Flow Patterns and Heat Transfer Characteristic of Two-Phase Closed Rectangular Cross Sectional Area Thermosyphon

Surachet Sichamnan

A Thesis Submitted in Partial Fulfillment of Requirements for
degree of Doctor of Philosophy in Mechanical Engineering

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ABSTRACT

This study investigates types of two-phase flow patterns that affect the heat transfer rate. Occurring within two-phase closed rectangular cross sectional area thermosyphon (RTPCT) and circle cross sectional area thermosyphon (TPCT) made of heat-resistant glass tube inner diameters of 7 and 25.2 mm. Aspect ratio were 5 and 20, the inclination angles were 0, 80 and 90°, the evaporator temperature were 50, 70 and 90 °C, the filling ration was 50% with respect to evaporator section and temperature water of the condenser section was 20 °C. From the test results, the RTPCT inner diameter 25.2 mm, the inclination angle was 90° and using water as working fluids.There are four types of flow pattern including bubble flow pattern, slug flow pattern, churn flow pattern and annular flow pattern for case aspect ratio was 20. By churn flow pattern and the annular flow pattern affect the heat transfer rate. Also found bubble flow pattern, slug flow pattern and churn flow pattern for case aspect ratio was 5. By slug flow pattern and churn flow pattern affects the heat transfer rate. And the heat flux obtained from the RTPCT within the diameter of 25.2 mm, aspect ratio was 5 is the heat transfer rate per unit area is 2.60 kW/m^2 at the evaporation temperature of 90 °C.

When considering the TPCT diameters of 7 and 25.2 mm. Aspect ratio was 5, the inclination angles were 0, 80 and 90°, using silver nanoparticles and adding oleic acid to reduce surface tension as working fluids. From the test results, the TPCT inner diameter 7 mm, the inclination angles were 80 and 90°. There are four types of flow pattern including bubble flow pattern, slug flow pattern, churn flow pattern and annular flow pattern. By churn flow pattern and the annular flow pattern affects the heat transfer rate of the TPCT with inner diameter of 7 mm the inclination angles were 80 and 90° respectively. In the TPCT test, the inner diameter of 25.2 mm at the inclination angle was 80°. There are four types of flow patterns, including the bubble flow pattern, slug flow pattern, churn flow pattern and stratified flow pattern respectively. By the churn flow pattern and stratified flow patterns affects the heat transfer rate for this test case. And the TPCT inner diameter of 25.2 mm at the inclination angle was 90°. There are four flow patterns, including the bubble pattern, slug flow pattern, churn flow pattern and the vortex flow pattern. The vertex flow pattern is a flow pattern that occurs and when flowing, the temperature in the evaporator section starts to rise from 70 to 90

°C. By the churn flow pattern and the vortex flow pattern affects the heat transfer rate for this test case. Also found the heat flux obtained from TPCT both inner diameter of 7 and 25.2 mm showed the highest heat transfer rate per unit area at evaporation temperature of 90 °C, the inclination angle was 80°, ie 32.33 and 5.25 kW/m^2, respectively.

Keyword : flow patterns thermosyphon heat transfer

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List of Abbreviations

RTPCT	The two-phase closed rectangular cross sectional thermosyphon
TPCT	The two-phase closed circular cross sectional thermosyphon
NP	De-ionized water mixed silver nanoparticles concentration of 0.5 wt%
OA	Oleic acid
OAK^+	Potassium oleate
Q	Heat transfer rate, W
ΔT	Temperature difference, °C
Z_{total}	Total thermal resistance
h_{eo}	Heat transfer coefficient at the evaporator section, $W/m^2 \cdot °C$
h_{co}	Heat transfer coefficient at the condenser section, $W/m^2 \cdot °C$
A_{eo}	Outside wall area of evaporator section, m^2
A_{co}	Outside wall area of condenser section, m^2
D_o	Outside diameter of the pipe, m
D_i	Inside diameter of the pipe, m
L_e	Length of the evaporator section, m
L_c	Length of the condenser section, m
k_x	Thermal conductivity of material, W/m·°C
g	Gravity, m/s^2
k_l	Thermal conductivity of the working fluid at liquid phase, W/m·°C
ρ_l	Density of the working fluid at liquid phase, kg/m^3
μ_l	Viscosity of the working fluid at liquid phase, $N \cdot s/m^2$
C_{pl}	Specific heat of the working fluid at liquid phase, kJ/kg·°C
ρ_v	Density of working fluid at vapor phase, kg/m^3
P_v	Vapour pressure of the working fluid, Pa
P_a	Atmospheric pressure 101.3 kPa
V_l	Volume of the working fluid, m^3
A	Area, m^2
DGCST	Difference geometric cross sectional area of thermosyphon
W_p	The wetted perimeter
R_h	The radius of hydraulic
G	Mass flux, $kg/s \cdot m^2$
X	Vapor quality
ρ_g	Density of working fluids in vapor state, kg/m^3
ρ_l	Density of working fluids in liquid state, kg/m^3
G_l	Liquid mass flux, $kg/s \cdot m^2$
G_g	Vapor mass flux, $kg/s \cdot m^2$
u_l	Velocity of working fluids in the state of liquid, m/s
u_g	Velocity of working fluids in the state of vapor, m/s

$\dot{V}_l$	Volumetric flow rate of working fluids in liquid state, m^3/s
$\dot{V}_g$	Volumetric flow rate of working fluids in vapor state, m^3/s
A_s	Cross section area of working fluids flow, m^2
h_{TP}	Enthalpy of two phase, J/kg
h_l	Enthalpy of liquid phase, J/kg
h_g, h_{fg}	Enthalpy of vapor phase, J/kg
V_{TP}	Specific volume values of two phase, m^3/kg
V_l	Specific volume values in liquid phase, m^3/kg
V_g	Specific volume values in vapor phase, m^3/kg
σ	Surface tension, N/m
v	Vapour
o	Out
l	Liquid
i	In
e	Evaporator
c	Condenser
a	Adiabatic

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CHAPTER 1

INTRODUCTION

1.1 Background

A two-phase closed thermosyphon (TPCT) is a wickless heat pipe. It has a high heat transfer rate even though the heat source and the heat sink temperature is slightly different. TPCT has a closed end pipe on both sides. Its components and working principles as shown in Figure 1.1. TPCT contains working fluid inside. In general, it consists of the evaporation section, the adiabatic section, and the condenser section. The working principle of TPCT follow as; the evaporator is heated by the heating source then working fluid as liquid phase change to vapor through the adiabatic section to the condenser section as a heat sink. When the vapor of working fluid is a move to the lower temperature, it is condensation. The condensation liquid will be return to the evaporator by the gravity. When the fluid return into the evaporator section. The advantages of TPCT are not external power to work, simple structure, very little heat resistance, high efficiency and low maintenance costs [1].

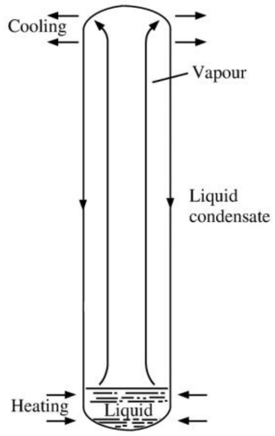

Figure 1.1 The two-phase closed thermosyphon [2].

The problems had found in TPCT such as 1) Generally, TPCT is constructed from the straight tube. It had limit installation area; 2) The traditional working fluid of TPCT for heat transfer process had low heat transfer properties. It was the reason for research on this problem to increase the efficiency of the TPCT and improve the heat transfer capacity of traditional working fluid by changing the cross sectional of the TPCT from the circular to the rectangular. The TPCT called a two-phase closed rectangular cross-sectional thermosyphon (RTPCT). RTPCT has more surface area for heat exchange [3] with the working fluid can receive and release the heat because it can reach to the centre of the cross section faster than the original TPCT [4]. The working fluid also matters in the heat transfer of TPCT. The traditional working fluid such as water or ethanol has low physical properties and hardly changed from liquid to vapor [5]. Silver nanoparticles are an option for mixing with the traditional working fluid because silver nanoparticles have the highest thermal conductivity of the transition metal and provide better stability in traditional working fluid than other metal [5]. However, the problem of nanoparticles is the integration of nanoparticles that are rarely fragmented, uniform, and have a low dispersion time [6, 7]. The addition of surfactant to silver nanoparticles improves the nanoparticles distribution time [6, 8]. The silver nanoparticles with surfactants are called “Nanofluids Containing Surfactant” It can increase the heat transfer to two-phase closed thermosyphon rather than the traditional working fluid [9]. For heat transfer problem of RTPCT and TPCT. It depends on the growing of internal flow pattern because each flow pattern has different heat transfer capacities [10]. It correlates with various variables such as working fluid, aspect ratio, the heat supplied to the evaporator, the inner diameter of pipe and angle of inclination. There are studies on the flow pattern of TPCT, such as the study of the internal flow pattern of inclined TPCT, which has the inner diameter 12 mm and the working fluid is water, the mixture of water and ethanol [11]. Chailangkar et al., study the visual of aspect ratio effects on the flow patterns inside an inclined two-phase closed thermosyphon. TPCT that used in the test inner diameter of 10, 12 and 28.5 mm and the working fluid is R123 [12]. They also study the effects of internal flow patterns of an inclined two-phase closed thermosyphon at normal operating condition [13]. From all relevant research found that it is a study of the heat transfer characteristics and flow pattern of TPCT. In normally condition, the study of TPCT used a straight tube with a circular cross sectional, which still lack of study on flow pattern of RTPTC, which have been used nanofluids containing surfactant is working fluid to identify the behavior and complex phenomena of the flow patterns and heat transfer that systematically and clearly occur. From the problems, this research aims to the study the behaviour and complex phenomena of flow patterns and the heat transfer occurring in RTPTC, which have been used Nanofluids Containing Surfactant is working fluid to understand the internal flow patterns and the heat transfer characteristics. The results will be able to use as a basis for a best performance of RTPCT application in the future.

1.2 Objectives of this study

1.2.1 To study the effect of working fluid, aspects ratio, the evaporator temperature, inner diameter and inclination angle to heat transfer rate of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPCT).

1.2.2 To study the effect of working fluid, aspects ratio, the evaporator temperature, inner diameter and inclination angle to the flow patterns two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPCT).

1.2.3 To create the flow patterns map of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPCT).

1.3 Scope of study

1.3.1 Independent variables [3]

1.3.1.1 The working fluids were;

1) De-ionized water.

2) De-ionized water mixed silver nanoparticles concentration of 0.5 wt% (NP) respect to total volume of water containing 1 wt% of oleic acid (OA) respect to total volume NP.

1.3.1.2 The aspect ratios were 5 and 20.

1.3.1.3 The evaporator temperature 50, 70 and 90 °C

1.3.1.4 The inclination angles were 0, 80 and 90°

1.3.1.5 The two-phase closed rectangular and circular cross sectional thermosyphon made by Pyrex tube an inner diameters were 7 and 25.2 mm.

1.3.2 Dependent variables

1.3.2.1 The average length of bubble.

1.3.2.2 The average speed of bubble.

1.3.2.3 The heat transfer rate.

1.3.2.4 The internal flow patterns of the two - phase closed rectangular and circle cross sectional thermosyphon.

1.3.3 Control variables

1.3.3.1 Temperature water of the condenser section was 20 °C

1.3.3.2 The mass flow rate of feed water was 0.25 l/min.

1.3.3.3 The filling ration was 50% with respect to evaporator section.

1.4 Benefits of this study

1.4.1 The effect of working fluid, aspects ratio, the evaporator temperature, inner diameter and inclination angle to heat transfer rate of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPCT) will be achieved.

1.4.2 The effect of working fluid, aspects ratio, the evaporator temperature, inner diameter and inclination angle to the flow patterns two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPCT) will be achieved.

1.4.3 The flow patterns map of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPCT) will be achieved.

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CHAPTER 2

Literature Review

For research on internal flow patterns and the heat transfer characteristics of the two phase closed thermosyphon and study the theory and research papers related to thermosyphon include.

2.1 Theory and working principle of a two phase closed thermosyphon
2.2 Nanofluids
2.3 Two phase flow pattern
2.4 Flow patterns map
2.5 Literature review

2.1 Theory and working principle of a two phase closed thermosyphon

The two phase closed thermosyphon (TPCT) is a wickless heat pipe. It is a heat exchanger used to transfer heat from a heat source to a heat sink. The TPCT is a straight pipe consisting of an evaporator section, an adiabatic section and a condenser section as shown in figure 2.1.

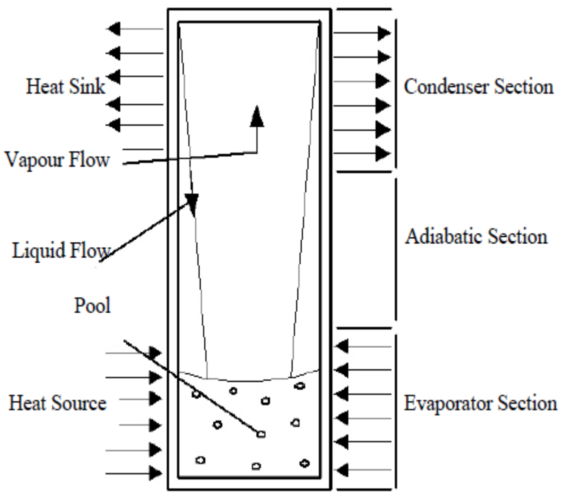


Figure 2.1 Schematic of the two phase closed thermosyphon (TPCT) [9].

For the use of the TPCT, the evaporator section must be at a lower level than the condenser section. Add a number of working fluid into the pipes that have drawn air and sealed the pipes. The working fluid is in the saturated liquid state. The evaporator is heated by the heating source. The working fluid in the thermosyphon causes the change of state. From saturated fluids become vapor and float up to the condenser section. It is a bubble boil and a vapour plug. Using the latent heat of vaporization and move to the condenser section when the vapour touch the area of the condenser section at a lower temperature than the evaporator section. The vapor plug will change state from vapour.Become liquid by collapsing into the evaporator section by based on the gravity of the world. The working fluid is a vapour plug. It can transfer heat from one end the other [1]. From the problem of the two-phase closed circular cross sectional thermosyphon (TPCT) as mentioned in the background section of chapter 1. Bring more study and research a two-phase closed rectangular cross-sectional thermosyphon (RTPCT). By working principle of the RTPCT, It has a working principle similar to the TPCT. Change cross sectional of a two-phase closed rectangular cross-sectional thermosyphon (RTPCT). The RTPCT could be solved with limited space availability for receiving thermal in the evaporator section and heat transfer [3]. Which the rectangular cross sectional is affects the contact area for obtaining more heat which affects boiling of the working fluids in the RTPCT. It also causes the bubble to move better from the evaporator to the condenser and affects the heat transfer.

2.1.1 Heat transfer characteristics

The heat transfer performance (Q) of a TPCT can be calculated from equation (2.1) [3, 9].

$$Q = \frac{\Delta T}{Z_{total}} \tag{2.1}$$

Thermosyphon at the incline position is the same as the vertical position. But it is different in the internal flow behavior that occurs. As shown in Figure 2.2. Formed a stratified flow pattern in the thermosyphon at the inclined position. The heat transfer performance (Q) of TPCT at incline position was higher than the TPCT at the vertical position. The condensed liquid flows down the bottom wall of the tilted side. It is a wide area in the flow of vapors caused by volatile liquids from evaporation.

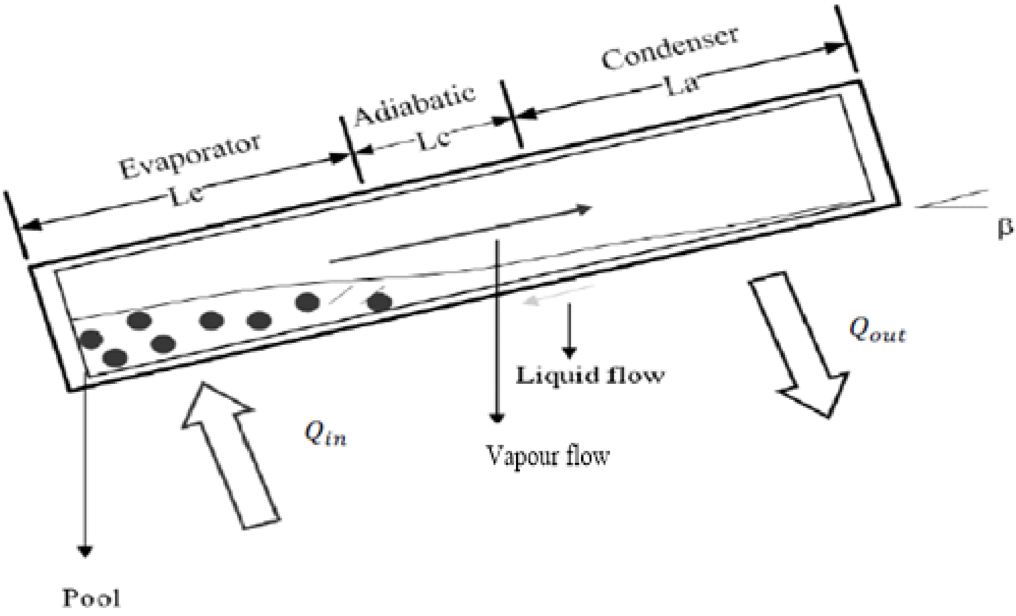


Figure 2.2 Schematic of thermosyphon at the incline position [9].

The heat transfer performance of thermosyphon at the incline position can be calculated form equation (2.2) (2.3) [3, 9].

$$Q_{incline} = Q_{vertical} \text{ x } f(\beta) \quad (2.2)$$

$$Z_{incline} = Z_{vertical} \text{ x } f(\beta) \quad (2.3)$$

By ΔT is the temperature difference between the evaporator and condenser
$Z_{inclined}$ is the thermal resistance of inclination
$Z_{vertical}$ is the thermal resistance of vertical
$Q_{incline}$ is the heat transfer rate of inclination
$Q_{vertical}$ is the heat transfer rate of vertically
$f(\beta)$ is the function of the inclination angle

2.1.2 Heat transfer characteristics

The resistance of a TPCT device can be split into ten values and divided into three groups [3, 9]. Resistance is explained as follows in Figure. 2.3.

2.1.2.1 External resistance (Z_1 and Z_9).
2.1.2.2 Resistance form material property (Z_2 and Z_8).
2.1.2.3 Internal resistance (Z_3 ,Z_4 ,Z_5 ,Z_6 ,Z_7 and Z_{10}).

The external resistance is the resistance from the outside wall of the TPCT at both the evaporator and condenser sections. The internal resistance is the resistance from the phase change of working fluids such as pool boiling or film boiling, when the vapour pressure drops along the pipe. The resistance from the material property is dependent on the type of material used [3, 9].

2.1.2.1 External resistance (Z_1 and Z_9).

Z_1 and Z_9 represent the resistance from the external convection of the pipe [3, 9].

$$Z_1 = \frac{1}{h_{eo}A_{eo}} \quad (2.4)$$

$$Z_9 = \frac{1}{h_{co}A_{co}} \quad (2.5)$$

By h_{eo} is heat transfer coefficient at the evaporator section, $W/m^2 \cdot °C$
h_{co} is heat transfer coefficient at the condenser section, $W/m^2 \cdot °C$
A_{eo} is outside wall area of evaporator section, m^2
A_{co} is outside wall area of condenser section, m^2

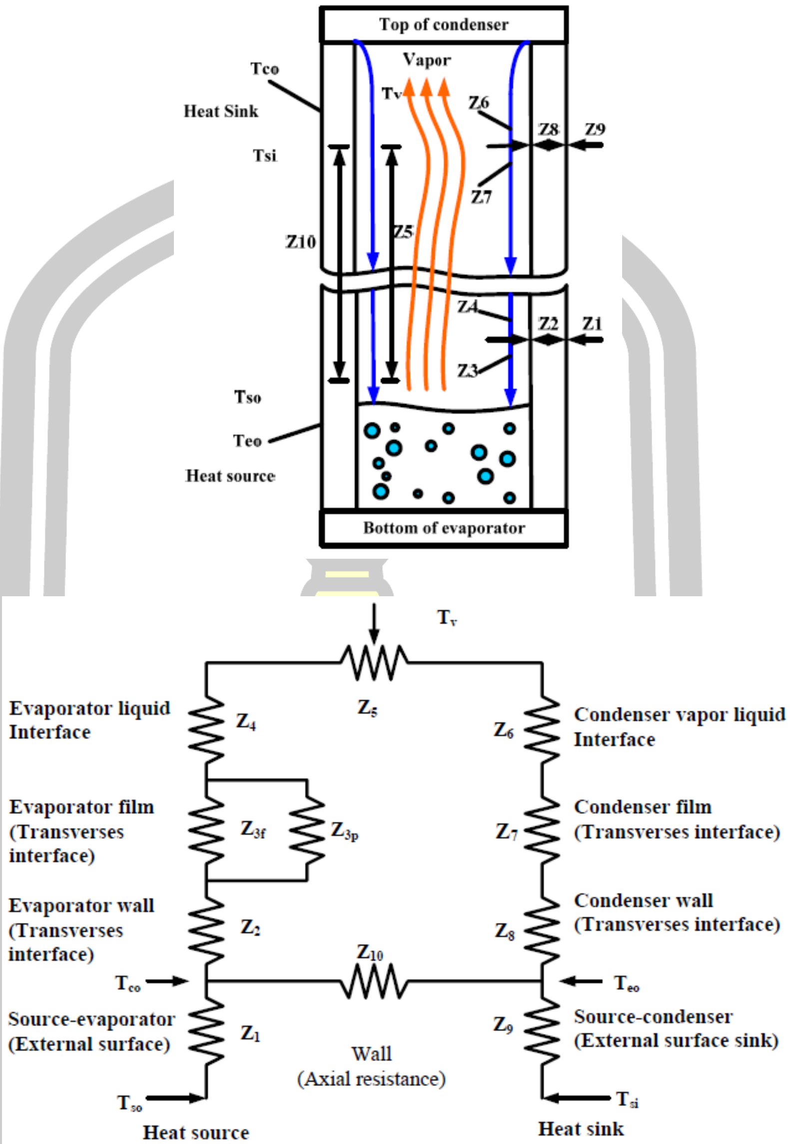


Figure 2.3 Model of total resistance of TPCT [3].

