Heat transfer of a heat pipe using titanium dioxide as working fluid

S Somasri and P Meena*
Energy Innovation and Heat Pipe Technology Research Unit (EIHTR), Department of Physics, Faculty of Science, Mahasarakham University, 44150, Thailand

*E-mail: pattanapol.m@hotmail.com

Abstract. This research aims to study the heat transfer of a heat pipe using nanofluid as a working fluid by using a closed loop oscillating heat pipe with check valve (CLOHP/CV). The nanoparticles used in this study are deionized water and TiO$_2$ as a working fluid. The experiment the operating temperature was adjusted in the range of 60, 70 and 80 degrees Celsius and the inclination angle of the heat pipe in the range of 0 and 45 degrees. It was found that when using TiO$_2$ as a working fluid, at inclination angle of 45 degrees, an operating temperature of 80 degrees Celsius, the highest heat transfer was 297.76 W, the highest heat flux was 2887.09 W/m$^2$. The highest heat transfer coefficient was 1547.53 W/m$^2$°C and the highest thermal efficiency was 0.17. When using TiO$_2$ as a working fluid, at inclination angle of 45 degrees, at operating temperature of 80 degrees Celsius the lowest heat resistance was 0.26 C/W. In addition, we found that CLOHP/CV using TiO$_2$, resulted in higher heat transfer (82.23%) than when using deionized water and lower heat resistance than using deionized water 92.85%.

1. Introduction
The heat pipe is one of the remarkable achievements of thermal physics and heat transfer engineering in this century because of its ability to transfer heat over long distances without much loss. The main applications of heat pipes deal with the problems of environmental protection, energy and fuel savings [1]. A closed-loop oscillating heat pipe with check valves (CLOHP/CV) is a type of heat exchanger that is very easy and straightforward to use [2]. As CLOHP/CV has a working mechanism involving two-phase heat transfer, gas-liquid heat and mass transfer and multivariate operation, complete understanding of the complex thermos hydrodynamics mechanism of CLPHP is still lacking [3-4]. The closed pulsating heat pipe is evacuated and then filled partially with a desired working fluid. When the heat is supplied to the evaporator section, the working fluid evaporates inside the evaporator section, so the vapor pressure in the tube increases due to the formation of bubbles in the evaporator section [5]. These bubbles form and collapse due to this action and the liquid will be pushed into the condenser section i.e. the liquid is supplied to a low temperature region [6]. Due to the movement of this bubble an oscillating motion is generated within the tube. Due to the low temperature in the condenser section the vapor pressure decreases and bubbles condense in the condenser section. [7]. Over the years, researchers have explored new ways to increase performance heat transfer. The results of employing different cooling liquids has proven to be an effective way to improve the overall performance. Nanofluid as a new working fluid for heat exchangers that do not pollute because water is used as a base liquid. Nanofluids are engineered by suspending delicate or nonmetallic nanoparticles in basic fluids. (Water, oil and ethylene glycol). In 2019 Meena and Saengmart [8] determine the heat transfer rate of the heat pipe using Silver nanofluid as a working fluid. It was found that the maximum value of the heat transfer rate and thermal effectiveness occurred when the air velocity and hot air temperature were 0.5
m/s and 80 degree Celsius, respectively. In 2019 Saengmart and Meena [9] studied the heat transfer characteristics of the closed-looped oscillating heat pipe with check valves (CLOHP/CV). It was found that the heat flux of the CLOHP/CV heat exchanger set with the fins was the highest at 80 degree Celsius, with a value of 9,743.11 W/m². The effectiveness is 0.3 and the internal pressure is 123.59 kPa. In 2007 Meena, Rittidech and Poomsa-ad [10] studied the design, construct, and test the CLOHP/CV air-preheater using recovering the waste heat from the drying cycle for reduced relative humidity in drying systems. With an increase in the hot-air temperature from 50 to 70 °C, the heat-transfer rate slightly increases and the effectiveness slightly increases. The velocity increases from 0.5 to 1 m/s, the heat-transfer rate slightly decreases and the effectiveness slightly decreases. In 2018 Meena and Inyim [11] studied the effect of position of heat mode to close loop oscillating heat pipe with check valves (CLOHP/CV) on fins. It was found that the heat exchanger of bottom heat mode had a temperature of 80 degrees Celsius and air velocity of 1.5 m/s with heat flux and thermal effectiveness the highest. In 2014 Meena, Tammasaeng, Kanphirom, Ponkho and Setwong [12] studied the enhancement of a thermosyphon heat exchanger with fins and without fins using Cu-nanofluid as a working fluid. It was found that the maximum value of heat transfer rate and thermal effectiveness occurred when the air velocity was 0.5 m/s, 1 cm of fin, temperature 80°C. In 2008 Meena and Rittidech [13] studied to design, construct and test the heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns for energy thrift. It indicated that the working fluid changed from water to R123, the heat transfer rate increased to 4,800 and 7,900 Watts and the effectiveness increased from 0.32 to 0.44. In 2018 Pinate, Rittidech and Pattanapol meena [14] the critical heat fluxes (CHFs) of two-phase closed thermosyphons with and without fins were studied. The CHF data when using fins of different thicknesses (1.0, 1.5 and 2.0 mm), radii (5, 10 and 15 mm), and spacing (10, 20 and 30 mm) were recorded. The CHF increased with the fin thickness and radius but decreased with the increase in fin spacing. In addition, the CHF increased with the diameter of the thermosyphon tube.

