# การผลิตน้ำร้อนจากความร้อนทิ้งของเครื่องปรับอากาศด้วยเครื่องแลกเปลี่ยนความร้อนชนิดท่อความร้อนชนิดสั่นวงรอบที่ติดตั้งวาล์วกันกลับ

# Water Heating from Waste Heat of Air-Conditioner using a Closed-Loop Oscillating Heat Pipe with Check Valves as a Heat Exchanger

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## บทคัดย่อ

งานวิจัยนี้มุ่งหมายเพื่อพัฒนาเครื่องผลิตน้ำร้อนจากความร้อนทิ้งของเครื่องปรับอากาศด้วยเครื่องแลกเปลี่ยนความร้อนชนิดท่อความร้อนชนิดสั่นวงรอบที่ติดตั้งวาล์วกันกลับ โดยชุดแลกเปลี่ยนความร้อนเป็นแบบท่อความร้อนชนิดสั่นวงรอบที่ติดตั้งวาล์วกันกลับ ทำจากท่อทองแดงมีขนาดเส้นผ่านศูนย์กลางภายในของท่อ 2.03 มิลลิเมตร มีความยาวส่วนทำระเหย ส่วนกันความร้อน และส่วนควบแน่นเท่ากับ 20,10และ 20 เซนติเมตร ตามลำดับ จำนวน 40 โค้งเลี้ยว ติดตั้ง 2 วาล์วกันกลับ มุมทำงาน 90 องศาจากแนวระดับ ใช้ R134a เอทานอล และน้ำเป็นสารทำงาน ที่อัตราการเติมสารทำงาน 50 % ของปริมาตรรวม ควบคุมอัตราการไหลของน้ำที่มารับความร้อน คือ 0.5, 0.75 และ1 ลิตร/วินาที จากการทดลอง พบว่าอุณหภูมิของน้ำในถังน้ำ อัตราการถ่ายเทความร้อน และประสิทธิผลทางความร้อน ที่อัตราการไหลของน้ำ 0.5 ลิตร/วินาที เมื่อเติมสารทำงาน R134a จะดีที่สุดในทุก ๆค่า สรุปได้ว่าการพัฒนาเครื่องผลิตน้ำร้อนจากความร้อนทิ้งของเครื่องปรับอากาศด้วยเครื่องแลกเปลี่ยนความร้อนชนิดท่อความร้อนชนิดสั่นวงรอบที่ติดตั้งวาล์วกันกลับสามารถประหยัดพลังงานไฟฟ้าและพลังงานทั้งในครัวเรือน และเชิงพานิชได้

**คำสำคัญ :** ท่อความร้อนแบบสั่นวงรอบ วาล์วกันกลับ เครื่องแลกเปลี่ยนความร้อน เครื่องปรับอากาศ น้ำร้อน

## Abstract

The aim of this research was to develop a water heater by using a closed-loop oscillating heat pipe with check valves (CLOHP/CV) as a heat exchanger. The CLOHP/CV heat exchanger was made from a copper capillary tube with an inner diameter of 2.03 mm. The lengths of evaporator, adiabatic and condenser were 20, 10 and 20 cm, respectively. The number of bends and check valves were 40 and 2, respectively. The inclination angle was 90$^{o}$ from horizontal axis. The CLOHP/CV with a filling ratio of 50% (by total volume of tube), using R134a, ethanol and distilled water as the working fluids, were used for testing in this research. The water flow rate for heating was controlled at 0.5, 0.75 and 1 L/s. It was found that, the temperature of the water in the tank, the heat transfer rate and the effectiveness at a water flow rate of 0.5 L/s while the CLOHP/CV heat exchanger was filled with R134a as the working fluid gave the highest temperature, the heat transfer rate and the effectiveness of all experimental results. This research can be used to develop a more efficient CLOHP/CV heat exchanger for water pre-heating from waste heat from an air-conditioner for use in domestic and commercial structures to save electrical and energy costs.