2.1.2.2 Resistance form material property (Z_2 and Z_8).

Z_2 and Z_8 represent the resistance from the thermal conductivity if the material is [3, 9].

$$Z_2 = \frac{\ln(\frac{D_o}{D_i})}{2\pi L_e K_x} \tag{2.6}$$

$$Z_8 = \frac{\ln(\frac{D_o}{D_i})}{2\pi L_c K_x} \tag{2.7}$$

By D_o is outside diameter of the pipe, m

D_i is inside diameter of the pipe, m

L_e is length of the evaporator section, m

L_c is length of the condenser section, m
k_x is thermal conductivity if he material, W/m·°C

2.1.2.3 Internal resistance (Z_3, Z_4, Z_5, Z_6, Z_7 and Z_{10}).

Z_3 and Z_7 represent the internal resistance due to the working fluid of pool and film boiling and is devised into [3].

Z_{3p} is resistance from pool boiling

$$Z_{3p} = \frac{1}{\Phi_3 g^{0.2} Q^{0.4} (\pi D_i L_e)^{0.6}} \tag{2.8}$$

Z_{3f} is resistance from film boiling at the evaporator section

$$Z_{3f} = \frac{CQ^{1/3}}{D_i^{4/3} g^{1/3} L_e \Phi_2^{4/3}} \tag{2.9}$$

By g is gravity, m/s^2
C is constant of cylinder tube.
$C = \left(\frac{1}{4}\right)\left(\frac{3}{\pi}\right)^{4/3} = 0.325$

Φ_2 is figure of merit (2)

$$\Phi_2 = \left(\frac{LK_l\rho_l^2}{\mu_l}\right)^{1/4} \tag{2.10}$$

Φ_3 is figure of merit (3)

$$\Phi_3 = 0.325x\frac{\rho_l^{0.5} k_l^{0.3} C_{pl}^{0.7}}{\rho_v^{0.25} L^{0.4} \mu_l^{0.1}} \left[\frac{P_v}{P_a}\right]^{0.23} \tag{2.11}$$

By C_{pl} is specific heat of the working fluid at liquid phase, kJ/kg·°C
ρ_v is density of working fluid at vapour phase, kg/m^3
P_v is vapour pressure of the working fluid, Pa
P_a is atmospheric pressure 101.3 kPa

And the condition using Z_{3p} and Z_{3f}

$$Z_3 = Z_{3p}F + Z_{3f}(1 - F) \tag{2.12}$$

$$F = \frac{V_l}{AL_e} \tag{2.13}$$

By F is filling ratio that is defined by
A is area cross section of the pipe, m^2
Z_7 is resistance from film boiling of the working fluid at the condenser section:

$$Z_7 = \frac{CQ^{1/3}}{D_i^{4/3} g^{1/3} L_c \Phi_2^{4/3}} \quad (2.14)$$

Z_7 and Z_6 is resistance due to the phase change at the evaporator and condenser section respectively. Z_5 is resistance due to pressure drop along the pipe. Z_{10} is resistance due to heat conduction along the axial pipe. Normally, Z_4, Z_5, Z_6 and Z_{10} are of small value and can be negligible.

However, the thermal resistance of RTPCT based on the concept of TPCT. By thermal resistance both of TPCT and RTPCT depend on the body shape characteristic can be defined by the cross sectional area, aspect ratio, the wetted perimeter and radius of hydraulic in case DGCST.

For the aspect ratio (AR, AP), aspect ratio of RTPCT is the ratio between the evaporation length and the four times the radius of hydraulic as shown in equation (2.15). In part, aspect ratio of TPCT is the ratio between the evaporation length and the internal diameter of pipe as shown in equation (2.16). The physical characteristics of TPCT and RTPCT on the heat transfer phenomena of the difference geometric cross sectional area of thermosyphon (DGCST).

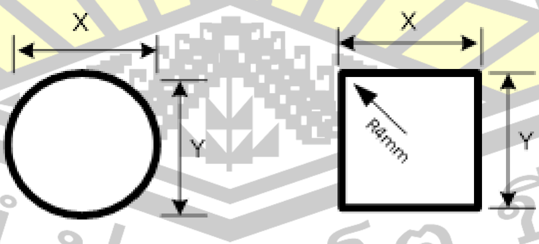
The aspect ratio of RTPCT (AR) can be calculated from equation (2.15) [3].

$$AR = \frac{L_e}{4R_h} \quad (2.15)$$

In addition, the aspect ratio of TPCT (AP) can be calculated from equation (2.16) [3].

$$AP = \frac{L_e}{D_i} \quad (2.16)$$

For the wetted perimeter and radius hydraulic of the difference geometric cross sectional area of thermosyphon (DGCST), as shown in Figure 2.4 [3].



(a) TPCT (b) RTPCT

Figure 2.4 Difference geometric cross sectional area of thermosyphon (DGCST) (a) circular cross sectional (b) rectangular cross-sectional.

The cross sectional area can be calculated from equation (2.17) [3].

$$A = \frac{\pi Y^2}{4} + (xy) \tag{2.17}$$

The wetted perimeter can be calculated from equation (2.18) [3].

$$W_p = \pi Y + 2x \tag{2.18}$$

The radius of hydraulic can be calculated from equation (2.19) [3].

$$R_h = \frac{A}{W_p} = \frac{(\pi/4)Y^2+(XY)}{\pi Y+2X} \text{ is meaning } 4R_h = D_i \tag{2.19}$$

For heat transfer areas, this refers to the area of the surface of the thermosyphon at the evaporation area or the surface of the condensed surface. In this study, the length of the evaporator and the condensate is the same. This causes the heat transfer area to evaporate and the heat transfer area from the condensate is equal. The heat transfer area can be obtained from Equation (2.20).

$$A = \pi d L_e \tag{2.20}$$

For changing the cross section of thermosyphon in this research. If considering the term change x. We find that the change is due to the y range change. Cause changes in the cross-sectional area wetted perimeter and radius of hydraulic. It affects the exposed areas that are exposed and exothermic. Due to the heat transferred to the center of the cut, the speed difference is different. From the appearance of different thermosyphon, it affects the flow pattern that occurs within the thermosyphon.Each flow pattern has the ability to provide different heat transfer values.

2.2 Nanofluids

"Nano" It measures the size, size or length of an object. According to the metric, nanometer means one billionth of a section (1 nanometer is 10^{-9} of 1 meter) with is about 10 times smaller than the smallest atom [9]. Most of the working fluid used in the thermosyphon is traditional liquids, such as ethanol, ethylene glycol [14, 15, 16] with have low heat transfer properties. Nowadays, the use of thermosyphon compounds has been developed to improve the efficiency of heat transfer. Using working fluid, there are nanoparticles mixed with traditional liquids such as gold, brass, copper, silver, and nanoparticles [17].

Nanofluids it is a solid and liquid material consisting of a solid nanoparticle or nanoparticle. The size is about 1-100 nm into the liquid. The nanoparticles suspended in the base fluid. It shows the efficiency of heat transfer and heat transfer coefficient [5, 9, 18]. Silver nanoparticles have very good thermal and electrical conductivity properties. As shown in Table 2.1 to 2.3 show the properties of silver nanoparticles [9].

Table 2.1 Silver nanoparticle properties [9].

General properties	
Name, symbol, atomic, number	silver, Ag, 47
Element category	transition metals
Standard atomic weight	107.8682 $g.mol^{-1}$
Electrons configuration	$4d^{10}$ $5s^1$
Electrons per shell	2, 8, 18, 18, 1
Physical properties	
Color	silver
Phase	Solid
Density (near r.t.)	10.49 $g.cm^{-3}$
Melting point	1234.93 K
Boiling point	2435 K
Heat of fusion	11.28 kJ mol^{-1}
Heat of vaporization	250.58 kJ mol^{-1}
Specific heat capacity	25.350 J $mol^{-1}.K^{-1}$ (25 °C)

Table 2.2 Vapour pressure of silver nanoparticles [9].

Vapour pressure						
P(Pa)	1	10	100	1 k	10 k	100 k
at T(K)	1283	1413	1575	1782	2055	2433

Table 2.3 Silver atomic properties [9].

Atomic properties	
Crystal structure	face-centered cubic
Crystal structure	1, 2, 3 (amphoteric oxide)
Electronegativity	1.93 (Pauling scale)
Ionization energies	1 st: 731.0 kJ/mol 2 nd: 2070 kJ/mol 3 rd: 3361 kJ/mol
Atomic radius	144 pm
Covalent radius	145 ± 5 pm
Van der Waals radius	172 pm
Miscellaneous	
Megnetic ordering	diamagnetic
Electrical resistivity	15.87 nΩ.m (20 °C)
Thermal conductivity	429 $W.m^{-1}.K^{-1}$ (300K)
Thermal diffusivity	174 mm^2/s (300K)
Thermal expansion	18.9 $\mu m.m^{-1}.K^{-1}$ (25 °C)
Speed of sound (thin rod)	2680 $m.s^{-1}$ (r.t.)

When nanofluids are used as working fluids within the two-phase closed thermosyphon. The nanoparticle fluid reduces heat resistance and heat transfer fluid [15]. Nano-fluid properties for high temperatures will depend on the thermal conductivity greater than the basic liquid. Heat conduction depends on the concentration of surfactants present in the nanosphere. In some cases, we will find that the nanoparticle is unstable and the nanoparticles are precipitated [19, 20, 21]. Surfactants improve the stability of the nanosphere. By constant dispersion of particles. Surfactants can absorb gases in the gaseous-fluid interface and reduce the tension between the skins. The thinning agent may be trapped in a large amount of solution [6, 22]. There are researchers have studied the properties of nanoparticles and surfactants, as well as their applications. Including the behaviour characteristics of surfactant-based nanoparticles and different methods of nano-fluid synthesis.

Studies on the thermal conductivity of 0.1- 0.4% nanoparticles (Ag) nanoparticles were performed by ultrasonic vibration for 3 hours. Heat is increased to 10% at a concentration of 0.4% [23]. Nanofluids synthesis using high-pressure nanoparticles silver powder the concentration of 0.1 - 0.3% (Ag). It was found that, the thermal conductivity increased to 18% at 0.3% [24]. It can be seen that nanoparticles in fluid has a better cooling capacity compared to water used in the traditional heat pipe. Because nanoparticles can spread the temperature of the liquid and reduce the boiling limits [18, 25]. Flow properties play a very important role in the flow of fluid during use. Nano fluids have either natural or forced flow behaviour including flow properties such as viscosity, stress, shear and shear rate. Different systems will resist flow behaviour [26, 27]. In all the fluid, there is friction between the molecules and therefore the flow resistance can be measured as the viscosity. From studying the behaviour of flow of nanofluids. Titania nanoparticles at a concentration of 8% in the EG group exhibit Newtonian behaviour at low shear rate and shear viscosity, depending on the temperature and the concentration of nanoparticles [28]. The investigated properties of 1% silver nanoparticles in ethanol and polyvinylpyrrolidone (PVP) [8]. The results showed that PVP reduced the size of nanoparticles. The viscosity of the liquid is low and the fluid behaviour is neonatal, leading to higher thermal conductivity. Another reason is that nanofluids with surfactant added affects surfactant and viscosity, resulting in altered physical properties [29]. For example, Al_2O_3 in water at a ratio of 1:10 to ammonium poly (PMAA-NH4), has shown reduced slump behaviour. (Reduced viscosity with increased stress), good decomposition rate with 47.5% PMAA suspension. In addition, it was found that at 4% by volume of c-Al_2O_3, TiO_2 and CuO nanofluids were mixed with 0.5% by weight. Carboxymethyl cellulose (CMC) in deionized water. It was found that at 4% by volume, nanofluids exhibited Non-newtonian behaviour with reduced shear [30].

Researchers have been trying to learn more about the properties of surfactant nanoparticles. The investigation nanoparticles of silver nanoparticles (Ag) at a concentration of 0.5%. By using oleic acid (OA) and potassium oleate (OAK^+) surfactant found nanofluids containing 1% of potassium oleate by mass gave rise to a thermal conductivity of 11% at 20 °C to 28% at 80 °C. Compared to Deionized water, the base fluid at work. It also found that shear and viscosity were reduced by the addition of surfactants [17]. The silver nanoparticles contained in deionized water containing OAK^+ will affect the flow behaviour of the nanofluids as a cause of viscosity reduction [31]. Newtonian flow behaviour has been demonstrated [17].

2.3 Two-Phase Flow Pattern

Two-phase flow is the flow of matter with two simultaneous states. For the internal flow of thermosyphon. It is the flow of vapor and liquid. This is very complicated at the time of the flow. When considering the two-phase flow pattern between the vapor and the liquid formed within the vertical pipe and the horizontal flow pattern as follows.

2.3.1 Vertical Pipeline Flow Patterns [32]. As shown in Figure 2.5, it consists of

2.3.1.1 Disperse bubble flow. There will be a small bubble group in the space of the liquid. Between the bubbles, a thin film of foam bubble chamber.

2.3.1.2 Bubble flow. It is a fluid-state pattern that is continuous with internal bubbles.

2.3.1.3 Slug or plug flow. In this flow. There will be bubbles formed like a ball bearing. This may be intermittent and small bubbles are inserted.

2.3.1.4 Churn flow. When the flow speed is greater. The slug flow will vary. The bubbles gather together to form an unstable range. If it is a large diameter pipe, the liquid will shake up and down the pipe. If it is a small diameter pipe, there may be no vibration of the liquid. However, it may be noted that the flow will change into annular flow instead.

2.3.1.5 Annular flow. Fluid will flow around the pipe wall in thin film form. Gas flow in the core. Some of the liquid will be whipped up in small drops. In the gas core, or sometimes the gas bubbles will be swept into the liquid film as well.

2.3.1.6 Wispy annular flow. In the annular flow. If the flow rate of the liquid film increases. The proportion of liquid droplets within the core of the gas will also increase. Liquid droplets may form a large liquid within the core. This pattern occurs when the flow rate is very high.

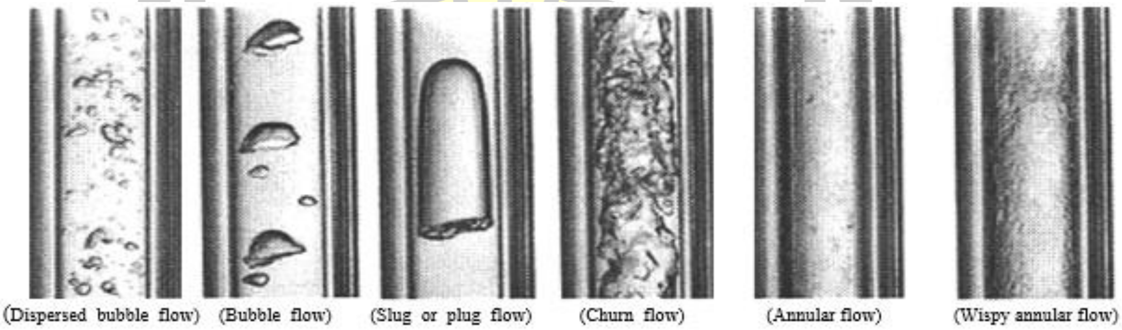


Figure 2.5 Two-phase flow pattern vertical pipe [34].

2.3.2 The two-state flow pattern between the vapor and the liquid formed within the horizontal pipe [33]. As shown in Figure 2.6, consists of:

2.3.2.1 Stratified flow. Each phase is separated by gravity. The liquid flows along the bottom of the pipe. The gas flows along the top of the pipe.

2.3.2.2 Stratified wavy flow. In a stratified flow, if the gas velocity increases. There will be waves at the surface between gas and liquid. Different from stratified flow.

2.3.2.3 Dispersed bubble flow. In this flow, the gas bubbles are exhaled into the liquid. If the flow is horizontal, the bubbles will gather at the top of the pipe. At high system speeds. Bubbles may be unevenly dispersed and may clump together.

2.3.2.4 Annular-dispersed flow. The shape is similar to the vertical annular flow. The difference is that the thickness of the film is not constant. The film is thicker than the bottom of the pipe.

2.3.2.5 Intermittent flow. It is a pattern of periodic flow. Complexes in different types of pipes in the horizontal. It is usually considered to be another kind of extra flow. However, this flow can be divided into three types together.

2.3.2.5.1 Plug flow. In this flow. It is the same as in the vertical. There will be a bubble slug to be observed. But it moves in a position near the top of the pipe.

2.3.2.5.2 Slug flow. This flow is controlled by the flow channel along with the air channel. The liquid state is continuous, but with large bubbles. The liquid was drawn into it.

2.3.2.5.3 Semislug flow. A fluid wave forms at the surface of the layer separating the bottom of the pipe.

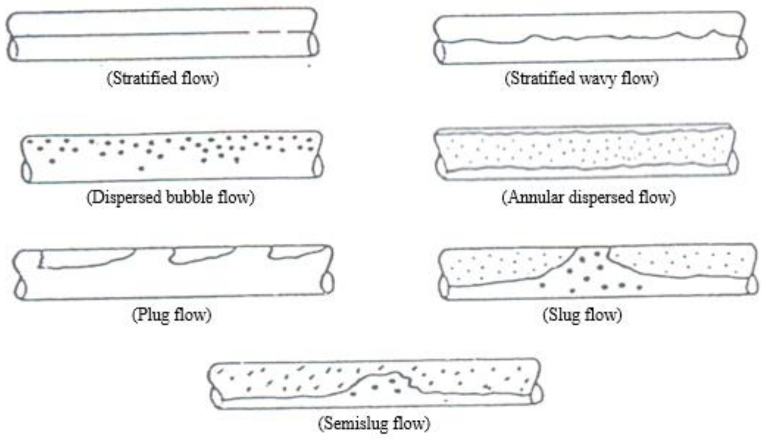


Figure 2.6 Two-phase flow pattern horizontal pipe [35].

For thermosyphon with the physical characteristics and different forms such as Cross-sectional area, wetted perimeter and radius of hydraulic. It will directly affect the boiling and flow patterns of the inner workings of the thermosyphon. The cross-sectional area, wetted perimeter and radius of hydraulic of the appropriate thermosyphon will result in a rapid movement of vapors from the evaporator to the condenser section. On the other hand, it is appropriate to flow the liquid film from condensation into the evaporator. The flow pattern affects the heat transfer characteristics of the thermosyphon. Because each flow pattern has the ability to provide different heat transfer values.

2.4 Flow patterns map

Flow patterns is a graph showing the relationship between flow patterns Between vapors and liquid within a pipe. The purpose is to study flow patterns and change flow patterns from one form to another. The flow chart is a 2D graph. With showing the range (Regime) of the various flow patterns. The results of the plot. With chart flow pattern for vertical flow. The popular propositions are generally presented by Hewitt and Roberts [34]. As shown in Figure 2.7. By momentum flux is the rate of momentum-to-space transfer. For momentum flux in vapor state and fluid flux momentum. Can be obtained from equations (2.21) and (2.22).

Equation for calculating liquid momentum flux [10] is given by.

$$\rho_l u_l^2 = \frac{[G(1-x)]^2}{\rho_l} \tag{2.21}$$

The equation for calculating gas momentum flux [10] is given by.

$$\rho_g u_g^2 = \frac{[GX]^2}{\rho_g} \tag{2.22}$$

By G is mass flux, kg/s·m^2
- x is vapor quality
- u_l is superficial liquid velocity, m/s
- u_g is superficial gas velocity, m/s
- ρ_g is density of working fluids in vapor state, kg/m^3
- ρ_l is density of working fluids in liquid state, kg/m^3

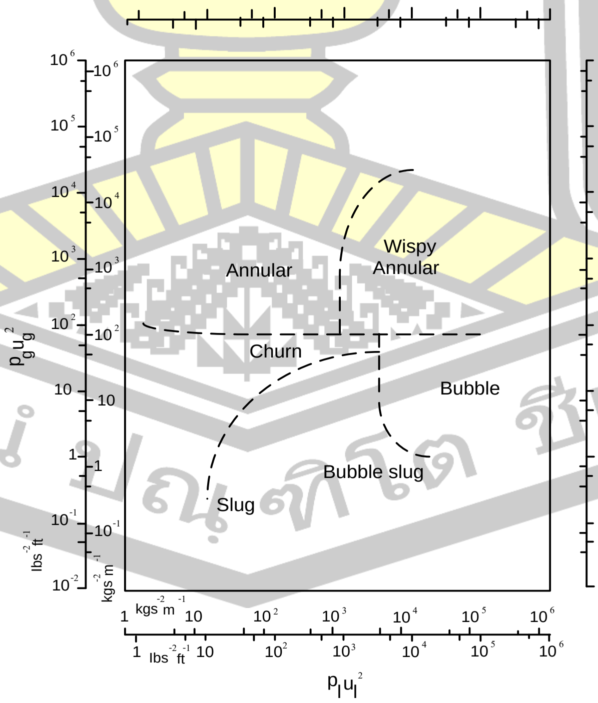


Figure 2.7 Chart flow patterns [36].