Review of related research indicated that CLOHP/CV is a device of interest to many researchers but nevertheless, there is still no information about the performance heat transfer of CLOHP/CV at different inclination angles and that use TiO²-water as a working fluid and the addition of TiO²-water will increase the thermal efficiency of CLOHP/CV. Therefore, the objective of this research is to study the performance heat transfer of CLOHP/CV using TiO² as a working fluid. This research expected to find additional information useful for the application of CLOHP/CV.

2. Theoretical consideration and experimental details
2.1. The performance heat transfer of CLOHP/CV
Calculation of the performance heat transfer. The heat transfer obtained from the experiment and can be calculated from the equation (1) [15].

\[ Q = \dot{m}C_p(T_{out} - T_{in}) \]  

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), A is the surface area of the heat pipe, \( T_{in} \) is the inlet temperature (°C), \( T_{out} \) is the outlet temperature (°C). The heat flux of the heat pipe can be obtained from the equation (2) [16].

\[ q = \frac{Q}{A} = \frac{Q}{\pi D_0 LN} \]  

\[ h = \frac{Q}{\Delta T} = \frac{q}{\Delta T} \]  

Q is the heat flux (W/m\(^²\)), \( D_0 \) is the Outside diameter of the tube (mm.), L is the length of heat pipe (mm), N is the number rods of heat pipe and h is the heat transfer coefficient.
Heat pipe thermal resistance, $R$ is calculated from:

$$R = \frac{T_e - T_c}{Q}$$

(4)

Where $T_e$ and $T_c$ are temperature values at the evaporator sections and condenser sections respectively and $Q$ is the heat supplied to the heat pipe.

The effectiveness ($\varepsilon$) can be defined as the ratio of the actual heat transfer rate ($Q_{\text{act}}$) for a CLOHP/CV to the maximum possible heat transfer rate ($Q_{\text{max}}$) [17]. This can be represented by the following.

$$\varepsilon = \frac{Q_{\text{act}}}{Q_{\text{max}}} = \frac{Q_c}{Q_{\text{max}}}$$

(5)

By definition, the effectiveness, which is dimensionless, must be in the range $0 < \varepsilon < 1$

2.2. Nanofluid preparation

Nanofluid is produced by metal or metal oxides nanoparticles that are suspended in base fluids such as water. The nanofluid used in the experiment was a mixture of deionized water (DI-water) and titanium dioxide ($\text{TiO}_2$) particles with a particle size of approximately <100 nm. 99.5% (metals basis). The $\text{TiO}_2$ nanoparticles were suspended into DI water with concentration of 1% w/v. The mixture was stirred with a magnetic stirrer using ultrasonic vibrations until all solvents were mixed. It was then soaked in the ultrasonic bath for two hours to make sure the nanoparticle powder was stable for a long time.

2.3. Experimental setup

This experiment aimed to study the performance heat transfer of a CLOHP/CV using nanofluid as a working fluid. We used circular copper pipes as heat pipes with a diameter of 5.0 mm, length of 500 mm, containing deionized water (DI-water) and nanofluids as working fluid in order to compare the performance heat transfer between heat pipes using nano fluids and heat pipes using deionized water at inclination angles of 0 degree and 45 degree. In this research, the nanofluid was stirred by sonicator for five hours. The sonicator had an operating frequency and power source of 43 kHz, AC100, and 120V/AC220–240V 50/60 Hz, respectively. The test set consisted of a heat pipe that is to be tested as a CLOHP/CV equipped with thermocouples (Chromel-Alumel, K-type, accuracy ± 0.20 °C) that were used for measuring the heating system temperature of the heat pipe. Use a heating wire as a heat source for the heating pipes. Use a fan to cool the condenser and measure the pressure inside the pipe with a pressure gauge. Record the results of the experimental data using the data logger device (Agilent Technologies 34970A) and use a computer to store the data. These experimental devices are shown in figure 1.