**Keywords:** Closed-loop oscillating heat pipe, Check valve, Heat exchanger, Air-conditioner, Water heater.

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## Introduction

In Thailand, air conditioners are used for reducing air temperatures from 30 – 40 °C to a more comfortable temperature (about 25°C). A lot of energy is used in this process, and waste heat is produced; if the waste heat could be recovered it would reduce the energy used. The oscillating heat pipe with check valve (CLOHP/CV) is widely accepted as the most efficient heat transfer device for high heat load. In the application of a closed-loop oscillating heat-pipe with check valves (CLOHP/CV) a heat exchanger for the water-preheater is able to use its waste heat on air conditioning systems. It can transfer the heat by itself with the latent heat of a working fluid in the tubes by akachi et al. [2] as shown in figure 1.

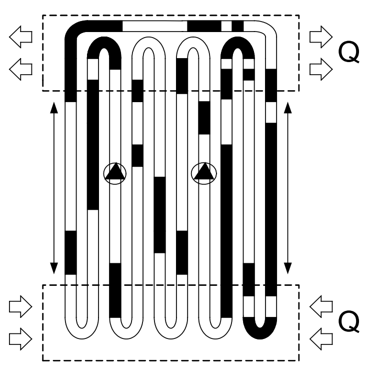


**Figure 1** Closed-loop oscillating heat pipe with check valves (CLOHP/CV)

Noie-Baghban et al. [5] studied a heat recovery system using heat pipe heat exchanger (HPHE) for surgery rooms in hospitals. It was found that the experimental results for absorbed heat by the evaporator section are very close to the heat transfer rate obtained from computer simulation. Considering the fact that this is one of the first practical applications of heat pipe heat exchangers, the research has given informative results and paved the way for further research. Ameen et al.[1] studied an investigation into the effectiveness of a heat pump assisted clothes dryer for humid tropical environments. It was found that experimental results indicate the viability of developing an integrated air conditioner cum dryer suitable for humid tropical climates. Pipatpaiboon et al.[3]studied the effect of inclination angle, working fluid and number of check valves on the characteristics of heat transfer in a closed-looped oscillating heat-pipe with check valves (CLOHP/CV). It was found that the CHOHP/CV equipped with 2 check valves, has highest heat transfer. Rittidech et al.[7] studied the correlation to predict heat transfer of a closed-looped oscillating heat-pipe with check valves (CLOHP/CV)]. Rittidech et al.[6]: studied the closed-ended oscillating heat-pipe (CEOHP) air-preheater for energy thrift in the dryer. It was found, from the experimental results, that thermal effectiveness increases and the (CEOHP) air-preheater achieves energy thrift. Meena et al.[4] studied the application of CLOHP/CV for reducing air humidity in the drying process. It was found that a CLOHP/CV can reduce air humidity in the drying processes. W.X. Ping *et al*.[8]: studied the application of heat-pipe exchangers for humidity control in an air-conditioning system. That research found that exchangers can reduce humidity in an air-conditioning system. So, the waste heat from air conditioner must be managed for heat recovery by heat exchanger. The CLOHP/CV heat exchanger is the most efficient heat transfer device. The heat transfer by itself with the latent heat of working fluids in the tubes can save energy using thermal process heat recovery and air or water pre-heating.

This research investigates the application of a CLOHP/CV heat exchanger for heating water using waste heat in air-conditioners. This research is expected to the development of a more efficient heat exchanger for water pre-heating that can be used in domestic and commercial scenarios to save energy and cost.

## Experimental apparatus and procedure

The CLOHP/CV heat exchanger was made from copper capillary tube with an inner diameter of 2.03 mm. The lengths of evaporator, adiabatic and condenser were 20, 10 and 20 cm, respectively. The number of bends and check valves were 40 and 2, respectively. The inclination angle was 90° from horizontal axis. The CLOHP/CV with a filling ratio of 50% (by total volume of tube), using R134a, ethanol and distilled water as the working fluids, with water flow rate of water through the condenser section of the CLOHP/CV heat exchanger tested at 0.5, 0.75 and 1 L/s. were used for testing in this research. Thermocouples were closed in the center points of all sections of the CLOHP/CV. The heat exchanger was covered with insulation to prevent heat loss from the system. Thermocouples in the air inlet and outlet of the evaporator box and in the water inlet and outlet of the condenser box were closed. The data logger Yokogawa-MX100 was used with type K thermocouples (Omega with ±1°C accuracy).The experimental results were recorded for 9 days from 08.00 until 18.00 hours.