Equation for mass flux of two phase flow (Mass flux) is the mass flowing through space per unit time [10], find it from.

$$G = G_g + G_l \tag{2.23}$$

Equation for liquid mass flux is the product of the liquid density versus the velocity of the working fluids in the liquid state (Superficial liquid velocity) [10], Find it from.

$$G_l = \rho_l u_l \tag{2.24}$$

The equation for the vapor mass flux is the product of the vapor density with the speed of the working fluids in the state of the vapor (Superficial gas velocity) [10], is obtained from.

$$G_g = \rho_g u_g \tag{2.25}$$

By G_l is liquid mass flux, kg/s·m^2
G_g is vapor mass flux, kg/s·m^2

The equation for determining the velocity of working fluids in the state of liquid (Superficial liquid velocity) [10], is obtained from.

$$u_l = \frac{\dot{V}_l}{A_s} = \frac{u_l A_s}{A_s} \tag{2.26}$$

The equation for determining the velocity of working fluids in the state of vapor (Superficial gas velocity) [10], is obtained from.

$$u_g = \frac{\dot{V}_g}{A_s} = \frac{u_g A_s}{A_s} \tag{2.27}$$

By u_l is velocity of working fluids in the state of liquid, m/s
u_g is velocity of working fluids in the state of vapor, m/s
$\dot{V}_l$ is volumetric flow rate of a working fluids in liquid state, m^3/s
$\dot{V}_g$ is volumetric flow rate of a working fluids in vapor state, m^3/s
A_s is cross section area of working fluids flow, m^2

Equation for vapor quality. The vapor quality value is the proportion of total flow. Which is usually thought of as a vapor state [10], most of which is obtained from.

$$x = \frac{G_g}{G} = \frac{G_g}{G_g + G_l} \tag{2.28}$$

For thermodynamic balance vapor quality values can be calculated based on the enthalpy or specific volume of two phase. And the enthalpy or specific volume of saturated liquid and vapor status [10], As shown in equation.

$$x = \frac{h_{TP}-h_l}{h_g-h_l} = \frac{V_{TP}-V_l}{V_g-V_l} \tag{2.29}$$

By h_{TP} is enthalpy values of two phase, J/kg
h_l is enthalpy values in liquid phase, J/kg
h_g is enthalpy values in vapor phase, J/kg
V_{TP} is specific volume values of two phase, m^3/kg
V_l is specific volume values in liquid phase, m^3/kg
V_g is specific volume values in vapor phase, m^3/kg

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2.5 Literature Review

Research-Researcher	Study	Results	Compared with research topics to study.
Terdtoon P and Chailungkar M. [13]. Effects of Aspect Ratios on Internal Flow Patterns of an Inclined Closed Two-Phase Thermosyphon at Normal Operating Condition.	Scope of study 1)The thermosyphon tube used has an internal diameter of 11.1 mm. 2) The inclination angles were 90, 30 and 5°. 3) The aspect ratios chosen to study were 30, 10 and 5. 4) Vapor temperature 30 ± 3 °C. 5) Filling ratio 80%. 6) The working fluids used R123. Objectives of this study 1) To study the effect of aspect ratios at various inclination angles. With regard to the internal flow pattern and heat transfer of the thermosyphon.	1) At aspect ratio 10 and over. The flow pattern is annular and churn at the upright position. When tilted, the flow pattern is stratified. Meanwhile Improved heat transfer rates at upright and tilted locations. This causes the wet flow on the evaporator pipe in the normal working condition. 2) At aspect ratio less than 10. The flow pattern is bubbly, both upright and tilted. Each experiment resulted in a wet flow. When tilted vertically to the tilt angle, the flow pattern is still bubbly. The heat transfer rate was satisfactory and higher in each experiment. .	Something like a research topic to study 1) There are some variants of similar aspect ratios and inclination angle. It is different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular. 2) The working fluids used is; - DI-Water - Silver nanofluid concentration of 0.5wt% (NP)+ surfactant concentration OA was 1wt%

Research-Researcher	Study	Results	Compared with research topics to study.
Ponnikorn A et al. [11]. Study of Internal Flow Pattern of Inclined Two-Phase Closed Thermosyphon.	Scope of study 1) Thermosyphon is made of Pyrex glass tube and copper pipes, inside diameter 12 mm, outside diameter 16 mm, evaporation length 360 mm, adiabatic length 200 mm, and condensed length 305 mm. 2) The inclination angles were 30, 50, 70 and 90°. 3) The working fluids used is water, water mix ethanol 4) Temperature evaporator 50, 60, 70 and 80 °C. 5) The filling ratio 30, 50 and 70% of volume evaporation. Objectives of this study 1) To investigate the flow pattern of the working fluids within the thermosyphon in the inclined plane. 2) Study the effect of variables affecting flow patterns of working fluids within the thermosyphon and the heat transfer coefficient of the thermosyphon are tilted.	1) At different temperatures there will be different boils. There will be more intense boils. When the temperature rises, the internal flow pattern is different. And the frequency of flow patterns will change as well. From the flow, the slung flow will change to churn flow and Annular flow. 2) At different temperatures, the condensate will behave differently. That is, while the evaporation temperature is not very high. The condensate will not work, but when the evaporating temperature is higher, it will start to notice condensation drops. Because of the high enough vapor pressure to evaporate from the evaporation of the active substance, it floats to condense at the condensate. The amount of this drop will increase if the evaporation temperature is higher. 3) At different temperatures, the different heat transfer coefficients are the higher the evaporator temperature, the higher the heat transfer rate. By the same trend. All fill rates and tilt angles. And that distilled water is a working fluids. At a filling rate of 50% and at the 70-degree tilt angle, the best heat transfer coefficient is 152.61 W.	Something like a research topic to study 1) There are some variants of similar water and inclination angle. It is different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular. 2) The working fluids used is; - DI-Water - Silver nanofluid concentration of 0.5wt% (NP) + surfactant concentration OA was 1wt%

Research-Researcher	Study	Results	Compared with research topics to study.
Srimuang W et al. [35]. Heat transfer characteristics of a vertical flat thermosyphon (VFT).	Scope of study 1) Thermosyphon is made of copper pipes with an external diameter of 9.5 mm within 8.6 mm. The lengths of 390, 690, 990 and 1290 mm are squeezed to have flat sections of 6.6, 4.6 and 2.6 mm. 2) The working fluids used is water, water, ethanol and R123. 3) Aspect ratios used 16, 19, 28, 30, 34, 40, 49, 52 and 75. 4) The filling ratio 20, 40, 60 and 80% of volume evaporation. Objectives of this study 1) Study of fill rate, hydraulic radius, type of working fluids, aspect ratios. The effect on the heat transfer characteristics of the vertical thermosyphon vertical position.	1) At filling ratios 20% volumetric evaporation. Thermosyphon flat at a 430 mm evaporation length and 4.6 mm flat, the heat flux is highest and the heat flux decreases with increasing filling ratios. 2) At a hydraulic radius of 1.7, the maximum flux value. 3) R123 used as working fluids. Has the lowest heat resistance. As a result, the flat thermosyphon using R123 as the working fluids had the highest heat flux. .	Something like a research topic to study 1) There are some variants of similar such as water. It different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular. 2) The working fluids used is; - DI-Water - Silver nanofluid concentration of 0.5wt% (NP) + surfactant concentration OA was 1wt%

Research-Researcher	Study	Results	Compared with research topics to study.
Bhuwakietkumjohn N and Rittidech S [36]. Internal flow patterns on heat transfer characteristics of a closed-loop oscillating heat-pipe with check valves using ethanol and a silver nano-ethanol mixture.	Scope of study 1) The number of check valves to the number of truns is equal to 0.2. (Check valves are 2 and 10) 2) The working fluids used is ethanol and silver nano-ethanol mixture. 3) The filling ratio 50% of total volume. 4) The closed-loop oscillating heat-pipe with check valves use glass pipe an internal diameter of 2.4 mm. 5) The evaporation length 50 and 100 mm. 6) The inclination angle was 90°. 7) Temperature evaporator 85, 105 and 125 °C Objectives of this study 1) To investigate the Internal flow patterns on heat transfer characteristics of a closed-loop oscillating heat-pipe with check valves using ethanol and a silver nano-ethanol mixture.	1) At 50 mm evaporation length using ethanol and silver nano-ethanol mixture as working fluids found at evaporation temperatures of 85ºC, the heating flux was 1.08 and 1.61 kW/m^2, respectively. The flow pattern found was composed of annular flow, but in small quantities. Slug flow is more abundant. It will notice the lower and middle parts of the evaporator. The working fluids is a silver nano-ethanol mixture. There will be a shorter length of slug bubble used as ethanol. And the speed of the slug bubble is over. 2) At 50 mm evaporation length using ethanol and silver nano-ethanol mixture as working fluids found at evaporation temperatures of 105ºC, the heating flux was 1.18 and 1.74 kW/m^2. The flow pattern found is composed of slug flow, but in small quantities. The bubble flow is in greater quantity. It will notice the central and upper parts of the evaporator. The working fluids is silver nano-ethanol mixture. There will be a shorter length of slug bubble used as ethanol. And the speed of the slug bubble is over. 3) At 50 mm evaporation length using ethanol and silver nano-ethanol mixture as working fluids found at evaporation temperatures of 125ºC, the heating flux was 1.31 and 2.04 kW/m^2. The flow patterns found are bubble flow, but in small quantities. It is noticeable at the bottom of the evaporator, where the bubble group merges and floats from the evaporator to the condensate. The working fluids is silver nano-ethanol mixture. There will be a shorter length of slug bubble used as ethanol. And the speed of the slug bubble is over.	Something like a research topic to study 1) There are some studies of variants of similar such as. nanoparticles It different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular. 2) The working fluids used is; - DI-Water - Silver nanofluid concentration of 0.5wt% (NP) + surfactant concentration OA was 1wt%

Research-Researcher	Study	Results	Compared with research topics to study.
		4) At 100 mm evaporation length using ethanol and silver nano-ethanol mixture as working fluids found at evaporation temperatures of 85ºC, the heating flux was 0.462 and 1.59 kW/m^2 respectively. The flow pattern found was composed of annular flow, but in small quantities, the slug flow was larger. It will notice the lower and middle parts of the evaporator. The working fluids of silver nano-ethanol mixture is shorter than that of ethanol as the working fluids. And the speed of the slug bubble is over. 5) At 100 mm evaporation length using ethanol and silver nano-ethanol mixture as working fluids found at evaporation temperatures of 105ºC, the heating flux was 0.582 and 1.627 kW/m^2 respectively. The flow pattern found was composed of slug flow, but in small quantities, the bubble flow was larger. It will notice the central and upper parts of the evaporator. The working fluids is silver nano-ethanol mixture. There will be a shorter length of slug bubble used as ethanol. And the speed of the slug bubble is over. 6) At 100 mm evaporation length using ethanol and silver nano-ethanol mixture as working fluids found at evaporation temperatures of 125ºC, the heating flux was 0.639 and 1.8 kW/m^2 respectively. The flow patterns found are bubble flow, but in small quantities. It will be noticed at the bottom of the evaporation section. The bubble group merges and floats from the evaporator to the condensate. The working fluids is silver nano-ethanol mixture. There will be a shorter length of slug bubble used as ethanol. And the speed of the slug bubble is over. 7) Nano fluid can improve the heat transfer rate due to higher thermal conductivity. By the nanoparticle, silver particles with small particles increase the surface and allow for more heat transfer. Affects boiling in the fluid	

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Research-Researcher	Study	Results	Compared with research topics to study.
Amatachaya P and Srimuang W [37]. Comparative heat transfer characteristics of a flat two-phase closed thermosyphon (FTPCT) and a conventional two-phase closed thermosyphon (CTPCT) .	Scope of study 1) Thermosyphon pipes are made of 32 mm internal diameter copper tubes. 3.5mm thick, 980 mm long and squeezed to a flat cross. 2) The tested thermosyphon has both circle and flat cross-sectional area. 3) Use water as a working fluids. 4) Aspect ratios 9.52, 12.56 and 15.08 for thermosyphon circular cross section area. 5) Aspect ratios 19.77, 26.09 and 36.32 for thermosyphon flat cross section area. 6) The filling ratio 30, 60 and 90% of total volume Objectives of this study 1) Study of cross sectional area (flat and circular), filling ratio and aspect ratios on the efficiency of thermosyphon.	1) At filling ratio 60%. Thermosyphon with a flat cross-section has higher thermal efficiency thermosyphon circular cross section. 2) Thermosyphon with circular cross section increased thermal efficiency following the increase of aspect ratio. And has the highest thermal efficiency at aspect ratios of 12.56 and will have a lower thermal efficiency of 15.08. 3) Thermosyphon flat area has increased thermal efficiency following the increase of aspect ratios. It has the highest thermal efficiency at aspect ratios of 26.09 and the thermal efficiency decreases to 36.32. .	Something like a research topic to study 1) There are some variants of similar such as water. It different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular. 2) The working fluids used is; - DI-Water. - Silver nanofluid concentration of 0.5wt% (NP) + surfactant concentration OA was 1wt%

Research-Researcher	Study	Results	Compared with research topics to study.
Paramatthanuwat T et al. [38]. Heat transfer characteristics of a two-phase closed thermosyphon using de ionized water mixed with silver nano.	Scope of study 1) The inclination angle was 90°. 2) The filling ratio 30, 50 and 80% of volume evaporation. 3) Thermosyphon is made of copper tubes with internal diameters of 7.5, 11.1 and 25.4 mm. 4) Aspect ratios 5, 10 and 20 5) Working fluid of silver nanofluid concentration (silver nanofluid) of 0.5% w/v and pure water. 6) Working temperature of 40, 50 and 60 °C. 7) Condenser water temperature constant at 20 ºC. 8) Flow rate of condensed water is 0.25 l/min. Objectives of this study 1) Effect of operating temperature, aspect ratios, inner diameter of pipe. The effect on the thermal performance of two-phase closed thermosyphon using de ionized water, de ionized water mixed with silver nano.	1) At an inner diameter of 25.4 mm. Thermosyphon using de ionized water mixed with silver nano has the highest heat transfer coefficient. And higher than thermosyphon using de ionized water. Throughout all the values of the inner diameter. (Consider Le/di = 5, working temperature = 50 ºC, filling ratio = 50%). 2) At aspect ratio 20. Thermosyphon using de-ionized water mixed with silver nano has the highest heat transfer coefficient. And higher than thermosyphon using de ionized water. Throughout all the values of aspect ratios. (Considering a diameter of 25.4 mm, working temperature = 50 ºC, filling ratio = 50%). 3) At working temperature = 60 ºC, Thermosyphon inner diameter 25.4 mm using de ionized water mixed with silver nano. The maximum heat transfer rate (Consider Le/di = 5, filling ratio = 50%). 4) At filling ratio 50% of volume evaporation. The best heat transfer value. Both of the thermosyphon using de ionized water, de ionized water mixed with silver nano.	Something like a research topic to study 1) There are some variants of similar such as using de-ionized water, de ionized water mixed with silver nano. It different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular. 2) The working fluids used is; - DI-Water. - Silver nanofluid concentration of 0.5wt% (NP) + surfactant concentration OA was 1wt%

Research-Researcher	Study	Results	Compared with research topics to study.
Paramatthanuwat T et al. [39]. Application of silver nanofluid containing oleic acid surfactant in a thermosyphon economizer.	Scope of study 1) Use thermosyphon inner diameter 12.7 mm. 2) At the evaporation length, the adiabatic and condensate The three equal lengths are 250 mm. 3) The filling ratio 30, 50 and 80% of volume evaporation. 4) The volumetric flow rates for the coolant (in the condenser) were 1, 2.5 and 5 l/min. 5) Working fluid of silver nanofluid concentration (silver nanofluid) of 0.5% w/v (NP). 6) Working fluid of pure water. 7) Working fluid of NP + surfactant concentration OA was 0.5, 1 and 1.5% w/v. 8) Water temperature at condensation 25 ºC. Objectives of this study Design and test thermosyphon economizer. In order to increase heat transfer to water. By heating is beneficial to increase the efficiency of the thermosyphon economizer.	1) At working temperatures of 60, 70 and 80ºC. The working fluids is NP + surfactant concentration OA was 1% w/v. There will be a higher thermal flux than any working fluids used in the test throughout the working temperature range. And at a working temperature of 80ºC, it has the highest thermal flux. (Flow rate of condensed water is 1 l/min, the filling ratio 50 of volume evaporation). 2) At filling ratio 30, 50 and 80% of volume evaporation. The working fluids is NP + surfactant concentration OA was 1% w/v. It has a higher thermal flux than any test working fluids. Throughout all the filling ratio. And filling ratio 50% of volume evaporation. It has the highest heat flux. (Use flow rate of condensed water is 1 l/min. at 80ºC operating temperature). 3) At volumetric flow rate. The heat flux is higher due to the increase in volumetric flow rate. The working fluids is NP + surfactant concentration OA was 1% w/v. It has a higher thermal flux than any test working fluids. Throughout all volumetric flow rates. And flow rate of condensed water is 5 l/min. It has the highest heat flux. (At working temperatures 80ºC, The filling ratio 50% of volume evaporation).	Something like a research topic to study 1) There are some variants of similar such as The working fluids used is; - DI-Water. - Silver nanofluid concentration of 0.5wt% (NP). + surfactant concentration OA was 1% w/v. It different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular.

Research-Researcher	Study	Results	Compared with research topics to study.
Paramatthanuwat T et al. [18]. Experimental investigation on thermal properties of silver nanofluids.	Scope of study 1) The working fluids used is; - Silver nanofluid concentration of 0.5 wt% (NP) - NP + surfactant concentration OA was 0.5, 1 and 1.5wt%. - NP + surfactant concentration OAK^+ was 0.5, 1 and 1.5wt%. - DI-Water. 2) Operating temperatures are 20, 30, 40, 50, 60, 70 and 80ºC. Objectives of this study The properties of the test working fluids, such as thermal conductivity, specific heat, viscosity, contact angle, flow behaviour. (Relationship of shear stress and shear rate).	1) Silver nanofluid concentration of 0.5 wt% NP + surfactant concentration OAK^+ was 1wt% has the best thermal conductivity of the experiment of all operating temperature ranges. 2) By adding surfactants. Viscosity and shear stress are reduced with increasing temperature. Viscosity and shear stress affect the flow of working fluids. 3) NP + surfactant concentration OA. It has a higher specific heat than water. 4) NP + surfactant concentration OAK^+ was 1wt%. Best contact angle is 38.23º. By the contact of the working fluids, Oleic fillers are good wetting agents and improve colloidal stability. Potassium ions (K^+) increase the length of time that does not precipitate.	Something like a research topic to study 1) There are some variants of similar such as The working fluids used is; - DI-Water. - Silver nanofluid concentration of 0.5 wt% (NP) + surfactant concentration OA was 1wt%. It different with the research topic studied. 1) The shape of the thermosyphon tube is rectangular. 2) A study flow patterns.

Research-Researcher	Study	Results	Compared with research topics to study.
Bhuwakietkumjohn N and Parametthanuwatt T [3]. Heat transfer behaviour of silver particles containing oleic acid surfactant: application in a two phase closed rectangular cross sectional thermosyphon (RTPTC).	Scope of study 1) Aspect ratio was 5, 10 and 20 2) The heat supplied 20, 40, 60, 80 and 100 % from heater 2000 W 3) The working fluids used is; De-ionized water, de-ionized water mixed silver nanoparticles concentration of 0.5 wt% (NP) respect to total volume of water, NP containing 0.5, 1 and 1.5 wt% of oleaic acid (OA) respect to total volume NP. 4) Diameter of stainless tube (AISI-304) was 25.4 mm. 5) The velocity of air inlet of condenser section is at 0.6 m/s. 6) The wetted perimeter of TPCT and RTPCT were equal. 7) The filling ratio was 30, 50 and 80 % respect to the evaporator section volume. Objectives of this study Heat transfer rate, Relative thermal efficiency, Thermal resistance, Heat transfer coefficient of two phase closed rectangular cross sectional thermosyphon.	Consider the heat transfer rate. 1) The heat supplied 100 % from heater 2000 W to evaporator of the thermosyphon. Aspect ratio was 20. The filling ratio was 50% respect to the evaporator section volume. It was found that the working fluids used as NP containing 1wt% of oleaic acid (OA) respect to total volume NP used in RTPCT had the highest rate of heat transfer. Compared to RTPCT used in the experiments. 2) At the filling ratio was 50% respect to the evaporator section volume. Aspect ratio was 20 and the heat supplied 100 % from heater 2000 W to evaporator of the thermosyphon. It was found that the working fluids used as NP containing 0.5, 1 and 1.5 wt% of oleaic acid (OA) respect to total volume NP used for RTPCT. It has the highest heat transfer rate. Compared to RTPCT using other working fluids in the experiment. 3) Aspect ratio was 20, The filling ratio was 30, 50% respect to the evaporator section volume, The heat supplied 100 % from heater 2000 W. It was found that the working fluids used as NP containing 0.5, 1 and 1.5 wt% of oleaic acid (OA) respect to total volume NP used with RTPCT pipe has the highest heat transfer rate. Compared to RTPCT used in the experiments. Consider the heat resistance. 4) All tested aspect ratios of 5,10 and 20 use NP containing 1 and 1.5 wt% of oleaic acid (OA) respect to total volume NP as the working fluids with RTPCT. Has the lowest heat resistance. Compared to other RTPCT used in the experiments. It was found that the increased aspect ratios increased slightly the heat resistance. Which has a similar look at all the samples tested.	Something like a research topic to study 1) There are some variants of similar such as The working fluids used is; - DI-Water. - Silver nanofluid concentration of 0.5 wt% (NP) + surfactant concentration OA was 1 wt%. It different with the research topic studied. 1) A study flow patterns.

