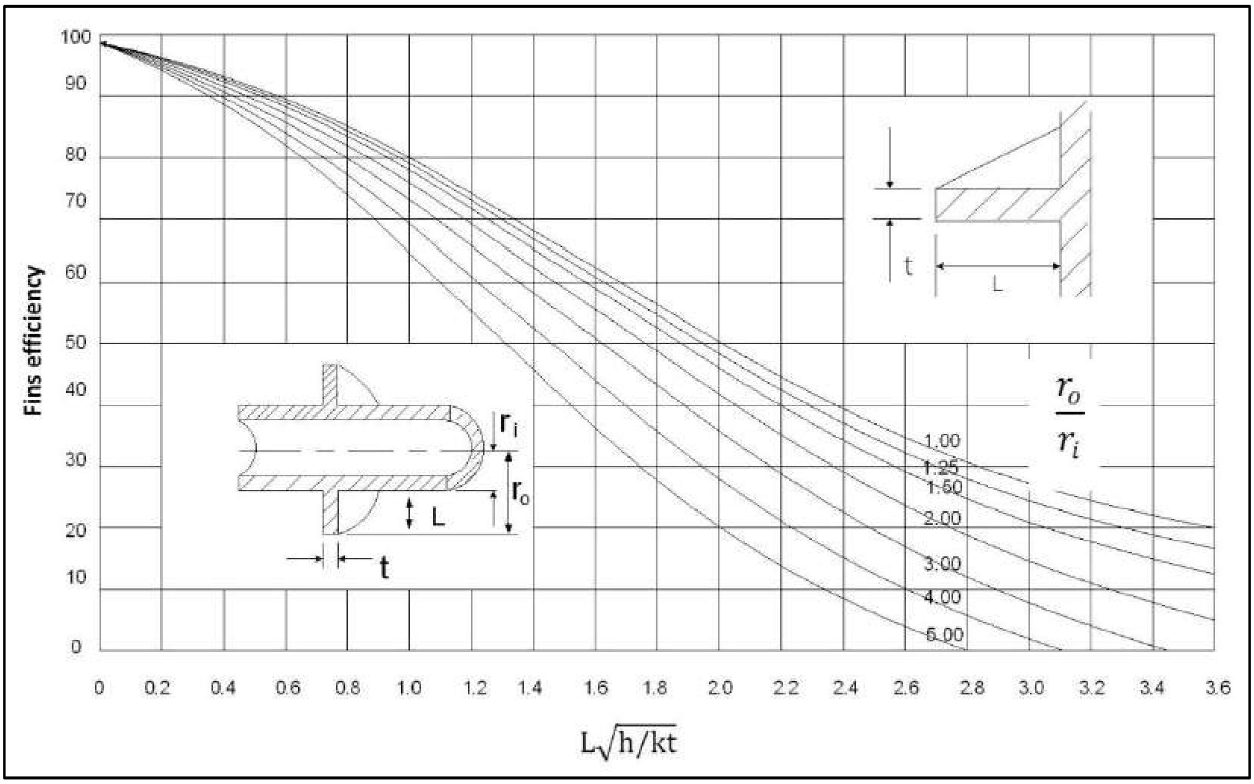


Figure 2 Performance graphs of circular copper fin form Gardner[12]

The y axis is given by the following equation:

$$y=\frac{r_o}{r_i} \tag{8}$$

And the x axis is given by the following equation:

$$x=L\sqrt{\frac{h}{kt}} \tag{9}$$

When L is the length of the tube surface to the fin (mm) and k is the thermal conductivity of the fin material (W/m^2-K).

Effectiveness of CLOHP/CV with fins

The effectiveness (ε) of the CLOHP/CV can be to define as the ratio of the actual heat transfer rate $\left(Q_{act}\right)$ for a CLOHP/CV to the maximum possible heat transfer rate $\left(Q_{\max}\right)$[13] This can be represented by the following equation:

$$\varepsilon=\frac{Q_{act}}{Q_{\max}} \tag{10}$$

When:

$$Q_{act}=\dot{m}_h C_{p,h}\left(T_{e,in}-T_{e,out}\right)/\dot{m}_c C_{p,c}(T_{c,out}-T_{c,in}) \tag{11}$$