Figures2, 3and 4 show an experimental setup consisting of a CLOHP/CV heat exchanger with the evaporator section being given heat by the waste heat from an air-conditioner while the condenser section is being cooled by water in a tank.

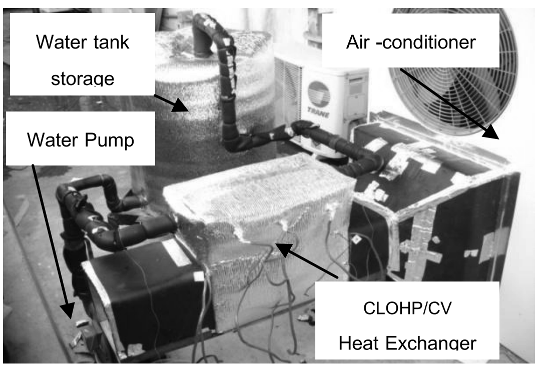


**Figure 2** Experimental set up

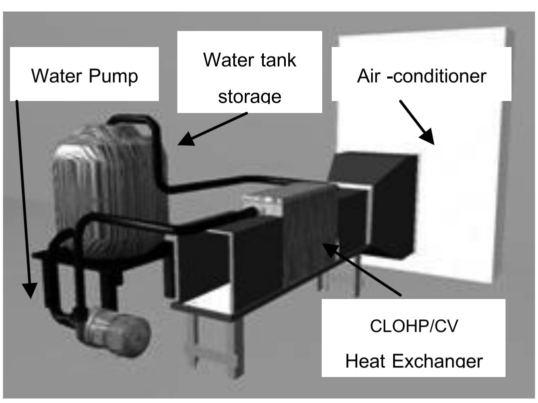


**Figure 3** Test rig

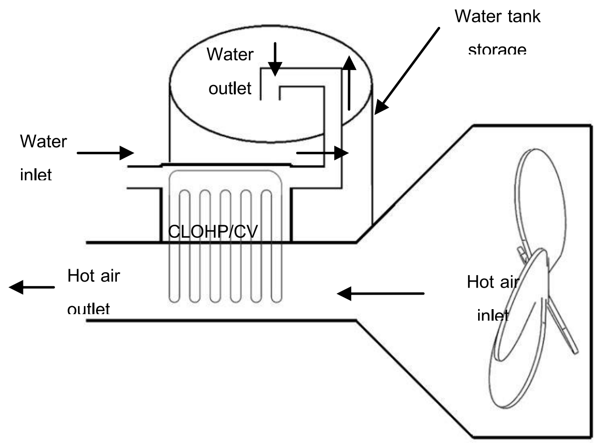


**Figure 4** Schematic diagram of experimental apparatus

The thermocouples were used to calculate the heat transfer of the test CLOHP/CV by using the calorific method, as the following eq:

$$Q = m^{\bullet} c_p \left(T_{out} - T_{in}\right) \qquad (1)$$

Effectiveness of heat exchanger as a comparison, the rate of heat transfer rate with a disposable heating up of the exchange of heat can be written as following eq:

$$\varepsilon = \frac{Q_{act}}{Q_{\max}} \qquad (2)$$

Where

$$Q_{\max} = C_{\min}(T_{hi} - T_{co}) \qquad (3)$$

And

$$Qact = C_o(T_{co} - T_{ci}) \qquad (4)$$

**Variable parameters were:**

Working fluids were:

R134a, Ethanol and Water.

Water flow rate were:

0.5, 0.75 and 1 L/s.