Research-Researcher	Study	Results	Compared with research topics to study.
		5) All the heat supplied 20, 40, 60, 80 and 100 % from heater 2000 W. The working fluids used is NP containing 1 wt% of oleaic acid (OA) respect to total volume NP used with RTPCT has the lowest heat resistance. Compared to other RTPCT used in the experiments. And it was found that The heat supplied 100 % from heater 2000 W. It will cause the lowest heat resistance value, which has similar characteristics of all tested samples. heat resistance. Compared to other RTPCT used in the experiments. It was found that the increased aspect ratios increased slightly the heat resistance. Which has a similar look at all the samples tested.	

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CHAPTER 3

Methodology

In order for the experiment to proceed properly and achieve the objectives. Therefore, it is important to know the variable used in the experiment. Experimental set, experimental procedure and analysis of experimental results. This is explained in detail below.

3.1 Variable used in the experiment.
3.2 Building the two - phase closed rectangular sectional thermosyphon.
3.3 Nanofluid preparation.
3.4 Experiment set.
3.5 Equipment and tools used in experiments.
3.6 Installation procedure and experimental.
3.7 Analysis of experimental results.

3.1 Variable used in the experiment

3.3.1 Independent variables [3]
3.3.1.1 The working fluids were
1) De-ionized water.
2) De-ionized water mixed silver nanoparticles concentration of 0.5 wt% (NP) respect to total volume of water containing 1 wt% of oleic acid (OA) respect to total volume NP.
3.3.1.2 The aspect ratios were 5 and 20.
3.3.1.3 The evaporator temperature 50, 70 and 90 °C.
3.3.1.4 The inclination angles were 0, 80 and 90°.
3.3.1.5 The two-phase closed rectangular and circular cross sectional thermosyphon made by Pyrex tube an inner diameter of 7 and 25.2 mm.
3.3.2 Dependent variables
3.3.2.1 The average length of bubble.
3.3.2.2 The average speed of bubble.
3.3.2.3 The heat transfer rate.
3.3.2.4 The internal flow patterns of the two - phase closed rectangular and circle cross sectional thermosyphon.
3.3.3 Control variables
3.3.3.1 Temperature water of the condenser section was 20 °C.
3.3.3.2 The mass flow rate of feed water was 0.25 l/min.
3.3.3.3 The filling ration was 50% with respect to evaporator section.

3.2 Building the two-phase closed rectangular sectional thermosyphon

The process of building the following.
3.2.1 Change the two-phase circular cross sectional thermosyphon (TPCT) to the two - phase rectangular cross sectional thermosyphon (RTPCT). The body shape

of the change of TPCT to RTPCT can be determined by the wetted perimeter [3] as shown in Figure 3.1.

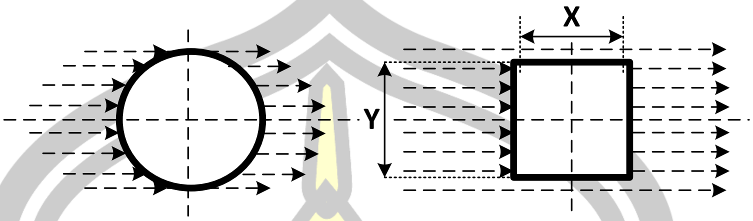

Figure 3.1 Outside surface area of fluid flow/Wetted perimeter [3].

The wetted perimeter [3], can be calculated from equation (3.1).

$$W_p = \pi Y + 2x \qquad (3.1)$$

3.2.2 Select the rectangular cross sectional pipe to be approximately the same size as calculated by the wetted perimeter. As shown in Figure 3.2.

Figure 3.2 The rectangular cross sectional pipe.

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3.2.3 Close pipe head with a copper plate. Small tubes are used for vacuuming the pipe and filling working fluids. As shown in Figure 3.3.

Figure 3.3 The rectangular cross sectional pipe with installation Copper plate and small tubes.

3.2.4 Make a vacuum inside the pipe and filling the working fluids.

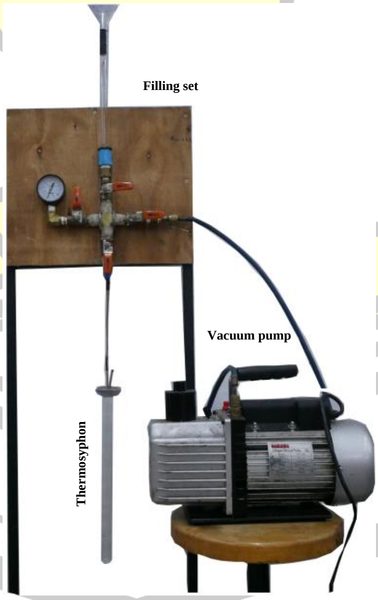

Figure 3.4 The vacuum inside the two phase closed thermosyphon and fill working fluids by the filling set.

3.2.5 When complete the steps. will get the two - phase rectangular cross sectional thermosyphon (RTPCT). as shown in Figure 3.5.

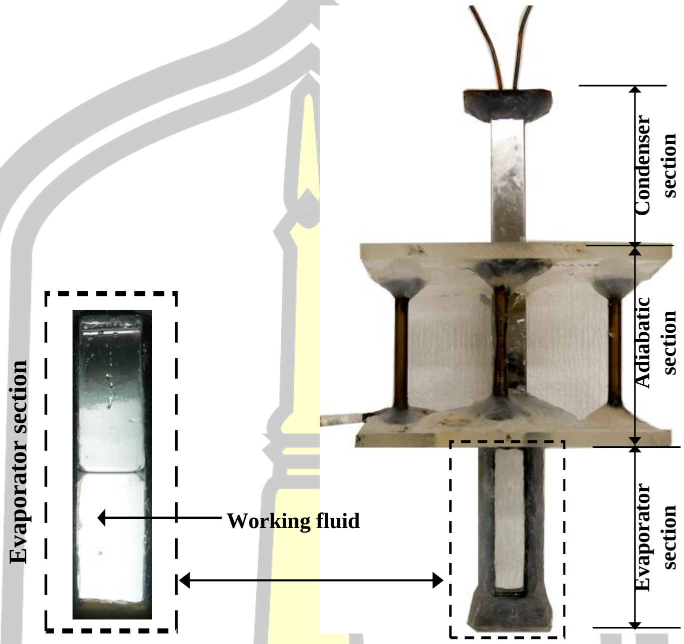

Figure 3.5 The two - phase rectangular cross sectional thermosyphon (RTPCT).

3.3 Nanofluid preparation

For this research, the nanofluid was prepared in a sonicator (Bath type, operating frequency and power source of the sonicator are 43 kHz and AC100 ~120V/AC220~240V 50/60Hz, respectively.) for 6 hours. Nanoparticles were prepared by a SIGMA-ALDRICH, Inc, USA. Firstly, Silver nanopowder < 100 nm particle size, 99.9% (metals basis) were suspended into deionized water with concentrations of 0.5 wt%. Secondly, silver nanoparticles were suspended into de-ionized water with concentrations of 0.5 wt% mixed with oleic acid (surfactant) concentration of 1 wt%. and mixed with potassium oleate (surfactant) concentration of 1 wt% [9].

3.4 Experiment Setup

3.4.1 The TPCT and RTPCT used in the experiment is made by Pyrex tube. It has heat resistant properties. It is divided into 3 parts, evaporator section, adiabatic section and condenser section, as shown in Figure 3.6. The length of the evaporation section length of the adiabatic section and length of the condenser section are the same length.

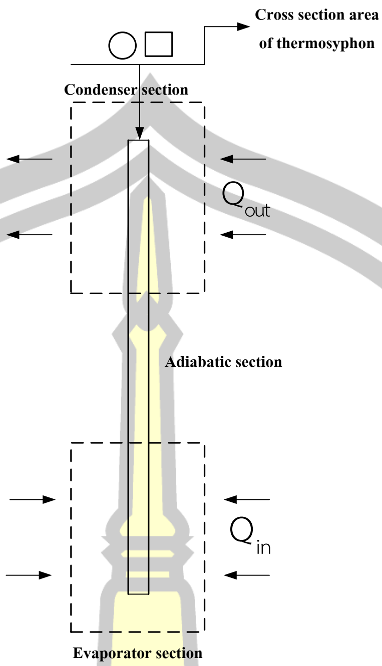

Figure 3.6 The two-phase closed circular cross sectional thermosyphon (TPCT) and rectangular cross sectional thermosyphon (RTPCT) [3].

3.4.2 Hot jacket in the evaporation section and cold jacket in the condenser section. made of clear acrylic. This is used to record fluid flow behavior within the thermosyphon. Supply and cooling will use water to circulate in both the evaporator and the condenser. As shown in Figure 3.7.

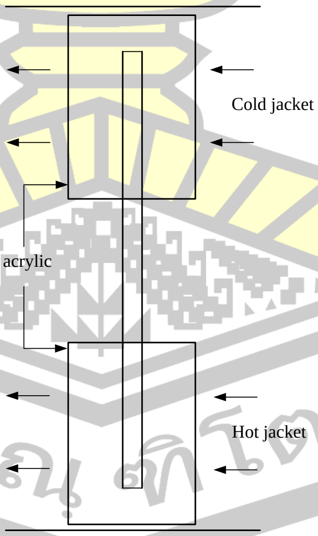

Figure 3.7 Supply and cooling in both the evaporator and the condenser.

3.4.3 The experimental setup. As shown in Figure 3.8. Schematic diagram of Experimental apparatus.

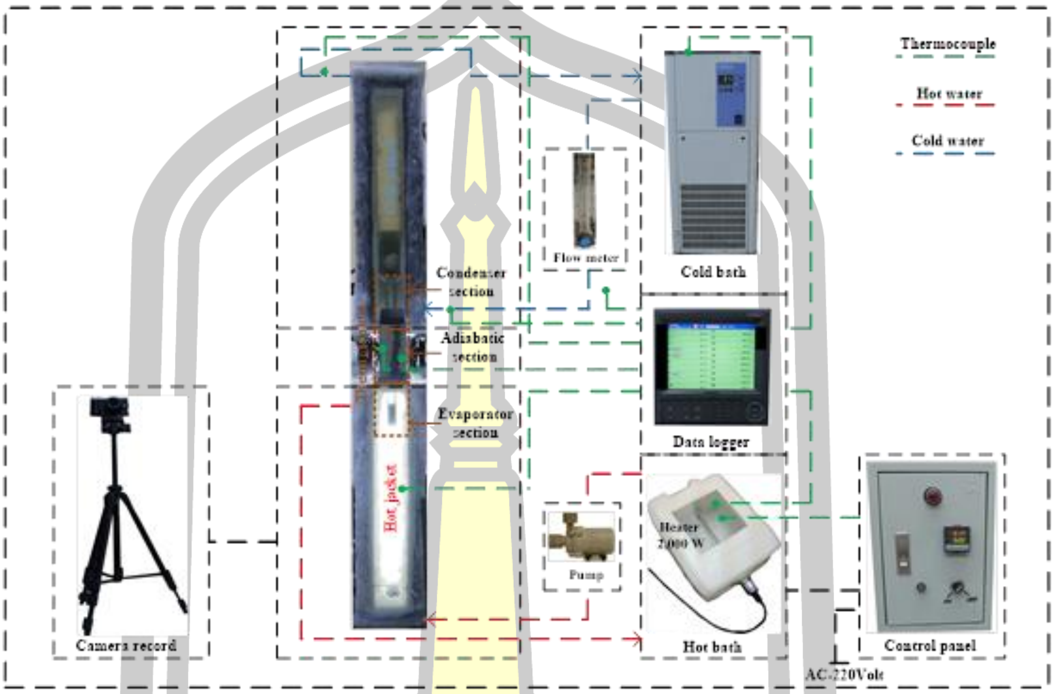

Figure 3.8 Schematic diagram of experimental apparatus.

Figure 3.8 Schematic diagram of experimental apparatus which of the TPCT and RTPTC. The parameters in this study consisted of the RTPCT and TPCT made by Pyrex tube with an inner diameter of 7 and 25.2 mm, the working fluids were de-ionized water, de-ionized water mixed silver nanoparticles concentration of 0.5 wt% (NP) respect to total volume of water containing 1wt% of Oleic acid (OA) respect to total volume NP and the filling ration was 50% with respect to evaporator section respectively. The evaporator section temperatures were 50, 70, and 90 °C, the aspect ratio were 5 and 20. The inclination angle were 0, 80 and 90° from the horizontal. The condenser section temperature was 20 °C. The mass flow rate of feed water was 0.25 liter/min. In the experiments as show in Figure 3.8 the evaporator section of TPCT soaked in the hot water within the glass box. The heat from the heater is controlled by temperature control. The condenser section of TPCT is cooled by cold water and control flow rate of cold water with flow meter. Temperature data were measures by 9 points type k-thermocouples with accuracy and Record by Data logger (Yokogawa DX200) with accuracy. The flow meter used is Disco-BBBW1B98 with accuracy. The point in temperature measurement consists, 1 point in hot water at the evaporator section, 2 points in the hot bath by 1 point connect with the temperature control and 1 point connect with the Data logger, 2 points at the adiabatic section, 1 point for environment, 1 point at inlet water of the condenser section, 1 point at outlet water of the condenser section and 1 point at the cold bath. By the outlet and inlet water temperature of the condenser section. It is used to determine the heat transfer rate that can be obtained from equation 3.2.

$$Q = \dot{m}C_p(T_{co} - T_{ci}) \tag{3.2}$$

Thus the;

$$Q = f(\dot{m}, T_{co}, T_{ci}) \tag{3.3}$$

By Q is heat transfer rate, W
$\dot{m}$ is mass flow rate, kg/s
C_p is specific heat capacity, kJ/kg·°C
T_{co} is outlet water temperature at the condenser, °C
T_{ci} is inlet water temperature at the condenser, °C

For by heat transfer rate per unit area [1] obtainable from.

$$q = \frac{Q}{A_c} = \frac{Q}{\pi D_o L_c N} \tag{3.4}$$

By q is heat transfer rate per unit area, W/m^2
Q is heat transfer rate, W
D_o is outer diameter of the pipe, m
A_c is total surface area in condensate, m^2
L_c is condensed length, m
N is number of rods of condensed heat pipe

Error analysis of the heat transfer [9], can be obtained from;

$$Q = \left[\left(\frac{\partial Q}{\partial \dot{m}} x\ \dot{m}\right)^2 + \left(\frac{\partial Q}{\partial T_{co}} x\ T_{co}\right)^2 + \left(\frac{\partial Q}{\partial T_{in}} x\ T_{in}\right)^2\right]^{0.5} \tag{3.5}$$

3.5 Equipment and tools used in the experiment

3.5.1 Data logger was used to measure the temperature at any point and to record the data, the YOKOGAWA DX200 model, 20 channels, has a temperature range of -200 - 1100 °C with a resolution of ± 0.1 °C. As shown in Figure 3.9.

Figure 3.9 Data logger

3.5.2 Thermocouple, OMEGA model, Type-K. For measuring the temperature difference between inlet and outlet water at the condenser, adiabatic surface temperature, hot water evaporator temperature, environmental temperature, cold water temperature at cold bath and the hot water temperature at the hot bath. As shown in Figure 3.10.

Figure 3.10 Thermocouple

3.5.3 Filling working fluids set, Used to filling working fluids. It is connected to a vacuum pump to vacuum within the thermosyphon. Includes pressure gauge and glass tube for measuring the amount of filling working fluids. As shown in Figure 3.11.

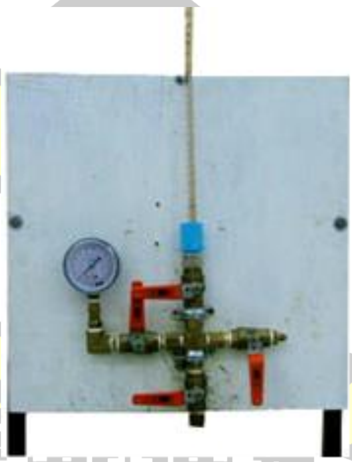

Figure 3.11 Filling working fluids set

3.5.4 Vacuum pump, Brand: 1 Stage Vacuum Pump (VE135) 3.5 CFM compressed air volume 5 Pa. The vacuum pump is used for making vacuum inside the thermosyphon. Before filling the working fluids. As shown in Figure 3.12.

Figure 3.12 Vacuum pump

3.5.5 Video camera, Fuji film Fuji HS10 30-x focus lens 10.3 megapixel resolution. Full HD movies (1,920x1,080). Used to record the flow pattern of thermosyphon. As shown in Figure 3.13.

Figure 3.13 Video camera

3.5.7 Flow meter, Brand LZT Model M-15, Accuracy of 4%, Used to measure the flow of water at the entrance of the condenser. As shown in Figure 3.14.

Figure 3.14 Flow meter

3.5.8 Cold bath is used to control the water temperature before entering condenser section. The model used is an EYELA CA -1111, an operating temperature range of -20 °C to 30 °C and ±2 °C, as shown in Figure 3.15.

Figure 3.15 Cold bath

3.5.9 Hot bath made of heat-resistant plastic. Install heater 2000 watts for heating. As shown in Figure 3.16.

Figure 3.16 Hot bath

3.5.10 High Temperature Water Pump DC 12 volt. Maximum flow rate: 8 L/min (2.1GPM). Maximum water temperature: 100 °C. As shown in Figure 3.17.

Figure 3.17 Pump DC 12 volt

3.6 Installation Procedure and experimental

3.6.1 Vacuum and filling the working fluids into the TPCT and RTPCT.

3.6.2 Assemble the TPCT, RTPCT and experimental kits into the experimental stand.

3.6.3 Installation of measuring instruments and video cameras.

3.6.4 Turn on the Back Light. In order to clearly see the flow pattern inside.

3.6.5 Turn on the hot bath switch and the hot water will be sent in the evaporator. And adjust the voltage as set in the variable.

3.6.6 Turn on the water cooler (cold bath). The cold water is sent to the condenser.

3.6.7 When the system enters a steady state, record video with a video camera and still images with a digital camera.

3.6.8 Record the temperature difference between inlet and outlet water at the condenser, adiabatic surface temperature, hot water evaporator temperature, environmental temperature, cold water temperature at cold bath and the hot water temperature at the hot bath with temperature recorder.

3.6.9 Experiment from the first to the last. To the extent prescribed. All experiments were completed.

3.7 Analysis of the results

3.7.1 A study of factors affecting the internal flow pattern and heat transfer characteristics of rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT). Apply techniques and theories. Used to analyze the results.

3.7.2 The experimental results obtained from the observation of video and photographs were compared with the two phases flow pattern theory in vertical and horizontal tubes. To summarize the internal flow patterns of the rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT), respectively.

3.7.3 The average length of the bubble (L_v) analyzes the average length of the bubble from the photo obtained from the digital camera. It measures the length of the bubble in the axial direction of the rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT). And then gives the average length of the bubble.

3.7.4 The average velocity of the bubbles (u_g) is the average velocity of the bubbles analyzed by the motion picture obtained from the video camera. Analyze the internal flow patterns that occur. The video camera can control the movement of the image to speed or slow, as you want. This makes it possible to calculate the velocity of the bubbles. The internal flow pattern will be measured from the start of the vapors in the evaporator section until the bubbles float through the adiabatic section to the condensate section, respectively.

3.7.5 Analyze data for heat transfer. Calorimeter is calculated from equation.

$$Q = \dot{m}C_p(T_{CO} - T_{Ci}) \tag{3.8}$$

By Q is heat transfer value, W
$\dot{m}$ is mass flow rate, kg/s
C_p is specific heat capacity, kJ/kg·°C
T_{CO} is condensate water outlet temperature, °C
T_{Ci} is condensate water inlet temperature, °C

Heat transfer rate per unit area, Find the equation.

$$q = \frac{Q}{A_c} = \frac{Q}{\pi D_o L_c N} \tag{3.9}$$

By q is heat transfer rate per unit area, W/m^2
Q is heat transfer value, W
D_o is outside diameter of pipe, m
A_c is total surface area condensate, m^2
L_c is length in the condenser, m
N is number of thermosyphon in the condenser

3.7.6 The data from the experimental results were used to create a flow pattern map for predicting the behavior of internal flow patterns and grouping flow patterns relative to momentum flux in vapor states and momentum flux in liquid states. Find the equation.