As:

$$\varepsilon_e=\dot{m}_h C_{p,h}(T_{e,in}-T_{e.out})/\left(\dot{m}\ C_p\right)_{\min}(T_{e,in}-T_{c.in}) \tag{12}$$

$$\varepsilon_c=\dot{m}_c C_{p,c}(T_{c,out}-T_{c.in})/\left(\dot{m}C_p\right)_{\min}(T_{e,in}-T_{c.in}) \tag{13}$$

From which it follows:

Where dmax [m] maximum inner diameter of the capillary tube, σ [N/m] is the surface tension of the fluid, ρl [kg/m^3] is the liquid density and g [m/s^2] is the gravitational acceleration.

$$\varepsilon=Q_e/Q_{\max}=Q_c/Q_{\max}=Q_{ave}/Q_{\max} \tag{14}$$

Where the maximum possible heat transfer rate $\left(Q_{\max}\right)$ can be represented by the following equation:

In case $C_c<C_h$

$$Q_{\max}=C_c\left(T_{e,in}-T_{c,in}\right) \tag{15a}$$

In case $C_c>C_h$

In case $C_c>C_h$

$$Q_{\max}=C_h\left(T_{e,in}-T_{c,in}\right) \tag{15b}$$

When $C_c=\dot{m}_c C_{p,c}$ and $C_h=\dot{m}_h C_{p,h}$ Equations 19a and 20b can be rewritten to obtain the general expression[14]:

$$\begin{aligned} Q_{\max}&=C_{\min}\left(T_{hi}-T_{ci}\right)\\ Q_{ave}&=(Q_e+Q_c)/2 \end{aligned} \tag{16}$$

By definition the effectiveness, which is dimensionless, must be in the range

$$0\le\varepsilon\le1 \tag{17}$$

Experimental details

An important factor that has to be considered in building a CLOHP/CV is the tube diameter. The maximum inner diameter of the CLOHP/CV can be defined by the equation derived by Maezawa et al.[15]

$$d_{\max}\le2\sqrt{\frac{\sigma}{\rho_l g}} \tag{18}$$

Where *d*max [m] is the maximum inner diameter of the capillary tube, σ [N/m] is the surface tension of the fluid, ρ*l* [kg/m^3] is the liquid density and *g* [m/s^2] is the gravitational acceleration.

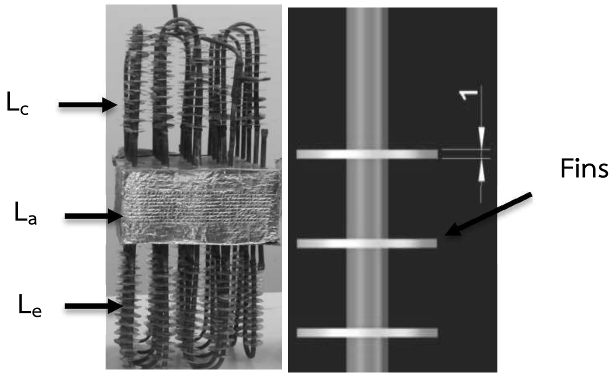


Figure 3 CLOHP/CV used in experiment[12]

Table 1 Specification of CLOHP/CV.

	Parameters	Specification
Copper tube	Inlet diameter (mm)	5.0
	Material	Copper
	Number of turns	24
	Alignment	Inline
	Length total (mm)	500
	Length of condenser (mm)	200
	Length of evaporator (mm)	200
	Length of adiabatic (mm)	100
Fin	Fin type	Annular
	Material	Copper
	Fin pitch (mm)	10
	Diameter (mm)	16
	Thickness (mm)	1.0
	Alignment	Inline

Specifications of the CLOHP/CV used in the experiment are shown in Table 1. The check valve is a floating-type valve that consists of a stainless steel ball and a copper tube, in which a ball stopper and conical valve seat are provided at the ends of the top and bottom of the check valve case, respectively (Figure 4). The ball can move freely between the ball stopper and the conical valve seat. The conical valve seat contacts the stainless-steel ball in order to prevent the working fluid from flowing in reverse. The ball stopper allows the working fluid to travel to the condenser section for transferring heat. The CLOHP/CV operation principle relies on three driving forces: surface tension, gravity, and oscillating forces. These forces are influenced by many parameters.