**Nomenclature**

$\dot{m}$ = Mass per unit time

$C_p$ = Specific heat capacity, constant pressure

$T_{out}$ = Outlet temperature at condenser section

$T_{in}$ = Inlet temperature at condenser section

$\varepsilon$ = Effectiveness

$Q_{exp}$ = Experiment heat transfer rate

$Q_{exp}$ = Maximum heat transfer rate

## Results and Discussion

1. Effect of water flow rate on water temperature in tank

Figure 5 shows the relationship of water temperature in the tank against time at a water flow rate of 0.5 L/s. The highest water temperature in the tank was 42.68 °C when using R134a as the working fluid. The water temperature in the tank, when using ethanol as the working fluid in the CLOHP/CV, was 41.67 °C, higher than when using distilled water as the working fluid in the CLOHP/CV, 40.52 °C. Figure 6 shows the relationship of water temperature in the tank against time at a water flow rate of 0.75 L/s. The water temperature in the tank, when using R134a as the working fluid, was 41.80 °C. The water temperature, when using ethanol as the working fluid in the CLOHP/CV, was 40.90 °C, and the distilled water temperature, when using water as the working fluid in the CLOHP/CV, was 39.83 °C. For the water flow rate of 1.0 L/s, the highest water temperature in the tank was 41.22 °C when using R134a as the working fluid in the CLOHP/CV. The water temperature in the tank, when using ethanol as the working fluid in the CLOHP/CV, was 40.44 °C, higher than when using distilled water as the working fluid in the CLOHP/CV, was 39.03 °C as shown in figure 7.

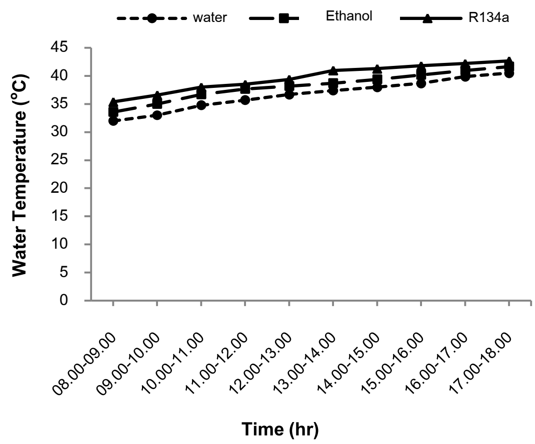


**Figure 5** The relationship of water temperature in tank against time at a water flow rate of 0.5 L/s

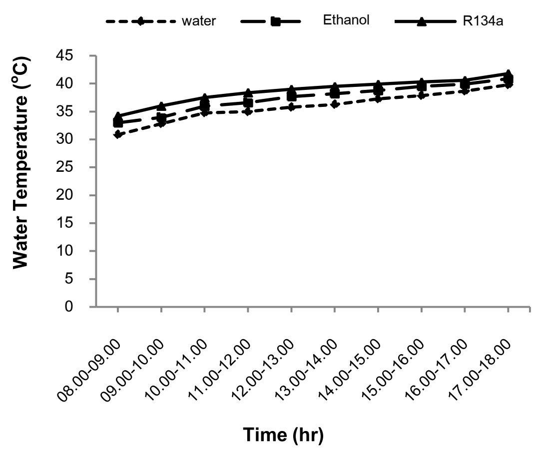


**Figure 6** The relationship of water temperature in tank against time at a water flow rate of 0.75 L/s

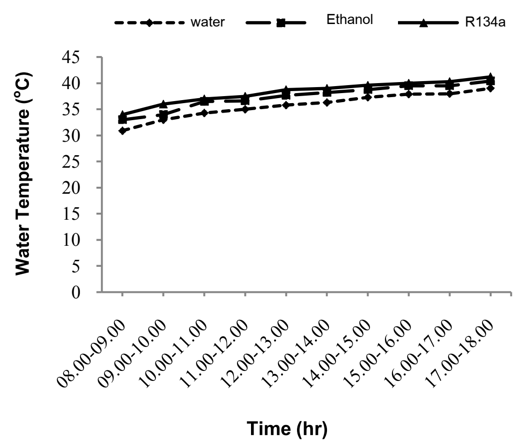


**Figure 7** The relationship of water temperature in tank against time at a water flow rate of 1.0 L/s

Figure 8 shows the relationship of water flow rate against water temperature in the tank. It was found that at a water flow rate of 0.5 L/s the temperature of the water in the tank can increase more than when the water flow rate was 0.75 or 1.0 L/s. Therefore, the water flow rate of water into the condenser section of the CLOHP/CV heat exchanger was opposite to the water temperature in tank. In other words, if the water flow rate was high, the water temperature in the tank was low.