The liquid momentum flux is determined by the equation.

$$\rho_l u_l^2 = \frac{[G(1-X)]^2}{\rho_l} \tag{3.10}$$

The gas momentum flux is determined by the equation.

$$\rho_g u_g^2 = \frac{[Gx]^2}{\rho_g} \tag{3.11}$$

By G is mass flux, kg/s·m^2
x is vapor quality
ρ_g is density of working fluids in vapor phase, kg/m^3
ρ_l is density of working fluids in liquid phase, kg/m^3

Vapor quality is the proportion of total flow. This is usually thought of as a vapor phase. Find the equation.

$$x = \frac{G_g}{G} = \frac{G_g}{G_g + G_l} \tag{3.12}$$

The quality of the vapor can be calculated from the enthalpy or the specific volume of two phase and enthalpy. The specific volume of the liquid is saturated and the vapor phase. As shown in equation.

$$x = \frac{h_{TP} - h_l}{h_g - h_l} = \frac{V_{TP} - V_l}{V_g - V_l} \tag{3.13}$$

By h_{TP} is enthalpy of two phase, J/kg
h_l is enthalpy in liquid phase, J/kg
h_g is enthalpy in vapor phase, J/kg
V_{TP} is specific volume of two phase, m^3/kg
V_l is specific volume of liquid phase, m^3/kg
V_g is specific volume of vapor phase, m^3/kg

Flux Mass of two phase flow is the mass flowing through space per unit time. Find the equation.

$$G = G_g + G_l \tag{3.14}$$

Liquid mass flux is the product of the liquid density and the surface velocity of the working fluids in the liquid phase. Find the equation.

$$G_l = \rho_l u_l \tag{3.15}$$

Vapor mass flux is the product of the vapor density and the superficial velocity of the working fluids in the vapor phase. Find the equation.

$$G_g = \rho_g u_g \tag{3.16}$$

By u_l is the superficial velocity of working in the liquid phase, m/s
u_g is the superficial velocity of working in the vapor phase, m/s
G_l is liquid mass flux, kg/s·m^2
G_g is vapor mass flux, kg/s·m^2

Superficial velocity of working in the liquid phase. Find the equation.

$$u_l = \frac{\dot{V}_l}{A_s} = \frac{u_l A_s}{A_s} \tag{3.17}$$

Superficial velocity of working in the vapor phase. Find the equation.

$$u_g = \frac{\dot{V}_g}{A_s} = \frac{u_g A_s}{A_s} \tag{3.18}$$

By u_l is the superficial velocity of working in the liquid phase, m/s
u_g is the superficial velocity of working in the vapor phase, m/s
$\dot{V}_l$ is volumetric flow rate of the working fluids in the liquid phase, m^3/s
$\dot{V}_g$ is volumetric flow rate of the working fluids in the vapor phase, m^3/s
A_s is cross-sectional area flow of working fluid, m^2

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CHAPTER 4

Results and Discussion

From studying about the effect of working fluid, aspects ratio, the evaporator temperature, inner diameter and inclination angle to flow patterns and heat transfer rate of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT). By two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT) made of heat-resistant glass tube inner diameters of 7 and 25.2 mm. Aspect ratio was 5, the inclination angles were 0, 80 and 90°, the evaporator temperature were 50, 70 and 90 °C, the filling ration was 50% with respect to evaporator section and temperature water of the condenser section was 20 °C and the mass flow rate of feed water was 0.25 l/min. The working fluids were De-ionized water, de-ionized water mixed silver nanoparticles concentration of 0.5 wt% (NP) respect to total volume of water containing 1 wt% of oleic acid (OA) respect to total volume NP.

For photography, the internal flow pattern obtained from the experiment will show only the image within the evaporator section of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT). Which will select the photos that have the behavior of boiling and flow caused by changing the flow pattern clearly.

4.1 The work and behavior of flow patterns within two phase closed thermosyphon

Flow behavior within two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT) as shown in Figure 4.1 starts from the heat that evaporates through the pipe wall. The temperature of the pipe surface will gradually rise to higher than the saturation temperature of the working fluids. The heat transfer from the pipe wall to the working fluids. Resulting in a decrease in the viscosity and density of the working fluid when the temperature of the evaporator increases. The temperature difference between the pipe surface temperature and the temperature of the working fluids will also increase as well. The formation of a vapor bubble and the movement of the fluid up. It is a bubble flow with the accumulation of energy in the form of velocity and pressure. By increasing velocity of bubble flow, resulting in a vapor bubble colliding and gathering together. Resulting in the expansion of the vapor bubble until it is larger in size, which is similar to the bearing, also known as the slug flow. When there is a collision between lumps, it changes the flow pattern from the slug flow pattern to the churn flow. When the speed of the bubble has a very high speed, it will cause a gap in the middle of the pipe. Which the gas is flowing in the middle of the pipe and there is the working fluids that is a liquid film on the surface of the pipe, also known as annular flow. From the flow pattern mentioned above is considered a basic flow pattern found in testing with two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circular cross sectional thermosyphon (TPCT) at the angle of 80 and 90° as shown in Figure 4.2. In addition also found stratified flow patterns and vortex flow patterns occurring with the TPCT test within the inner diameter of 25.2 mm at the inclination angles of 80 and 90° respectively, use working fluids while testing is de-ionized water mixed silver nanoparticles concentration of 0.5 wt% (NP) respect to total volume of water containing 1 wt% of oleic acid (OA) respect to total volume NP. With a vortex flow pattern found at the inclination angle of 90° evaporation temperature 70 and 90 °C. Which the flow characteristics of the vapor are moving near the surface of the inner tube on both sides, by the gap in the middle of the pipe is the fluid part which the gap in the middle of the pipe is found to be the characteristic of the working fluids that is in the liquid phase that flows back from the condensation that condenser section into the evaporator section. In terms of stratified flow there will be a clear separation from each other. There is a liquid flow at the bottom of the pipe and the vapor will flow along the top of the pipe [33] as shown in Figure 4.2. The flow pattern that occurs will move up to heat the condenser section. When the working fluids is condensed and changed from vapor to liquid as a result, the working fluids has increased weight and moved down to the gravity to get the heat that the evaporator section is a continuous working cycle.

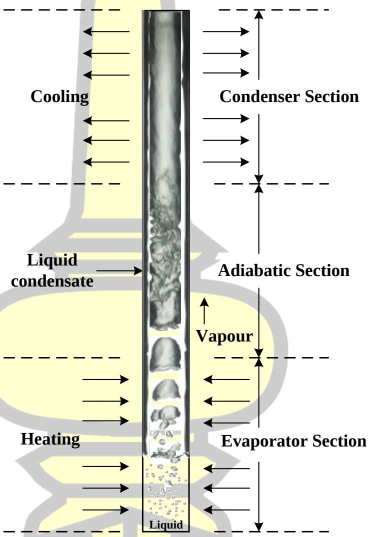

Figure 4.1 The working of two-phase closed thermosyphon.

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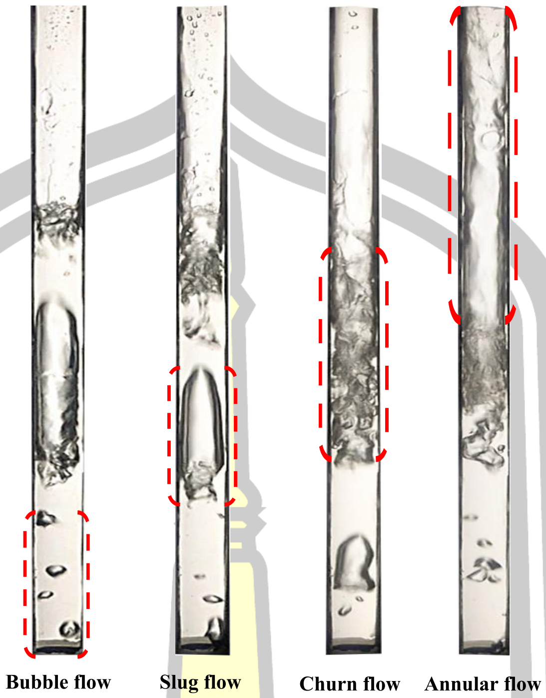


Figure 4.2 Behavior of flow patterns; bubble flow, slug flow, churn flow and annular flow.

Figure 4.3 Behavior of flow patterns; stratifield flow and vortex flow.

4.2 Effect of the evaporator temperature and aspect ratio on flow patterns of two-phase closed rectangular cross sectional thermosyphon (RTPTC)

From Table 4.1, the effect of evaporator temperature 90, 70 and 50 °C, aspect ratio was 20 and the inclination angle of 90°. The working fluids used is water tested with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm. From the test found that at the evaporator temperature 90 °C, found were four flow patterns consists of bubble flow pattern (BF) formed a flow pattern of 0.52% and the average velocity of the bubble and the average length of the bubble is 0.063 m/s, 0.0054 m respectively. Slug flow pattern (SF) formed a flow pattern of 11.73% and the average velocity of the bubble and the average length of the bubble is 0.122 m/s, 0.0369 m respectively. Churn flow pattern (CF) formed a flow pattern of 15.96% and the average velocity of the bubble and the average length of the bubble is 0.134 m/s, 0.074 m respectively and annular flow pattern (AF) formed a flow pattern of 32.12% and the average velocity of the bubble and the average length of the bubble is 0.162 m/s, 0.125 m respectively. No flow pattern was found at 20.26%. Which the velocity of the flow pattern will tend to increase as the flow pattern changes from the bubble flow pattern, slug flow pattern, churn flow pattern and annular flow pattern. In the case of no flow pattern. When considering the heat transfer value obtained from the experiment, it is lower than the theoretical heat transfer value. Causes the convection coefficient that should be caused by the experiment in the two-phase flow pattern is lower than the theoretical value. Which convection coefficient has a direct impact on the no flow patterns. Together with the area of the formation of two - phase flow patterns consisting of gas phase and liquid phase in which the liquid phase is directly affected by the no flow patterns.

From the consideration of evaporator temperature 70 °C as shown in table 4.1 found were four flow patterns consists of bubble flow pattern (BF), slug flow pattern, churn flow pattern (CF) and annular flow pattern (AF) respectively. Bubble flow pattern (BF) formed a flow pattern of 0.78% and the average velocity of the bubble and the average length of the bubble is 0.05 m/s, 0.0072 m respectively. Slug flow pattern (SF) formed a flow pattern of 12.17% and the average velocity of the bubble and the average length of the bubble is 0.0095 m/s, 0.0367 m respectively. Churn flow pattern (CF) formed a flow pattern of 13.69% and the average velocity of the bubble and the average length of the bubble is 0.11 m/s, 0.060 m respectively and annular flow pattern (AF) formed a flow pattern of 25.52% and the average velocity of the bubble and the average length of the bubble is 0.13 m/s, 0.120 m respectively. No flow pattern was found at 47.84%. Also found that at the evaporator temperature of 50 °C, heat transferred from the hot jacket to the evaporator section and pass through the wall pipe to the working fluids is not high enough. Which the bonding force between the molecules of the working fluids with the particles that are the internal components of the RTPCT pipe with a high value. Therefore, the heat at the evaporator temperature of 50 °C through the wall of the pipe into the working fluids cannot destroy the bond between the molecules of the working fluids causing the flow pattern to not be found.

Table 4.1 Effect of the evaporator temperature 50, 70 and 90 °C, aspect ratio was 20 and the inclination angle was 90°. The working fluids is water tested with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm.

The evaporator temperature was 90 °C													
annular flow			Churn flow			Slug flow			Bubble flow			Q (W)	q (kW/m^2)
%	U_g (m/s)	L_v (m)	%	U_g (m/s)	L_v (m)	%	U_g (m/s)	L_v(m)	%	U_g(m/s)	L_v(m)		
32.12	0.162	0.125	15.96	0.134	0.074	11.73	0.122	0.0369	0.52	0.063	0.0054		
												77.65	1.52

Table 4.1 (continuous) Effect of the evaporator temperature 50, 70 and 90 °C, aspect ratio was 20 and the inclination angle was 90°. The working fluids is water tested with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm.

The evaporator temperature was 70 °C													
Annular flow			Churn flow			Slug flow			Bubble flow			Q(W)	q(kW/m^2)
%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)		
25.52	0.130	0.120	13.69	0.110	0.060	12.17	0.095	0.0367	0.78	0.050	0.0072		
												25.62	0.50

Table 4.2 Effect of the evaporator temperature 50, 70 and 90 °C, aspect ratio was 5 and the inclination angle was 90°. The working fluids is water tested with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm.

The evaporator temperature was 90 °C										
Churn flow			Slug flow			Bubble flow			Q(W)	q(kW/m^2)
%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)		
17.34	0.208	0.053	7.4	0.185	0.0217	6.32	0.089	0.0051		
									33.29	2.60

From Table 4.2 the effect of evaporator temperature 90 70 and 50 °C, aspect ratio was 5 and the inclination angle of 90°. The working fluids used is water tested with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm. From the test found that at the evaporator temperature 90 °C found were three flow patterns consists of bubble flow pattern (BF) formed a flow pattern of 6.32 % and the average velocity of the bubble and the average length of the bubble is 0.089 m/s, 0.0051 m respectively. Slug flow pattern (SF) formed a flow pattern of 7.40 % and the average velocity of the bubble and the average length of the bubble is 0.185 m/s, 0.0217 m respectively. Churn flow pattern (CF) formed a flow pattern of 17.34 % and the average velocity of the bubble and the average length of the bubble is 0.208 m/s, 0.053 m respectively. From the percentage data of the flow pattern, the velocity of the average flow pattern which churn flow pattern is the flow pattern that found the percentage of high flow pattern formation and has a higher moving velocity than slug and bubble flow patterns. And no flow pattern is found 68.94 %. When considering the evaporator temperature 70 °C as shown in Table 4.2 found were three flow patterns consists of bubble flow pattern (BF) formed a flow pattern of 4.07 % and the average velocity of the bubble and the average length of the bubble is 0.090 m/s, 0.0049 m respectively. Slug flow pattern (SF) formed a flow pattern of 5.17 % and the average velocity of the bubble and the average length of the bubble is 0.180 m/s, 0.0202 m respectively. Churn flow pattern (CF) formed a flow pattern of 13.24 % and the average velocity of the bubble and the average length of the bubble is 0.198 m/s, 0.041 m respectively and no flow pattern is found 77.55 %. Also found that at the evaporator temperature of 50 °C, heat transferred from the hot jacket to the evaporator section and pass through the wall pipe to the working fluids is not high enough. Which the bonding force between the molecules of the working fluids with the particles that are the internal components of the RTPCT pipe with a high value. Therefore, the heat at the evaporator temperature of 50 °C through the wall of the pipe into the working fluids cannot destroy the bond between the molecules of the working fluids causing the flow pattern to not be found.

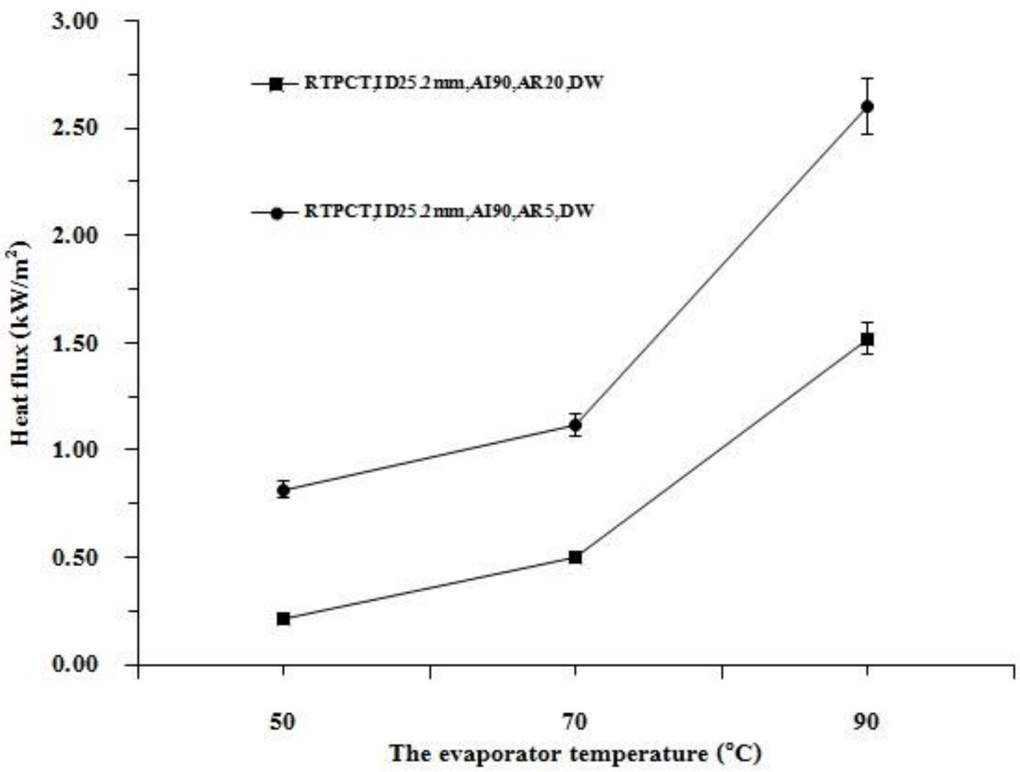
Table 4.2 (continuous) Effect of the evaporator temperature 50, 70 and 90 °C, aspect ratio was 5 and the inclination angle was 90°. The working fluids is water tested with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm.

The evaporator temperature was 70 °C										
Churn flow			Slug flow			Bubble flow			Q(W)	q(kW/m^2)
%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)		
13.21	0.198	0.041	5.17	0.180	0.0202	4.07	0.090	0.049		
									14.29	1.12

When considering the comparison of aspect ratio were 5 and 20 which affects the flow pattern of two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm. It was found that the bubble flow pattern, slug flow pattern and churn flow are the basic flow patterns that can be found both in the test with the aspect ratio were 5 and 20. In addition, only the annular flow pattern is found in the test with the aspect ratio was 20. Due to the aspect ratio was 20, the length of the evaporator section is relatively longer than the aspect ratio was 5.Thus allowing the flow pattern to have a longer distance and time to change the flow pattern from the churn flow pattern to the annular flow pattern. Therefore, making the annular flow pattern and churn flow pattern is the main flow pattern that found the percentage of high flow patterns and flow patterns that affect the heat transfer in the case of tested with the aspect ratio was 20. When considering the aspect ratio was 5, which has the length of the evaporator section and the condenser section is relatively short. Therefore is another reason for the movement of the vapor bubble using the short and fast moving distance to go up to cool the condenser section.

4.3 Effect of the evaporator temperature and aspect ratio on heat transfer of two-phase closed rectangular cross sectional thermosyphon (RTPTC)

From the graph 4.1 show the relationship between the evaporator temperature and aspect ratio on heat transfer of two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm, the inclination angle of 90° and use water as working fluids. Found when the evaporator temperature increases resulting in higher heat transfer values per unit area or heat flux as well. Due to the increased the evaporator temperature causing the heat that the evaporator section through the pipe wall to working fluids more with different temperatures between the surface temperature of the pipe and the temperature of the working fluids. As a result, the specific heat capacity of the working fluids increases as the evaporator temperature increases. Combined with a higher convection coefficient from the two-phase flow pattern consisting of gas flow phase and liquid flow phase that occurs within the two-phase closed rectangular cross sectional thermosyphon (RTPTC) as shown in Table 4.1 and 4.2. When considering the characteristics of the pipe shape compared to the heat flux that was found two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm aspect ratio (AR) 5 has relatively short evaporator section length. Due to the short evaporator section length will have a space within the pipe and the flow distance of the working fluids that is less than the internal area and the flow distance of the working fluids of the ratio of aspect ratio (AR) 20.Making the working fluids able to breathe the heat transfer from the evaporator section into the condenser section in the short and fast moving distance which leads to the average heat flux of 1.51 kW/m^2 which is higher than the average heat flux obtained from the test with aspect ratio (AR) 20 which is 0.74 kW/m^2. With the highest heat flux obtained from the test at the evaporator temperature 90 °C equal to 2.60 and 1.52 kW/m^2 for cases tested with aspect ratio (AR) 5 and 20, respectively.



Graph 4.1 Effects of the evaporator temperature and aspect ratio on heat transfer of two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameters of 25.2 mm, the inclination angle of 90° and use water as working fluids.

4.4 Effect of the evaporator temperature and inclination angle on flow patterns of two - phase closed circle cross sectional thermosyphon (TPTC)

From Table 4.3 the effect of evaporator temperature 50, 70 and 90 °C, the inclination angles of 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 7 mm aspect ratio (AR) 5 found at the evaporator temperature of 50 °C, heat transferred from the hot jacket to the evaporator section and pass through the wall pipe to the working fluids is not high enough. Which the bonding force between the molecules of the working fluids with the particles that are the internal components of the TPCT pipe with a high value. Therefore, the heat at the evaporator temperature of 50 °C through the wall of the pipe into the working fluids cannot destroy the bond between the molecules of the working fluids causing the flow pattern to not be found. When the evaporator temperature increases based on the test data at the evaporator temperature of 70 and 90 °C, the inclination angle of 0, 80 and 90°, as shown in Table 4.3 when considering the evaporator temperature of 70 and 90 °C, it was found that the angle of test 0° of both the evaporator temperature 70 and 90 °C, no flow pattern occurs within RTPCT because it is a limitation cannot work in every test angle because the working fluid that is condensed in the liquid phase will flow back to the evaporator section of the earth by gravity, therefore the evaporation section must be below only. In the inclination angle of 80 and 90 ° with the evaporator temperature 70 and 90 °C, found were four flow patterns consists of bubble flow pattern (BF), slug flow pattern (SF), churn flow pattern (CF) and annular flow pattern (AF) respectively. Due to increase the evaporator temperature resulting in the working fluids phase of the liquid being boiling and becoming vapor, occurs as a two-phase flow pattern consisting of gas flow phase and liquid flow phase.