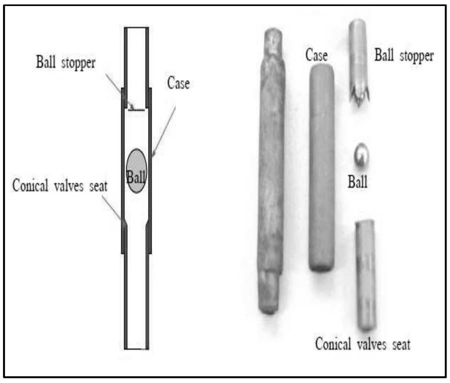


Figure 4 Check valve structure[9]

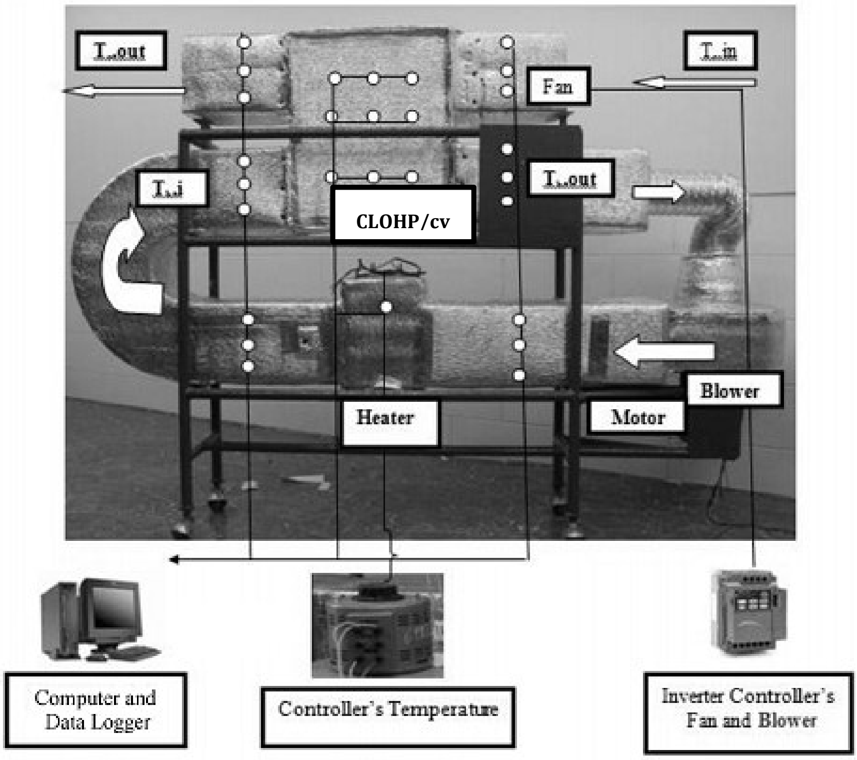


Figure 5 Schematic diagram of the experimental setup

Table 2 Experimental conditions

Parameters	
Inlet temperature evaporator section (°C)	60 °C
Inlet temperature of fresh air (°C)	25 °C
Working fluid	Di-Water, Silver-nano
Velocity of hot air (m/s)	0.5
Filling ratio	50 % by volume

The experimental setup used in this study and the thermocouple locations are shown in Figure 5. The specifications of the CLOHP/CV are given in table 1. The test consisted of three main sections: the CLOHP/CV section, the heating loop and the cooling section. The device use in the experiment was completely insulated with the glass wool. The amount of heat loss from the evaporator and condenser surfaces is negligible. The adiabatic section of the heat exchanger is completely insulated with **polyethylene**, in Figure 3. Measurements were taken using thermocouples (K-type) with an uncertainty of ±0.1°C at a total 25 points. These were attached to a Data Logger (Agilent Technologies 34970A and the 34970A features 61/2 digits (22bits) of resolution, 0.004% basic DCV accuracy). The heating loop was in the region of the evaporator section of CLOHP/CV. The heating was controlled by a voltage regulator to the heater, which is attached to the evaporator section, and the controlled temperature of hot air to the evaporator section was 60 °C. A blower was used to control the heating loop with an inverter (Siemens sinamics g110, output frequency 0 Hz-650 Hz and Cos $\varphi \geq 0.95$) to controller the speed motor. The air inlet and outlet temperatures of the experiment were measured when the system reached a steady state condition. The cooling loop is in the region of the condenser section of the CLOHP/CV. This was cooled by a fresh air and the velocity was controlled at 0.5 m/s by an inverter. The cool air was allowed to flow through the condenser to cool the CLOHP/CV, the experiment condition are shown in Table 2.