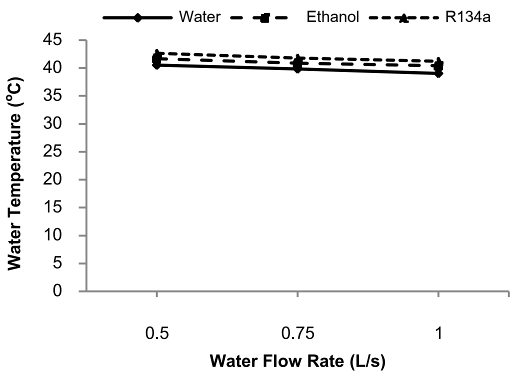


**Figure 8** The relationship of water flow rate against water temperature in the tank

2. Effect of working fluid on water temperature in tank

Figures 9, 10 and 11 show the relationship of water temperature in the tank against time when using distilled water, ethanol and R134a as working fluids, in the CLOHP/CV respectively. It was found that the highest water temperature in the tank was when the water flow rate at the inlet of CLOHP/CV heat exchanger was 0.5 L/s.

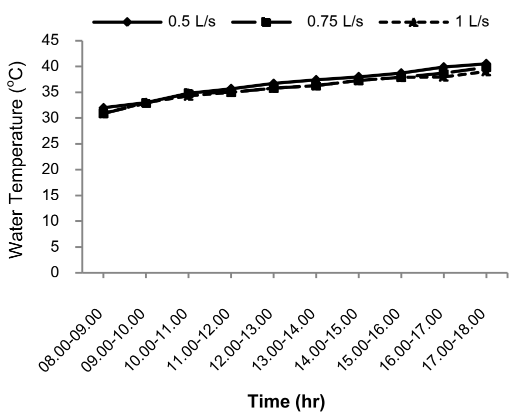


**Figure 9** The relationship of water temperature in tank against time when distilled water was used in the CLOHP/CV

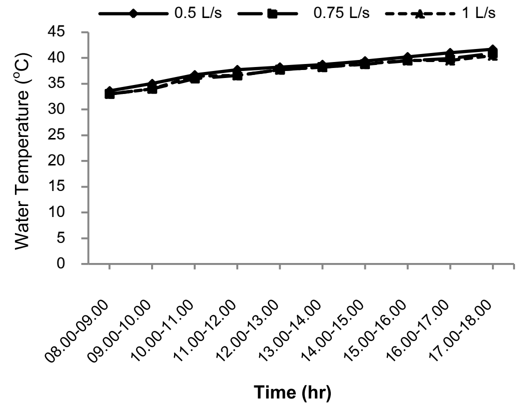


**Figure 10** The relationship of water temperature in tank against time when ethanol was used in the CLOHP/CV

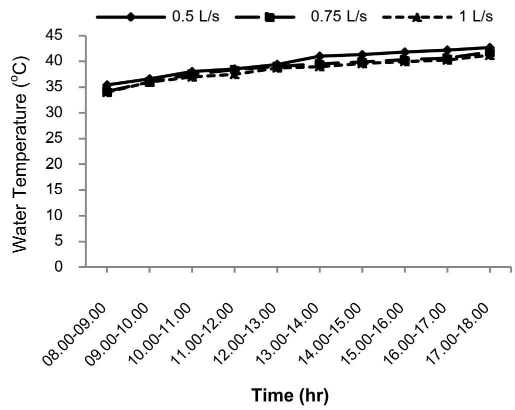


**Figure 11** The relationship of water temperature in the tank against time when R134a was used in the CLOHP/CV

3. Effect of working fluid on water temperature

Figures 12 show the relationship of water temperature in the tank against time when using distilled water, ethanol and R134a as working fluids, in the CLOHP/CV respectively. It was found that the highest water temperature in the tank was when the water flow rate at the inlet of CLOHP/CV heat exchanger was 0.5 L/s.