When considering the evaporator temperature of 70 and 90 °C, the inclination angle of 80°. It is the bubble flow pattern (BF) is 7.87% and 6.04%, average velocity of the bubble is 0.0765 and 0.0939 m/s, the average length of the bubble is 0.0057 and 0.0082 m respectively. Formed the slug flow pattern (SF) is 10.43% and 7.82%, average velocity of the bubble is 0.0416 and 0.0811 m/s, the average length of the bubble is 0.0154 and 0.0175 m respectively. Formed the churn flow pattern (CF) is 25.00% and 34.37%, average velocity of the bubble is 0.2514 and 0.3619 m/s, the average length of the bubble is 0.0126 and 0.0679 m respectively. Formed the annular flow pattern (AF) is 32.97% and 42.52%, average velocity of the bubble is 0.4444 and 0.7166 m/s, the average length of the bubble is 0.0602 and 0.0743 m respectively.

When considering the evaporator temperature of 70 and 90 °C, the inclination angle of 90°. It is the bubble flow pattern (BF) is 1.95% and 1.76%, average velocity of the bubble is 0.0706 and 0.0833 m/s, the average length of the bubble is 0.0079 and 0.0054 m respectively. Formed the slug flow pattern (SF) is 7.39% and 5.14%, average velocity of the bubble is 0.0446 and 0.0333 m/s, the average length of the bubble is 0.0140 and 0.0106 m respectively. Formed the churn flow pattern (CF) is 23.40% and 34.37%, average velocity of the bubble is 0.2333 and 0.2083 m/s, the average length of the bubble is 0.0391 and 0.0574 m respectively. Formed the annular flow pattern (AF) is 31.94% and 39.39%, average velocity of the bubble is 0.3111 and 0.4003 m/s, the average length of the bubble is 0.0552 and 0.0727 m respectively.

Table 4.3 Effects of the evaporator temperature 50, 70 and 90 °C, the inclination angles were 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 7 mm aspect ratio (AR) 5.

The evaporator temperature was 50 °C		
The inclination angle was 0°	Q(W)	q(kW/m^2)
No flow patterns		
	1.05	1.06
The inclination angle was 80°	Q(W)	q(kW/m^2)
No flow patterns		
	8.54	8.63
The inclination angle was 90°	Q(W)	q(kW/m^2)
No flow patterns		
	8.19	8.28

Table 4.3 (continuous) Effects of the evaporator temperature 50, 70 and 90 °C, the inclination angles were 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 7 mm aspect ratio (AR) 5.

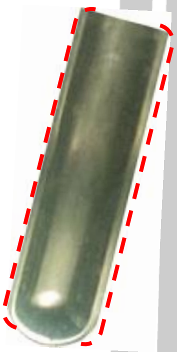
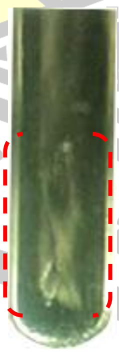
The evaporator temperature was 70 °C													
The inclination angle was 0°												Q (W)	q (kW/m^2)
No flow patterns													
												9.41	9.51
The inclination angle of 80°												Q (W)	q (kW/m^2)
Annular flow			Churn flow			Slug flow			Bubble flow				
%	U_g (m/s)	L_v (m)	%	U_g (m/s)	L_v (m)	%	U_g (m/s)	L_v (m)	%	U_g (m/s)	L_v (m)		
32.97	0.4444	0.0602	25.00	0.2514	0.0126	10.43	0.0416	0.0154	7.87	0.0765	0.0057		
												22.12	22.37
The inclination angle was 90°												Q (W)	q (kW/m^2)
Annular flow			Churn flow			Slug flow			Bubble flow				
%	U_g (m/s)	L_v(m)	%	U_g (m/s)	L_v (m)	%	U_g (m/s)	L_v (m)	%	U_g (m/s)	L_v (m)		
31.94	0.3111	0.0552	23.40	0.2333	0.0391	7.39	0.0446	0.0140	1.95	0.0706	0.0079		
												11.32	11.45

Table 4.3 (continuous) Effects of the evaporator temperature 50, 70 and 90 °C, the inclination angles were 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 7 mm aspect ratio (AR) 5.

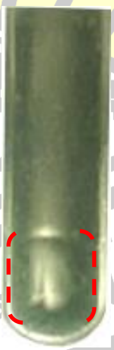
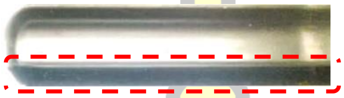
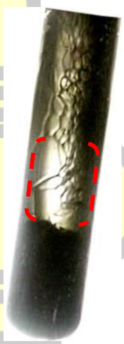
The evaporator temperature was 90 °C													
The inclination angle was 0°												Q(W)	q(kW/m^2)
No flow patterns													
												13.59	13.74
The inclination angle was 80°												Q(W)	q(kW/m^2)
Annular flow			Churn flow			Slug flow			Bubble flow				
%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)		
42.52	0.7166	0.0743	34.37	0.3619	0.0679	7.82	0.0811	0.0175	6.04	0.0939	0.0082		
												31.88	32.33
The inclination angle was 90°												Q(W)	q(kW/m^2)
Annular flow			Churn flow			Slug flow			Bubble flow				
%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)		
39.39	0.4003	0.0727	37.47	0.2083	0.0574	5.14	0.0333	0.0106	1.76	0.0833	0.0054		
												28.74	29.06

Table 4.4 Effects of the evaporator temperature 50, 70 and 90 °C, the inclination angles were 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 25.2 mm aspect ratio (AR) 5.

The evaporator temperature was 50 °C		
The inclination angle was 0°		
No flow patterns	Q(W)	q(kW/m^2)
	2.09	0.19

The inclination angle was 80°													
Stratified flow			Churn flow			Slug flow			Bubble flow				
%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	Q(W)	q(kW/m^2)
30.72	0.1016	0.0573	16.90	0.0500	0.0215	4.94	0.0295	0.0130	8.62	0.0234	0.0034		
												32.57	2.94

The inclination angle was 90°										
Churn flow			Slug flow			Bubble flow				
%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	%	U_g(m/s)	L_v(m)	Q(W)	q(kW/m^2)
34.40	0.0483	0.0387	9.57	0.0250	0.0120	38.36	0.0212	0.0038		
									29.09	2.63

Table 4.4 (continuous) Effects of the evaporator temperature 50, 70 and 90 °C, the inclination angles were 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 25.2 mm aspect ratio (AR) 5.

The inclination angle was 70°		
The inclination angle was 0°	Q(W)	q(kW/m^2)
No flow patterns		
	10.80	0.97

The inclination angle was 80°			Q(W)	q(kW/m^2)	The inclination angle was 90°			Q(W)	q(kW/m^2)
Stratified flow					Vortex flow				
%	U_g(m/s)	L_v(m)			**%**	U_g(m/s)	L_v(m)		
63.35	0.1600	0.0768			51.06	0.0577	0.0667		
			37.44	3.88				33.26	3.00

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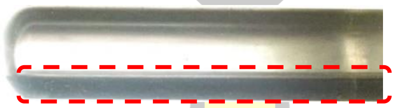
Table 4.4 (continuous) Effects of the evaporator temperature 50, 70 and 90 °C, the inclination angles were 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 25.2 mm aspect ratio (AR) 5.

<table>
<tr><td colspan="10">The inclination angle was 90°</td></tr>
<tr><td colspan="8">The inclination angle was 0°</td><td rowspan="2">Q(W)</td><td rowspan="2">q(kW/m^2)</td></tr>
<tr><td colspan="8">No flow patterns</td></tr>
<tr><td colspan="8"></td><td>14.10</td><td>1.27</td></tr>
<tr><td colspan="3">The inclination angle was 80°</td><td rowspan="4">Q(W)</td><td rowspan="4">q(kW/m^2)</td><td colspan="3">The inclination angle was 90°</td><td rowspan="4">Q(W)</td><td rowspan="4">q(kW/m^2)</td></tr>
<tr><td colspan="3">Stratified flow</td><td colspan="3">Vortex flow</td></tr>
<tr><td>%</td><td>U_g(m/s)</td><td>L_v(m)</td><td>%</td><td>U_g(m/s)</td><td>L_v(m)</td></tr>
<tr><td>55.94</td><td>0.1851</td><td>0.0700</td><td>58.57</td><td>0.0666</td><td>0.0729</td></tr>
<tr><td colspan="3"></td><td>58.15</td><td>5.25</td><td colspan="3"></td><td>52.06</td><td>4.70</td></tr>
</table>

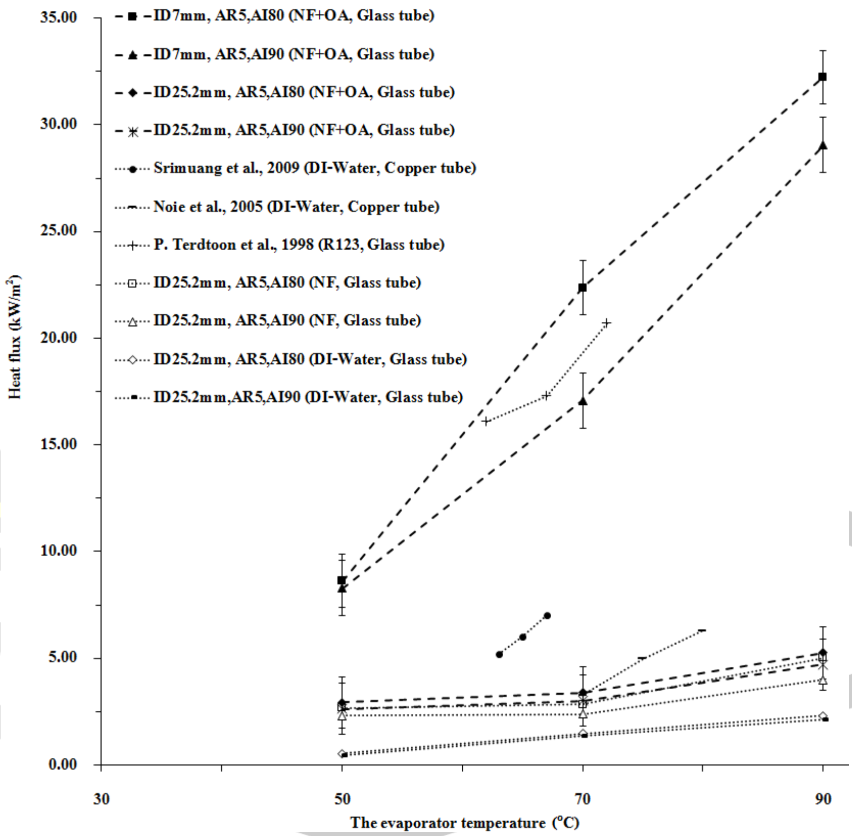
From Table 4.4 the effect of evaporator temperature 50, 70 and 90 °C, the inclination angles were 0, 80 and 90°. The working fluids used is silver nanofluid with oleic acid surfactant with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 25.2 mm aspect ratio (AR) 5. That the inclination angle of 0° both the evaporator temperature 50, 70 and 90 °C. The flow pattern is not found within the two-phase closed thermosyphon (TPCT), similar to the test case of TPCT inner diameter 7 mm. Because it is a limitation cannot work in every test angle because the working fluid that is condensed in the liquid phase will flow back to the evaporator section of the earth by gravity, therefore the evaporation section must be below only. When considering the evaporator temperature of 50 °C at the inclination angle of 80 and 90°, the flow pattern occurs within TPCT, which is different from testing with TPCT inner diameter 7 mm at no flow patterns were found. Due to the large diameter TPCT resulting in the bonding force between the molecules of the working fluids with the particles that are formed between the lower edge of the TPCT's inner tube. Together with the increasing area of heat that the evaporator section and the use of working fluids containing surfactants and silver nanoparticles. Which surfactants have properties to reduce surface tension and help disperse silver nanoparticles spread well in the base fluid as a result the working fluids are base fluids better boiling. Therefore causing the test at the evaporator temperature 50 °C of the inner diameter of TPCT 25.2 mm, the inclination angle of 80°. The flow pattern occurs within the TPCT by the flow pattern found. Consists of the bubble flow pattern (BF) representing 8.67%, average velocity of the bubble is 0.0234 m/s, the average length of the bubble is 0.0034 m respectively. The slug flow pattern (SF) representing 4.94%, average velocity of the bubble is 0.0295 m/s, the average length of the bubble is 0.0013 m respectively. The churn flow pattern (CF) representing 16.90%, average velocity of the bubble is 0.0500 m/s, the average length of the bubble is 0.0215 m respectively. The stratified flow pattern (strf-f) representing 30.72%, average velocity of the bubble is 0.1016 m/s, the average length of the bubble is 0.0573 m respectively. The evaporator temperature 50°C, the inclination angle of 90°, the flow pattern is found, the bubble flow pattern (BF) representing 38.36%, average velocity of the bubble is 0.0212 m/s, the average length of the bubble is 0.0038 m respectively. The slug flow pattern (SF) representing 9.57%, average velocity of the bubble is 0.0250 m/s, the average length of the bubble is 0.0120 m respectively. The churn flow pattern (CF) representing 34.40%, average velocity of the bubble is 0.0483 m/s, the average length of the bubble is 0.0387 m respectively.

When the evaporator temperature increased to 70 and 90 °C as shown in Table 4.4, it was found that the inclination angle of 80° formed the stratified flow pattern (Strf-F) representing the flow pattern is 63.35% and 55.94%, average velocity of the bubble is 0.1600 and 0.1851 m/s, the average length of the bubble is 0.0768 and 0.0700 m respectively. And the vortex flow pattern (Vt-f) is found at the inclination angle of 90° representing the flow pattern of 51.06% and 58.57%, average velocity of the bubble is 0.0577 and 0.0666 m/s, the average length of the bubble is 0.0667 and 0.0729 m respectively. In the case of the vortex flow pattern, Because at the inclination angle of 90° where the evaporator section of the TPCT will receive heat from the heat source to transfer heat from the heat source to the pipe wall to working fluids. Working fluids that are in the liquid phase when the heat accumulates more in the evaporator section. As a result, the viscosity and density of the working fluids in the liquid phase is reduced simultaneously. The working fluids then begins to boil and vaporize. Combined with the use of using working fluids as silver nanoparticles and adding oleic acid to reduce surface tension. Addition of oleic acid in addition to being a surfactant also helps dispersing nano-particle silver powder to disperse in the working fluids regularly. From the silver nanoparticles that are dispersed in the working fluids regularly, also helps the fluid-based working fluids to have more heat in the area, from the size of the nanoparticles and helps to make boiling working fluids easier and better. With a large tube diameter tube that results in a strong surface tension between the molecules of the working fluids pulled together at the surface of the working fluids and that touches the edge of the pipe wall will decrease. For the reasons mentioned above when heat is transferred from the pipe wall to the working fluids adjacent to the pipe wall edge. Resulting in the boiling of the working fluids that is in a saturated liquid phase forming vapor at the edge of the pipe wall first. The flow characteristics of the vapor are moving near the surface of the pipe on both sides because the inclination angle that is tested in the case of inclination angle 90° TPCT is placed in a straight and symmetrical location. Therefore observed the flow of the vapor moving on the surface of both sides of the pipe, and would float through the adiabatic section to transfer heat to a lower temperature source and condensation at the condenser section. When the working fluids is condensed and changed from vapor to liquid as a result, the working fluids is weighted and moves down in the middle of the pipe, which is the fluid that is returned to the evaporator section by moving down the gravity of the earth.

When comparing from the diameter of 7 and 25.2 mm of two-phase closed circle cross sectional thermosyphon (TPTC) that affects the flow pattern, it is found that the bubble flow, slug flow patterns and churn flow patterns are the basic flow patterns that can be found in both the of two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 and 25.2 mm. In addition, only the annular flow pattern was found with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 ratio 5. From the size of two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 25.2 mm with a large diameter tube resulting in the bonding force between the molecules of the working fluids with the particles that are formed between the lower edge of the TPCT's inner tube. Together with the increasing area of heat that the evaporator section and the use of working fluids containing surfactants and silver nanoparticles. Which surfactants have properties to reduce surface tension and help disperse silver nanoparticles spread well in the base fluid as a result the working fluids are base fluids better boiling. Resulting found vortex flow pattern and stratified flow pattern for cases with the case of inclination angle 90 and 80°.

4.5 Effect of the evaporator temperature and inclination angle on heat transfer of two-phase closed circle cross sectional thermosyphon (TPTC)

Considering the effect evaporator temperature and inclination angle on heat transfer of two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 7 and 25.2 mm, aspect ratio 5. The working fluids used is silver nanofluid with oleic acid surfactant as shown in graph 4.2 found when the evaporator temperature increases resulting in higher heat transfer values per unit area or heat flux as well. Due to the increased the evaporator temperature causing the heat that the evaporator section through the pipe wall to working fluids more with different temperatures between the surface temperature of the pipe and the temperature of the working fluids. As a result, the specific heat capacity of the working fluids increases as the evaporator temperature increases. Combined with a higher convection coefficient from the two-phase flow pattern consisting of gas flow phase and liquid flow phase that occurs within the TPCT. When considering the characteristics of the pipe shape compared to the heat flux obtained, it was found that at the TPCT with inner diameter 25.2 mm, the aspect ratio (AR). Due to the short evaporation length, there will be a space within the pipe and the flow distance of the working fluids that is less than the internal area and the flow distance of the working fluid at the TPCT with inner diameter 25.2 mm, makes the working fluid able to breathe the heat transfer from the evaporator section into the condenser section in the shortest moving distance bring the amount of high heat flux. For the case of testing with TPCT with inner diameter 7 mm, the aspect ratio (AR) 5 in comparison with the TPCT with inner diameter 25.2 mm and also found that at the inclination angle of 80° with an average heat flux of 21.08 kW/m^2 which is higher than the heat flux obtained in other test cases [13,37, 40]. At the inclination angle of 80°, the liquid film with condensation in the condenser section will have some characteristics as a result, the viscosity of the working fluid that is in the liquid phase that is ready to flow back into the evaporator section is reduced. As a result, the heat resistance of the condensed liquid film decreases as well. In addition, this test uses silver nanoparticles add oleic acid to reduce surface tension as a working fluid within TPCT. Which the working fluid is another important variable that affects the heat transfer characteristics, silver nanoparticles help improve the heat transfer rate due to the high thermal conductivity (k) and the presence of small particles directly affecting the contact area for receiving and exothermic heat. Along with the mixing of oleic acid as a surfactant which helps in the dispersion of nano-silver nanoparticles. Resulting in a higher proportion of heat distribution than traditional working fluid or the use of working fluid in the group of refrigerants which is useful for easy and fast boiling of working fluid.



Graph 4.2 Effects of the evaporator temperature and inclination angle on heat transfer of two - phase closed circle cross sectional thermosyphon (TPTC) inner diameters of 7 and 25.2 mm aspect ratio 5 and use silver nanofluid with oleic acid surfactant as working fluids.

4.6 Effect of the diameter and inclination angle on flow patterns of two-phase closed circle cross sectional thermosyphon (TPTC)

When considering Effects of the diameter and inclination angle on heat transfer of two-phase closed circle cross sectional thermosyphon (TPTC) has the information as shown in Table 4.3 and 4.4.

4.6.1 Consider the two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 and 25.2 mm, the inclination angle was 0°, the aspect ratio of 5, the evaporator temperature 50, 70 and 90 °C. Use silver nanofluid with oleic acid surfactant as working fluids. From the test found that both the inner diameter of 7 and 25.2 mm. No flow patterns are found because it is a limitation cannot work in every test angle because the working fluid that is condensed in the liquid phase will flow back to the evaporator section of the earth by gravity, therefore the evaporation section must be below only.

4.6.2 Consider the two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 and 25.2 mm, the inclination angle of 80°, the aspect ratio of 5, the evaporator temperature 50, 70 and 90 °C. Use silver nanofluid with oleic acid surfactant as working fluids. From the test found the evaporator temperature 50 °C, no flow pattern was found in the case of two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 mm but with the bubble flow pattern, slug flow pattern, churn flow pattern and stratified flow pattern due to the large diameter tube of TPCT. Resulting in the bonding force between the molecules of the working fluids with the particles that are formed between the lower edges of the TPCT's inner tube. Together with the increasing area of heat that the evaporator section and the use of working fluids containing surfactants and silver nanoparticles. Which surfactants have properties to reduce surface tension and help disperse silver nanoparticles spread well in the base fluid as a result the working fluids are base fluids better boiling. Therefore causing the test at the evaporator temperature 50 °C found flow patterns occurring. When considered at the evaporator temperature of 70 and 90 °C, it was found that bubble flow pattern, slug flow pattern, churn flow pattern and annular flow pattern with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 mm and found stratified flow pattern with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 25.2 mm the inclination angle of 80° with a large tube diameter making it noticeable with the formation of stratified flow pattern.