Table 1. Thermophysical properties of pure fluid and nanoparticles [18-20].

| Physical properties | DI water | TiO$_2$ |
|---------------------|----------|---------|
| Density (kg/m$^3$)  | 998.2    | 6,110   |
| Specific heat capacity (J/kg.K) | 4182 | 692 |
| Thermal conductivity (W/mK) | 0.615 | 21.9 |
| Particle size (nm)   | >100     | >100    |
2.4. Experimental procedure

The experimental methods were as follows. The CLOHP/CV was set into a test rig and adjusted to an inclination angle set (0 and 45 degree from horizontal) and the air temperature maintained at a constant 25 degrees Celsius for cooling the condenser section. The variable voltage transformer was then turned on to feed the electric current into the heater. The operating temperature was 30 degrees Celsius which is that of the evaporator section, then the temperature was recorded at various points until the system entered a stable state bring the temperature at the heat pipe wall at various points by the temperature measurement on the surface of the heat pipe uses a thermocouple K type (accuracy: ± 0.1 °C) was 24 points as shown in figure 1. After that, the temperature values at various points were measured to calculate the heat transfer value, heat flux, heat transfer coefficient and thermal efficiency. The operating temperature was then increased using the heater to heat the evaporator of the heat pipe to 60, 70 and 80 degree Celsius. Performance of heat transfer parameters, heat transfer (Q), heat flux (q), thermal resistance (R), effectiveness (Ɛ), were determined by using equation (1), (2), (3), (4) and (5), respectively.
3. Results and discussions
3.1. The effect of inclination angles on the performance heat transfer of a CLOHP/CV

![Figure 3](image1.png) Relationship between the inclination angle and the heat transfer of CLOHP/CV with TiO₂ as a working fluid.

![Figure 4](image2.png) Relationship between the inclination angle and the heat flux of CLOHP/CV with TiO₂ as a working fluid.

![Figure 5](image3.png) Relationship between the inclination angle and the heat transfer coefficient of CLOHP/CV with TiO₂ as a working fluid.

![Figure 6](image4.png) Relationship between the inclination angle and the thermal efficiency of CLOHP/CV with TiO₂ as a working fluid.

![Figure 7](image5.png) Relationship between the inclination angles and the thermal resistance of CLOHP/CV with TiO₂ as a working fluid.
The effect of the inclination angle on the performance heat transfer of CLOHP/CV at 45 degrees is higher than at 0 degrees, the CLOHP/CV using TiO$_2$ as a working fluid had a heat transfer efficiency higher than when using deionized water. An operating temperature of 80 degrees Celsius resulted in higher the performance heat transfers higher than at 70 or 60 degrees Celsius respectively. It can be concluded that best performance heat transfer of CLOHP/CV by using TiO$_2$ as a working fluid, used an inclination angle of 45 degrees, at operating temperature of 80 degrees Celsius. We found that the best heat transfer value was 297.76 W, the best heat flux was 2887.09 W/m$^2$, the best heat transfer coefficient was 1547.53 W/m$^2$°C, and the best thermal efficiency was 0.17, as shown in figures 3 – 7. In addition, when comparing the working fluids between TiO$_2$ and deionized water, it was found that heat pipes using TiO$_2$ as a working fluid, resulted that the heat transfer increased (82.23%), the heat flux increased (75.90%), the heat transfer coefficient Increased (72.82%), heat transfer efficiency Increased (64.170%). But on the other hand, the heat pipes used TiO$_2$ as a working fluid, resulting the thermal resistance decrease (92.85%).

4. Conclusions
When the inclination angle increases from 0 to 45 degrees from the horizontal axis, the heat transfer and thermal efficiency of CLOHP/CV increased. When operating temperature increased from 60, 70 to 80 degrees Celsius the heat transfer and the thermal efficiency of CLOHP/CV increased. Changing the working fluid from deionized water into TiO$_2$ increased the heat transfer and the thermal efficiency of CLOHP/CV. Therefore, it can be concluded that the CLOHP/CV using TiO$_2$ as a working fluid, at inclination angle of 45 degrees, at operating temperature of 80 degrees Celsius, had the best heat transfer (297.76 W) and the best thermal efficiency (0.17). It also had the best heat flux and the best heat transfer coefficient at 2887.09 W/m$^2$ and 1547.53 W/m$^2$°C respectively. It was also found that all variables affecting the heat resistance of the CLOHP/CV at using TiO$_2$ as a working fluid were lower than those of deionized water as working fluid. The CLOHP/CV using TiO$_2$ as a working fluid, operating temperature of 80 degrees Celsius, inclination angle of 45 degrees, resulted in the lowest heat resistance. The variables in this research were the inclination angle, the operating temperature and the working fluid of the nanoparticles. Variations in these can increase the heat transfer efficiency of CLOHP/CV and can reduce the heat resistance better than the basic fluid.

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