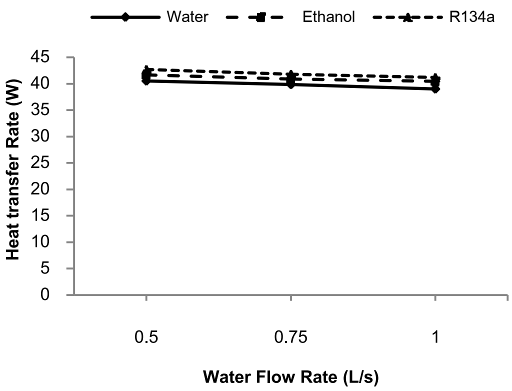


**Figure 12** The relationship of water temperature in the tank against time for all the working fluids

4. Effect of working fluid on heat transfer rate Figures 13 show the relationship of heat transfer rate against time when using distilled water, ethanol and R134a as working fluids, in the CLOHP/CV respectively. It was found that the highest heat transfer rate was when the water flow rate at the inlet of CLOHP/CV heat exchanger was 0.5 L/s.

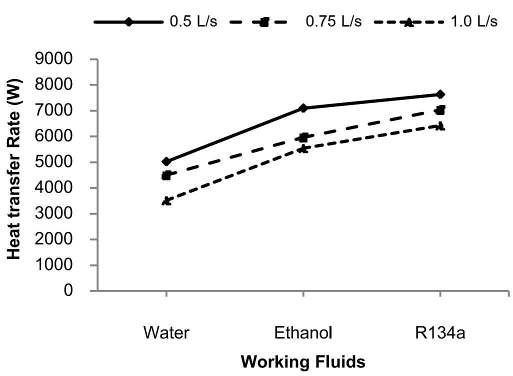


**Figure 13** The relationship between heat transfer rate against time for all the working fluids

3.5 Effect of working fluid on effectiveness

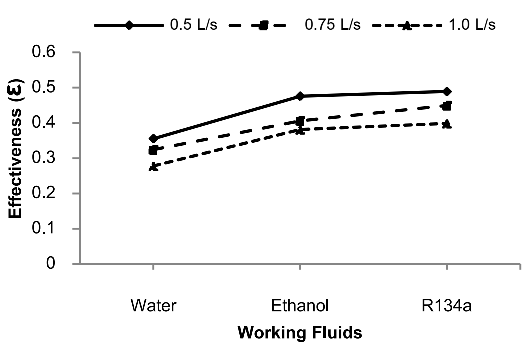


**Figure 14** The relationship between effectiveness against time for all the working fluids

Figures 14 show relationship between effectiveness against time when using distilled water, ethanol and R134a as working fluids, in the CLOHP/CV respectively. It was found that the highest effectiveness was when the water flow rate at the inlet of CLOHP/CV heat exchanger was 0.5 L/s.

## Conclusion

For the effect of water flow rate through the condenser section of the CLOHP/CV heat exchanger, it was found that the highest water temperature in the tank was at 0.5 L/s and the middle and the lowest water temperatures in tank were at 0.75 L/s and 1.0 L/s, respectively. The water flow rate of 0.5 L/s was the best water flow rate in this experiment because the time for heat transfer between the water and the surface of the CLOHP/CV heat exchanger was longer than with the water flow rate of 0.75 and 1.0 L/s, so the water was able to collect more heat from the CLOHP/CV heat exchanger than when the water flow rate were 0.75 or 1.0 L/s. In conclusion, the water temperature in the tank was controlled by the water flow rate, with 0.5 L/s giving the highest temperature, the heat transfer rate and the effectiveness.

For the effect of working fluid on water temperature in the tank, the heat transfer and the effectiveness it was found that when the CLOHP/CV heat exchanger used R134a as a working fluid the water temperature increased more than when ethanol and distilled water were used as the working fluids because the latent heat of R134a was the lowest in this experiment. So, the water temperature in the tank, the heat transfers rate and the effectiveness, when using R134a as the working fluid in the CLOHP/CV heat exchanger, were the highest.

Finally, development of the most efficient CLOHP/CV heat exchanger includes using R134a as the working fluid and a water flow rate of 0.5 L/s for the water pre-heater using waste heat from an air-conditioner. This CLOHP/CV will save on the use of energy and cost.

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