4.6.3 Consider the two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 and 25.2 mm, the inclination angle of 90°, the aspect ratio of 5, the evaporator temperature 50 70 and 90 °C. Use silver nanofluid with oleic acid surfactant as working fluids. From the test found the evaporator temperature 50 °C, no flow pattern was found in the case of two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 mm but with the bubble flow pattern, slug flow pattern, churn flow pattern with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 25.2 mm, the reasons mentioned in section 4.6.2. When considering the evaporator temperature of 70 and 90 °C, it was found that the bubble flow pattern, slug flow pattern, churn flow pattern and annular flow pattern with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 mm and the vortex flow pattern (Vt-f) is found at the inclination angle of 90° with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 25.2 mm. In the case of the vortex flow pattern, because at the inclination angle of 90° where the evaporator section of the TPCT will receive heat from the heat source to transfer heat from the heat source to the pipe wall to working fluids. Working fluids that are in the liquid phase when the heat accumulates more in the evaporator section. As a result, the viscosity and density of the working fluids in the liquid phase is reduced simultaneously. The working fluids then begins to boil and vaporize. Combined with the use of using working fluids as silver nanoparticles and adding oleic acid to reduce surface tension. Addition of oleic acid in addition to being a surfactant also helps dispersing nano-particle silver powder to disperse in the working fluids regularly. From the silver nanoparticles that are dispersed in the working fluids regularly, also helps the fluid-based working fluids to have more heat in the area, from the size of the nanoparticles and helps to make boiling working fluids easier and better. With a large tube diameter tube that results in a strong surface tension between the molecules of the working fluids pulled together at the surface of the working fluids and that touches the edge of the pipe wall will decrease. For the reasons mentioned above when heat is transferred from the pipe wall to the working fluids adjacent to the pipe wall edge. Resulting in the boiling of the working fluids that is in a saturated liquid phase forming vapor at the edge of the pipe wall first. The flow characteristics of the vapor are moving near the surface of the pipe on both sides because the inclination angle that is tested in the case of inclination angle 90° TPCT is placed in a straight and symmetrical location. Therefore observed the flow of the vapor moving on the surface of both sides of the pipe, and would float through the adiabatic section to transfer heat to a lower temperature source and condensation at the condenser section. When the working fluids is condensed and changed from vapor to liquid as a result, the working fluids is weighted and moves down in the middle of the pipe, which is the fluid that is returned to the evaporator section by moving down the gravity of the earth.

4.7 Effect of the diameter and inclination angle on heat transfer of two-phase closed circle cross sectional thermosyphon (TPTC)

When effects of the diameter and inclination angle on heat transfer of two-phase closed circle cross sectional thermosyphon (TPTC) contains information as shown in the graph 4.2. Consider the two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 and 25.2 mm, the inclination angle of 80 and 90°, the aspect ratio of 5 and the evaporator temperature 50 70 and 90 °C. Use silver nanofluid with oleic acid surfactant as working fluids. From the test found that two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 7 mm has an average heat flux throughout the test, higher than the two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter of 25.2 mm in both inclination angle and evaporator temperature. Due to the inner diameter of TPCT 7 mm, the aspect ratio of 5 is the length of the evaporator section is relatively short. There is a small amount of space within the pipe and the flow distance of the working fluids. Can breathe heat from the evaporator section into the condenser section at short and fast moving distances bring the amount of high heat flux. In addition, when considering the flow pattern in the two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 25.2 mm will be characterized by a relatively dense and full flow of bubbles throughout the area of evaporator section as shown in Table 4.3 and 4.4. Which is quite difficult as the bubble can move and gather, Because of the limited movement distance which leads to changes in the flow pattern from one flow pattern to another. Resulting in the convection coefficient from the two-phase flow pattern consisting of gas flow phase and liquid flow phase too low.

4.8 Flow pattern map

From Figure 4.4 shows the flow pattern of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPTC). Compare the relationship between momentum flux in the vapor and liquid phase. Which consists of velocity, the temperature of the working fluids within the RTPCT and TPCT obtained from the study of the variables in the experiment is two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPTC) inner diameter 25.2 and 7 mm, aspect ratio 5 and 20, using water, silver nanofluid, silver nanofluid with oleic acid surfactant as working fluids. The inclination angle of 80 and 90°, the evaporator temperature 70 and 90 °C. Found that the flow pattern map consists of four flow patterns, (Area1) annular/churn/slug/bubble, (Area2) stratifield/annular/churn/slug/bubble, (Area3) churn/slug/bubble and (Area4) annular/churn/slug/bubble.

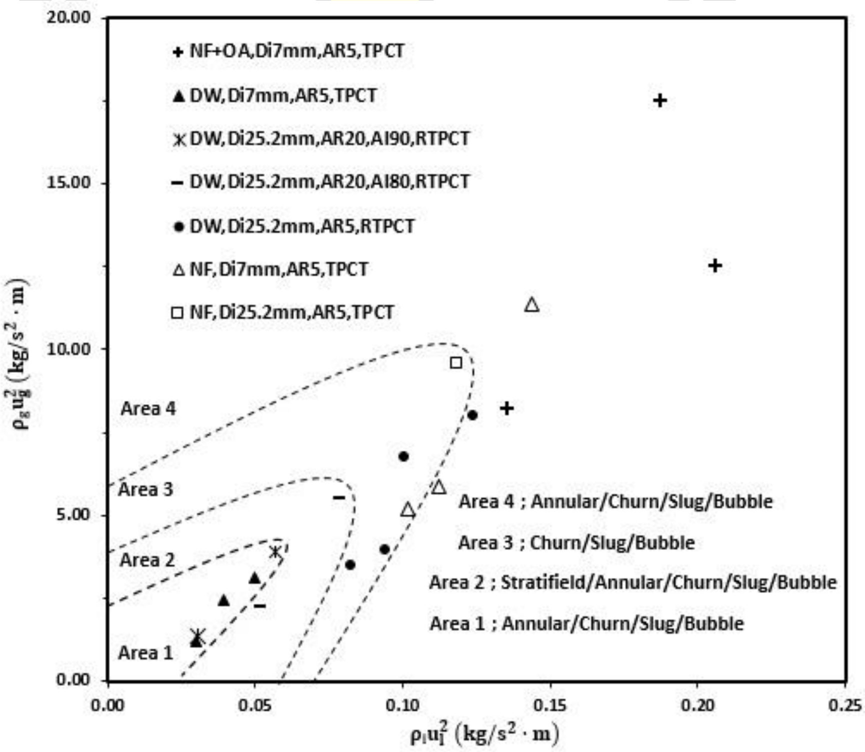


Figure 4.4 The flow pattern of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and circle cross sectional thermosyphon (TPTC) compare the relationship between momentum flux in the vapor and liquid phase.

4.8.1.1 Area1; Annular/Churn/Slug/Bubble

When considering the flow pattern map, the momentum flux values in the vapor and liquid phase are low. Find the flow pattern annular/churn/slug/bubble which happens to working fluids with water, aspect ratio of 5, two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 7 mm, inclination angle 80 and 90^o, the evaporator temperature 70 and 90 ^{o}C. Moreover, at aspect ratio of 20, two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameter 25.2 mm the inclination angle 90^o, the evaporator temperature 70 and 90^{o}C. This is because the working fluids is water, with the latent heat of vaporization. Therefore requiring the use of evaporator temperature at 70 and 90 ^{o}C to reduce the viscosity and density of the working fluids in the liquid phase. Is a combination of bubbles, combined with the physical shape of the thermosyphon, including the proportion of the add working fluids with the volumetric evaporator section.

4.8.1.2 Area 2; Stratifield/Annular/Churn/Slug/Bubble

When considering the flow pattern map, the momentum flux in the vapor and liquid phase is much higher than that of area 1, it is found that the flow pattern is Stratifield/Annular/Churn/Slug/Bubble Which occurs with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameter 25.2 mm, aspect ratio 20, the inclination angle 80^o, the evaporator temperature of 70 and 90 ^{o}C uses water as a working fluids, aspect ratio of 20. The diameter of the RTPCT is large resulting in a long and wide evaporator section with the inclination angle 80^o When the working fluids is boiling, it will result in a greater distance and movement distance. In addition, can easily change the flow pattern from one flow pattern to one flow pattern therefore found stratifield flow pattern from the characteristics of stratifield flow pattern. Which is a flow pattern that helps to reduce the flow problem between the vapor of the working fluids and the fluid of the working fluids while flowing back to the evaporator section. As can be seen from the momentum flux in the vapor phase and the liquid phase that is greater than the flow pattern area Annular/Churn/Slug/Bubble.

4.8.1.3 Area 3; Churn/Slug/Bubble

When considering the flow pattern map, the momentum flux in the vapor and liquid phase is much higher than that in areas 1 and 2, the flow pattern is found to be Churn/Slug/Bubble, which occurs with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameter 25.2 mm aspect ratio 5, the inclination angle 80^o, the evaporator temperature of 70 and 90 ^{o}C uses water as a working fluids. In addition, occurs with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 25.2 mm aspect ratio 5, the inclination angle 80^o, the evaporator temperature of 90 ^{o}C use silver nanofluid as working fluids. When considering the shape of the pipe. At the ratio of 5 in length is relatively short in the evaporator section when boiling of the working fluids. Therefore, the bubble can be moved to heat up to the condenser section relatively quickly. Combined with the inclination angle 80^o due to the inclination angle position, causing the liquid film with condensation in the condenser section to look thin as a result, the viscosity of the working fluids that is in the liquid phase that is ready to flow back into the evaporator section is reduced. Which can flow back to get the heat that the evaporator section is quite fast with higher volume. As can be seen from the momentum flux in the vapor phase and liquid phase that is greater than area 1 and 2.

4.8.1.4 Area 4; Annular/Churn/Slug/Bubble

When considering the flow pattern map, the momentum flux in the vapor phase and liquid phase is higher than all flow patterns. Found the flow pattern Annular/Churn/Slug/Bubble which occurs with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 7 mm aspect ratio 5, the inclination angle 80 and 90^{o}, the evaporator temperature of 70 and 90 ^{o}C. Use silver nanofluid, silver nanofluid with oleic acid surfactant as working fluids. Due to the working fluids containing silver powder nanoparticles which is small, will spread in the working fluids resulting in more space to receive heat, even if oleic acid is added as a surfactant. Properties of oleic acid that is a surfactant and also helps dispersing silver nanoparticles in working fluids that work more consistently. And helps the working fluids with the original basis, boiling better. When considering the shape of the pipe, at aspect ratio of 5 in length that is relatively short in the evaporator section. When boiling of the working fluids. The vapor bubbles can be moved to heat up to the condenser section relatively quickly and flow with friction between the working fluids and the lower inner tube edge with the properties of the working fluids as mentioned. As can be seen from the momentum flux in the vapor and liquid state that is higher than all the ground flow patterns.

CHAPTER 5

Conclusion

5.1 Summary of experimental results

5.1.1 Effect of working fluids considering the silver nanofluid with oleic acid (OA) surfactant as working fluids. Will cause boiling of the working fluids easily because surfactants have properties to reduce surface tension and help disperse silver nanoparticles in base fluids As well as increasing the surface area of heat and exothermic. As a result, the working fluids are base fluids better boiling with silver nanoparticles with high thermal conductivity. When boiling, the velocity of the bubble increases and the heat transfer rate per unit area increases respectively. As can be seen from the flow pattern when using the silver nanofluid with oleic acid (OA) surfactant as working fluids.

5.1.2 Effect of aspect ratio when considering the aspect ratio, it was found that the increasing aspect ratio has increased the length of the evaporator section as well. At the aspect ratio 5 with a relatively short evaporator section length. Due to the short evaporation length, there will be space inside the pipe and the flow distance of the working fluids is less than the aspect ratio of 20. Combined with the ratio of additives to working fluids with the volume evaporator section. When the working fluids starts to boil Therefore, the working fluids can breathe the heat transfer from the evaporator section into the condenser section in the short and fast moving distance that comes with the two-phase flow patterns and the length of the vapor bubble will be reduced in length.

5.1.3 Effect of the evaporator temperature, increased evaporator temperature results in higher heat transfer values. As the evaporator temperature increases, the heat that the evaporator section through the wall of the pipe into the working fluids increases as well. With the temperature difference between the surface temperature of the pipe and the temperature of the working fluids as well. As a result, the specific heat capacity of the working fluids increases as the evaporator temperature increases. Combined with higher convection coefficient from two-phase flow patterns that consist of gas flow phase and the fluid flow phase that occurs within the thermosyphon. Including the increased velocity of the vapor bubble, causing the bubble to the expansion in the evaporator section is reduced. However, this increased vapor bubble velocity will increase the heat transfer rate from the evaporator section to the condenser section.

5.1.4 Effect of inner diameter, when the inner diameter increases from 7 to 25.2 mm, the heat transfer rate per unit area will decrease. The large diameter of the pipe causes the bonding force between the molecules of the working fluids with particles that are lower between the inner tube edges. Together with the increasing area of heat to the evaporator section, from the use working fluids containing surfactants and silver nanoparticles. Which surfactants have properties to reduce surface tension and help disperse silver powder, nanoparticles spread well in the base fluid As a result, the working fluids are base fluids better boiling. Resulting in a high proportion of vapor bubbles in the evaporator section area resulting in the area of movement of the vapor bubble decreasing and affecting the velocity of movement of the vapor bubble.

Including changing the flow pattern from one model to another. Which directly affects the heat transfer rate from the evaporator section to the lower condenser section.

5.1.5 Effect of the inclination angle, At the inclination angle 80^o the liquid film with condensation in the condenser section will have some characteristics As a result, the viscosity of the working fluids that is in the liquid phase that is ready to flow back into the evaporator is reduced. As a result, the heat resistance of the condensed liquid film decreases as well. Including at the inclination angle of 80^o also helps to reduce the flow problem between the working fluids in the condensed liquid state that is ready to flow back into the evaporator section and the working fluids that is in the vapor phase that is rising from the evaporator section. Due to the inclination angle of 80^o. The working fluids that is in a liquid-weight phase will flow next to the side of the pipe with an inclined position. Helps to provide liquidity in the flow of two phase flow patterns that are in the phase of gas and liquid phase. Which directly affects the velocity of the movement of the vapor bubble that will move up to cool the condenser section which leads to increased heat transfer rate.

5.1.6 Flow patterns map of two-phase closed rectangular cross sectional thermosyphon (RTPTC) and two-phase closed circle cross sectional thermosyphon (TPTC) comparing the relationship between momentum in vapor phase and liquid phase. Found that the flow pattern chart consists of four flow patterns: Annular/Churn/Slug/Bubble, Stratifield/Annular/Churn/Slug/Bubble, Churn/Slug/Bubble and Annular/Churn/Slug/Bubble. Which the flow pattern area annular/churn/slug/bubble gave the highest heat transfer value per unit area with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 7 mm. and using the silver nanofluid with oleic acid (OA) surfactant as working fluids. And the flow pattern area Annular/Churn/Slug/Bubble giving the lowest heat transfer value per unit area by testing the working fluids as water two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 7 mm, aspect ratio 5, inclination angle 80 and 90^o, and two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner diameter 25.2 mm, aspect ratio 20, inclination angle 90^o due to the working fluid with the latent heat of high vaporization.

5.2 Suggestions

5.2.1 Should study the additional relationship between flow phenomena in the adiabatic section and condenser section. In this research, the focus is to study the flow patterns observed in the evaporator section only. In order to know the relationship between the flow phenomena in the evaporator section, adiabatic section and condenser section of two-phase closed rectangular cross sectional thermosyphon (RTPTC).

5.2.2 Should study and invent the process of constructing two-phase closed rectangular cross sectional thermosyphon (RTPTC) to ensure durability and support the use of acidic and corrosive working fluids.

5.2.3 Should be created correlation equation, for calculating momentum flux to know the exact extent of the flow pattern map.

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Appendices

Appendix A

Example of calculation

Example of calculation Volume of filling working fluids

Inner diameter of two-phase closed rectangular cross sectional thermosyphon (RTPTC) 25.2 mm, the evaporator section length 126 mm.

$$V_{100\%} = (XY)L_{evap}$$

$$L_{evap} = 12.6 \text{ cm}$$

$$X = Y = 2.52 \text{ cm}$$

$$V_{100\%} = (2.52x2.52)x12.6$$

$$V_{100\%} = (2.52x2.52)x12.6$$

$$= 80.01 \text{ cm}^3 = 80.01 \text{ ml}$$

The rate of filling of 50% of the evaporator section volume.

$$= 80.01x0.5 = 40.00 \text{ ml}$$

Therefore, the working fluids must be added as 40.00 ml.

Example of the calculation of heat transfer rate

Experiments that use water as a working fluids, the inclination angle was 90°, the evaporator temperature was 90 °C. Inner diameter of two-phase closed rectangular cross sectional thermosyphon (RTPTC) 25.2 mm, the evaporator section length 126 mm.

Heat transfer rate (Q)

$$Q = \dot{m}C_p(T_{co} - T_{ci})$$

By $\dot{m}$ is mass flow rate of condenser section inlet water 0.004167 kg/s
C_p is specific heat capacity of water 4183 J/kg.°C
T_{co} is outlet temperature of the water at condenser section 29.05 °C
T_{ci} is inlet temperature of the water at condenser section 27.14 °C

Representing the value in the equation will be

$$Q = 0.004167x4183(29.05-27.14)$$

$$Q = 33.29 \text{ J/s} = 33.29\text{W}$$

Heat transfer rate per unit area

$$q = \frac{Q}{A_C} = \frac{Q}{(2x+2y)L_{Conden}}$$

By Q is heat transfer value 33.29 W

A_C is cooling area in the condenser section (m^2)

L_{conden} is length in condenser section (m)

X, Y is each side length of RTPCT (m)

Representing the value in the equation will be

$$q = \frac{33.29}{(2(0.0252)+2(0.0252))x0.126}$$

$$q = 2.60\ kW/m^2$$

Example of calculating flux momentum flux in liquid phase and momentum flux in Vapor phase

Experiments that use water as a working fluids, the inclination angle was 90°, the evaporator temperature was 90 °C. The rate of filling of 50% of the evaporator section volume with two-phase closed rectangular cross sectional thermosyphon (RTPTC) inner 25.2 mm, the evaporator section length 126 mm.

1. Vapor quality (x)

From the formula $x = (h_{TP} - h_l)/(h_g - h_l)$

By $h_{TP} = h_l + C_P(T_{working} - T_{ambient})$

$$T_{working} = \frac{T_{surface\ of\ RTPCT\ at\ evaporator\ section} + T_{surface\ of\ RTPCT\ at\ condensor\ section}}{2} = \frac{90.00+29.19}{2} = 59.60\ ^{o}C$$

$$T_{ambient} = 25.0\ ^{o}C$$

$$h_l @ 59.60\ ^{o}C = 249.50\ kJ/kg$$

$$h_g @ 59.60\ ^{o}C = 2608.09\ kJ/kg$$

$$C_P @ 59.60\ ^{o}C = 4.18\ kJ/kg\ ^{o}C$$

Replace the values in the formula to find the value h_{TP} will get

$$h_{TP} = 394.21 \text{ kJ/kg}$$

Replace the values in the formula to find the value x will get $x = 0.0614$

2. Mass flux of vapor (G_g)

From the formula $G_g = \rho_g u_g$

By $\rho_g = 0.1283 \text{ kg/m}^3$

Replace the values in the formula to find the value G_g will get

$$G_g = 0.0155 \text{ kg/s.m}^2$$

3. Flux of two-phase flow (G)

From the formula $G = G_g/x$

By $G_g = 0.0155 \text{ kg/s.m}^2$

$x = 0.0614$

will get $G = 0.0155/0.0614$

will get $G = 0.2520$

4. Liquid flux momentum $(\rho_l u_l^2)$

From the formula $\rho_l u_l^2 = \dfrac{[G(1-x)]^2}{\rho_l}$

By $G = 0.2520$

$x = 0.0614$

$\rho_l = 983.45 \text{ kg / m}^3$

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Replace the values in the formula $\rho_l u_l^2 = \dfrac{[0.2520(1-0.0614)]^2}{983.45}$

$$\rho_l u_l^2 = 0.0569 \text{ kg/s.m}^2$$

5. Vapour flux momentum $(\rho_g u_g^2)$

From the formula $\rho_g u_g^2 = \dfrac{[G(x)]^2}{\rho_g}$

By $G = 0.2520$

$x = 0.0614$

$\rho_g = 0.1283 \text{ kg/m}^3$

Replace the values in the formula $\rho_g u_g^2 = \dfrac{[0.2520(0.0614)]^2}{0.1283}$

$$\rho_g u_g^2 = 3.8958 \text{ kg/s.m}^2$$

Appendix B

Summary table of results

Table B.1 The experiment results of using water as the working fluids with two-phase closed rectangular cross sectional thermosyphon (RTPTC)) inner diameter 25.2 mm, aspect ratio of 20.

AI(°)	T_{evap} (°C)	Flow patterns	L_v (m)	u_g(m/s)	q(kW/m²)
0	-	-	-	-	-
	-	-	-	-	-
	90	-	-	-	0.49
80	50	-	-	-	0.22
	70	Stratifield+Annular+Churn+Slug+Bubble	-	0.1254	0.62
	90	Stratifield+Annular+Churn+Slug+Bubble	-	0.1414	1.68
90	50	-	-	-	0.21
	70	Annular+Churn+Slug+Bubble	0.0653	0.0963	0.50
	90	Annular+Churn+Slug+Bubble	0.0603	0.1202	1.52

Table B.2 The experiment results of using water as the working fluids with two-phase closed rectangular cross sectional thermosyphon (RTPTC)) inner diameter 25.2 mm, aspect ratio of 5.