Results and discussion

Effect of inclination angles on the heat transfer rate in Figure 6 shows the relationship between the effects of the working fluid on the heat transfer rate of the CLOHP/cv heat exchanger. When the fresh air velocities were adjusted at three levels: 0.5, 1.0 and 1.5 m/s, and using Ag-nanofluid and Di-water as the working fluids, it was found that using the Ag-nanofluid as the working fluid gave the highest heat transfer rate performance, which was better than the Di-water for all variables. This indicated that the heat transfer rate performance increased when compared with the Di-water for all variables. The Ag-nanofluid improved the heat transfer rate performance because it has a high thermal conductivity that increases the proportion of the vapor more than Di-water, which increases the heat transfer rate.

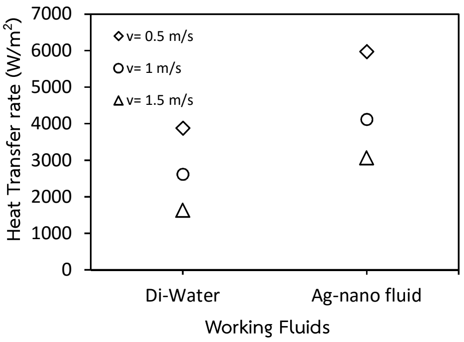


Figure 6 Effect of working fluid on heat transfer rate of CLOHP/cv heat exchanger at a temperature of 60 ^{0}C

Figure 7shows the relationship between the effects of the working fluid on the thermal effectiveness of the CLOHP/cv heat exchanger heat exchanger when the air velocity was changed between 0.5, 1.0 and 1.5 m/s and using the Ag-nanofluid and Di-water as the working fluids. It was found that when using the Ag-nanofluid as the working fluid that it gave the highest thermal effectiveness performance for all the variables. This indicated that the thermal effectiveness performance was increased when compared with the DI-water for all variables. The Ag-nanofluid improved the thermal efficiency performance because it has a high thermal conductivity that causes the heat transfer to increase and also caused the proportion of the vapor to be more than the Di-water, and this increased the thermal efficiency.

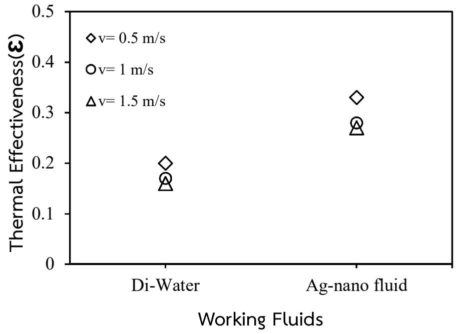


Figure 7 Effect of working fluid on thermal effectiveness of CLOHP/cv heat exchanger at a temperature of 60 ^{0}C

Conclusions

Experimental investigations were carried out on the effect of various parameters on the heat transfer rate and thermal effectiveness of the CLOHP/cv heat exchanger using Ag-nanofluid as the working fluid. The CLOHP/cv heat exchanger was made from copper. The copper tube and fin had an outside diameter were 5, 16 mm, respectively. The lengths of the evaporator, adiabatic and condenser sections were 200, 100 and 200 mm, respectively. The CLOHP/cv heat exchanger had 24 tubes with Silver-nanofluid or Di-water used as the working fluids, with a filling ratio of 50% by total volume. The evaporator section was heated by the heater while the condenser section was cooled by fresh air with velocities adjust to three levels: 0.5, 1.0 and 1.5 m/s. The experiments can be summarized as follows:

1. When the air velocity input into the condenser increased, the heat transfer rate decreased.
2. When the air velocity input into the condenser increased, the thermal effectiveness decreased.
3. When using the Ag-nanofluid, the heat transfer rate and thermal effectiveness was higher than when using DI-water for all variables.

Therefore, as indicated when comparing between the heat exchanger using silver-nanofluid and Di-water as the working fluid it was shown that the heat transfer rate and thermal effectiveness performance of the silver-nanofluid was better than the Di-water for all variables.

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