AI(°)	T_{evap} (°C)	Flow patterns	L_v (m)	u_g(m/s)	q(kW/m²)
0	50	-	-	-	-
	70	-	-	-	-
	90	-	-	-	1.12
80	50	-	-	-	0.91
	70	Churn+Slug+Bubble	-	0.1685	1.77
	90	Churn+Slug+Bubble	-	0.1803	2.74
90	50	-	-	-	0.82
	70	Churn+Slug+Bubble	0.0367	0.1423	1.12
	90	Churn+Slug+Bubble	0.0266	0.1608	2.60

Table B.3 The experiment results of using silver nanofluid with oleic acid surfactan as the working fluids with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 7 mm, aspect ratio of 5.

AI(°)	T_{evap} (°C)	Flow patterns	L_v (m)	u_g(m/s)	q(kW/m²)
0	50	-	-	-	1.06
	70	-	-	-	9.51
	90	-	-	-	13.74
80	50	-	-	-	8.63
	70	Annular+Churn+Slug+Bubble	0.0291	0.1650	22.37
	90	Annular+Churn+Slug+Bubble	0.0420	0.3134	32.33
90	50	-	-	-	8.28
	70	Annular+Churn+Slug+Bubble	0.0310	0.1833	11.45
	90	Annular+Churn+Slug+Bubble	0.0365	0.2035	29.06

Table B.4 The experiment results of using silver nanofluid with oleic acid surfactan as the working fluids with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 25.2 mm, aspect ratio of 5.

AI(°)	T_{evap} (°C)	Flow patterns	L_v (m)	u_g(m/s)	q(kW/m²)
0	50	-	-	-	0.19
	70	-	-	-	0.97
	90	-	-	-	1.27
80	50	Stratifield+Churn+Slug+Bubble	0.0238	0.0511	2.94
	70	Stratifield	0.0768	0.1600	3.88
	90	Stratifield	0.0700	0.1851	5.25
90	50	Churn+Slug+Bubble	0.0182	0.0315	2.63
	70	Vortex	0.0667	0.0577	3.00
	90	Vortex	0.0729	0.0666	4.70

Table B.5 The experiment results of using water as the working fluids with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 7 mm, aspect ratio of 5.

AI(°)	T_{evap} (°C)	Flow patterns	L_v (m)	u_g(m/s)	q(kW/m²)
0	50	-	-	-	1.76
	70	-	-	-	6.87
	90	-	-	-	6.69
80	50	-	-	-	2.11
	70	Annular+Churn+Slug+Bubble	0.0281	0.0951	11.10
	90	Annular+Churn+Slug+Bubble	0.0363	0.1159	13.74
90	50	-	-	-	1.41
	70	-	-	-	9.16
	90	Annular+Churn+Slug+Bubble	0.0414	0.1028	13.39

Table B.6 The experiment results of using water as the working fluids with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 25.2 mm, aspect ratio of 5.

AI(°)	T_{evap} (°C)	Flow patterns	L_v (m)	u_g(m/s)	q(kW/m²)
0	50	-	-	-	-
	70	-	-	-	-
	90	-	-	-	0.91
80	50	-	-	-	0.54
	70	Churn+Slug+Bubble	-	0.1000	1.49
	90	Churn+Slug+Bubble	-	0.1093	2.30
90	50	-	-	-	0.47
	70	Churn+Slug+Bubble	-	0.1100	1.35
	90	Churn+Slug+Bubble	-	0.1163	2.14

Table B.7 The experiment results of using silver nanofluid as the working fluids with two-phase closed circle cross sectional thermosyphon (TPTC) inner diameter 25.2 mm, aspect ratio of 5.

AI(°)	T_{evap} (°C)	Flow patterns	L_v (m)	u_g(m/s)	q(kW/m²)
80	90	Churn+Slug+Bubble	-	0.1583	5.02
90	90	Churn+Slug+Bubble	-	0.0957	3.98

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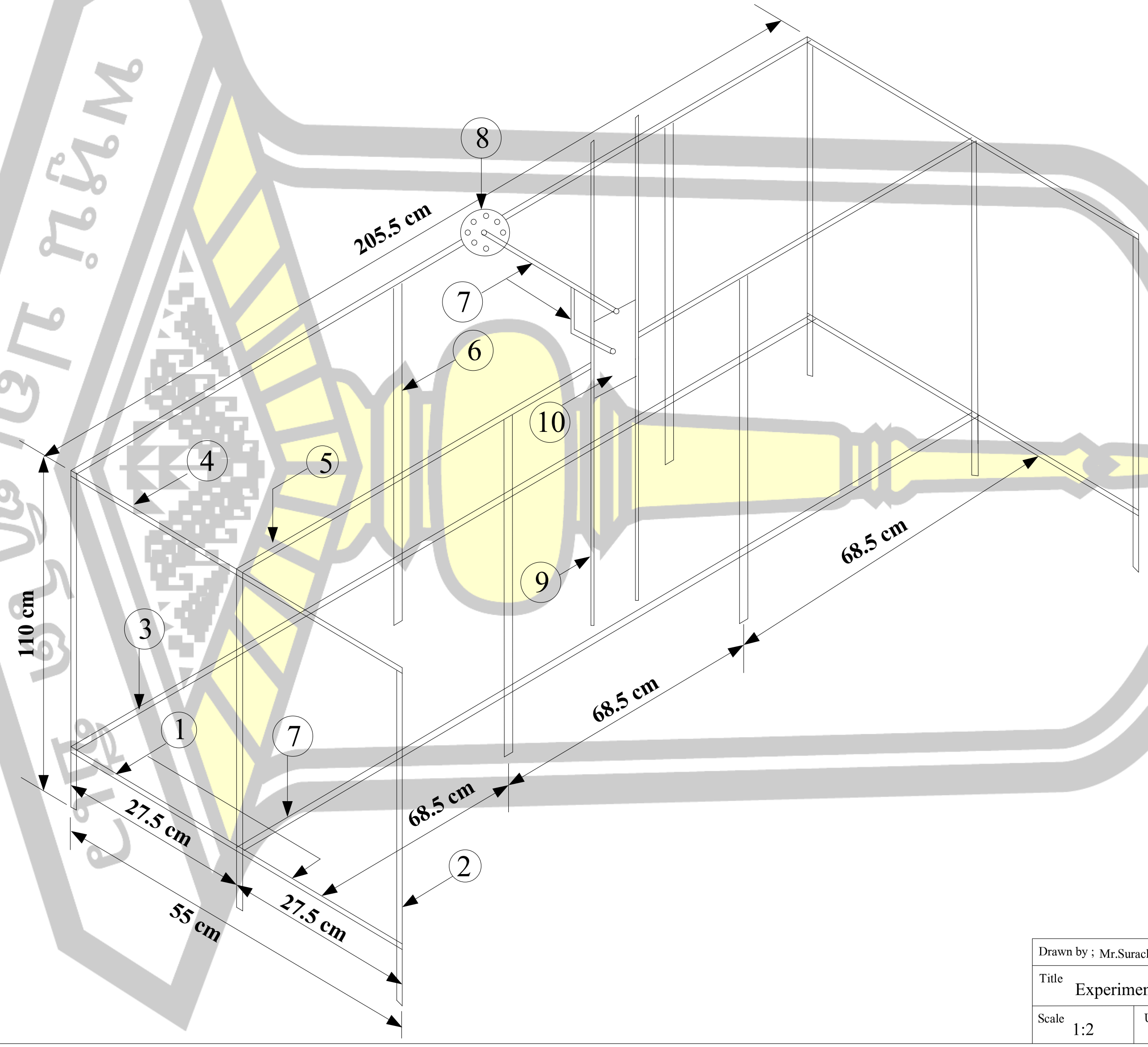
Appendix C

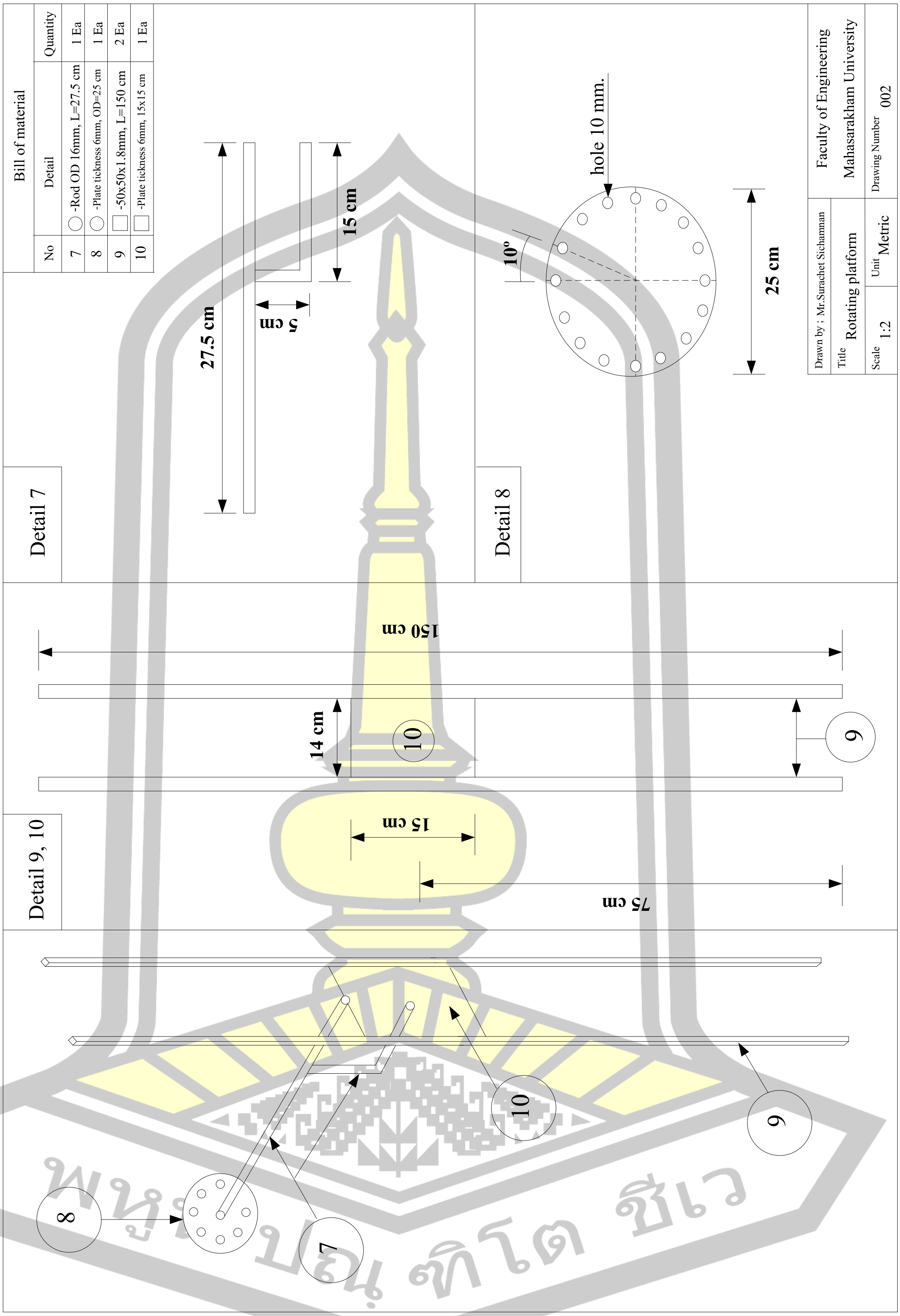
Experimental Set

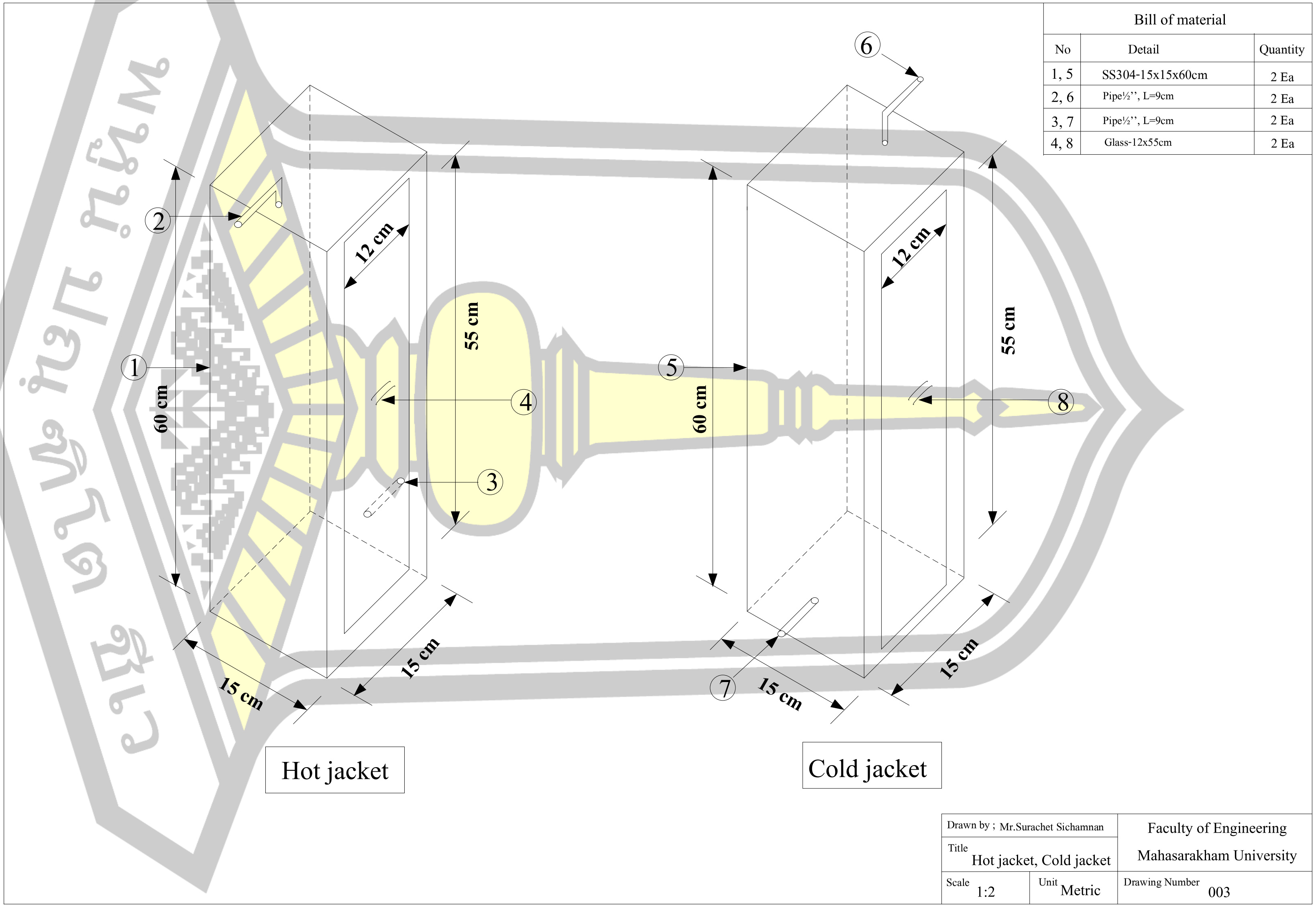


Bill of material

No	Detail	Quantity
1	-50x50x1.8mm, L=27.5 cm	4 Ea
2	-50x50x1.8mm, L=110 cm	6 Ea
3	-50x50x1.8mm, L=68.5 cm	6 Ea
4	-50x50x1.8mm, L=55 cm	2 Ea
5	-50x50x1.8mm, L=205.5 cm	2 Ea
6	-50x50x1.8mm, L=110 cm	4 Ea
7	-Rod OD 16mm, L=27.5 cm	1 Ea
8	-Plate tickness 6mm, OD=25 cm	1 Ea
9	-50x50x1.8mm, L=150 cm	2 Ea
10	-Plate tickness 6mm, 15x15 cm	1 Ea

Drawn by : Mr.Surachet Sichamnan	Faculty of Engineering
Title Experimental set	Mahasarakham University
Scale 1:2 / Unit Metric	Drawing Number 001


Bill of material
No
Detail
Quantity
7 -Rod OD 16mm, L=27.5 cm 1 Ea
8 -Plate tickness 6mm, OD=25 cm 1 Ea
9 -50x50x1.8mm, L=150 cm 2 Ea
10 -Plate tickness 6mm, 15x15 cm 1 Ea
Detail 7
27.5 cm
5 cm
15 cm
Detail 8
hole 10 mm.
10°
25 cm
Drawn by : Mr.Surachet Sichamnan
Title Rotating platform
Faculty of Engineering
Mahasarakham University
Scale 1:2
Unit Metric
Drawing Number 002
Detail 9, 10
150 cm
14 cm
15 cm
75 cm
9
10
7
8


Bill of material
No
Detail
Quantity
1, 5
SS304-15x15x60cm
2 Ea
2, 6
Pipe½'', L=9cm
2 Ea
3, 7
Pipe½'', L=9cm
2 Ea
4, 8
Glass-12x55cm
2 Ea
60 cm
55 cm
12 cm
15 cm
Hot jacket
Cold jacket
Drawn by ; Mr.Surachet Sichamnan
Title
Hot jacket, Cold jacket
Faculty of Engineering
Mahasarakham University
Scale 1:2
Unit Metric
Drawing Number 003

Appendix D

Physical Properties of Working Fluids

Table D.1 Thermo physical properties of water [1].

Temp. °C	Pressure MPa	Density kg/m^3	Volume m^3/kg	Enthalpy kJ/kg		Viscosity μ Pa.s		Specific Heat kJ/(kg.K)		Thermal C. mW/(m.K)		Surface Tension mN/m
		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	
0.01a	0.00061	999.8	205.98	0.0	2500.5	1792.4	9.22	4.229	1.868	561.0	17.07	75.65
5.00	0.00087	999.9	147.02	21.0	2509.7	1519.1	9.34	4.200	1.871	570.5	17.34	74.95
10.00	0.00123	999.7	106.32	42.0	2518.9	1306.6	9.46	4.188	1.874	580.0	17.62	74.22
15.00	0.00171	999.1	77.900	62.9	2528.0	1138.2	9.59	4.184	1.878	589.3	17.92	73.49
20.00	0.00234	998.2	57.777	83.8	2537.2	1002.1	9.73	4.183	1.882	598.4	18.23	72.74
25.00	0.00317	997.0	43.356	104.8	2546.3	890.5	9.87	4.183	1.887	607.1	18.55	71.98
30.00	0.00425	995.6	32.896	125.7	2555.3	797.7	10.01	4.183	1.892	615.4	18.88	71.20
35.00	0.00563	994.0	25.221	146.6	2564.4	719.6	10.16	4.183	1.898	623.2	19.23	70.41
40.00	0.00738	992.2	19.528	167.5	2573.4	653.2	10.31	4.182	1.905	630.5	19.60	69.60
45.00	0.00959	990.2	15.263	188.4	2582.3	596.3	10.46	4.182	1.912	637.3	19.97	68.78
50.00	0.01234	998.0	12.037	209.3	2591.2	547.0	10.62	4.182	1.919	643.5	20.36	67.95
55.00	0.01575	985.6	9.5730	230.2	2600.0	504.1	10.77	4.182	1.928	649.2	20.77	67.10
60.00	0.01993	983.2	7.6746	251.2	2608.8	466.5	10.93	4.183	1.937	654.3	21.18	66.24
65.00	0.02502	980.5	6.1996	272.1	2617.5	433.4	11.10	4.184	1.947	658.9	21.62	65.37
70.00	0.03118	977.8	5.0447	293.0	2626.1	404.0	11.26	4.187	1.958	663.1	22.07	64.49
75.00	0.03856	974.8	4.1333	314.0	2634.6	377.8	11.42	4.190	1.970	666.7	22.53	63.59
80.00	0.04737	971.8	3.4088	334.9	2643.1	354.5	11.59	4.194	1.983	670.0	23.01	62.68
85.00	0.05781	968.6	2.8289	355.9	2651.4	333.4	11.76	4.199	1.996	672.8	23.50	61.76
90.00	0.07012	965.3	2.3617	376.9	2659.6	314.5	11.93	4.204	2.011	675.3	24.02	60.82
95.00	0.08453	961.9	1.9828	398.0	2667.7	297.4	12.10	4.210	2.027	677.4	24.55	59.88
100.00	0.10132	958.4	1.6736	419.1	2675.7	281.8	12.27	4.217	2.044	679.1	25.09	58.92
105.00	0.12079	954.8	1.4200	440.2	2683.6	267.7	12.44	4.224	2.062	680.6	25.66	57.95
110.00	0.14324	951.0	1.2106	461.3	2691.3	254.8	12.61	4.232	2.082	681.7	26.24	56.97
115.00	0.16902	947.1	1.0370	482.5	2698.8	243.0	12.78	4.240	2.103	682.6	26.84	55.98
120.00	0.19848	943.2	0.89222	503.8	2706.2	232.1	12.96	4.249	2.126	683.2	27.46	54.97
125.00	0.23201	939.1	0.77089	525.1	2713.4	222.2	13.13	4.258	2.150	683.6	28.10	53.96
130.00	0.27002	934.9	0.66872	546.4	2720.4	213.0	13.30	4.268	2.176	683.7	28.76	52.94
135.00	0.31293	930.6	0.58234	567.8	2727.2	204.5	13.47	4.278	2.203	683.6	29.44	51.91
140.00	0.36119	926.2	0.50898	589.2	2733.8	196.6	13.65	4.288	2.233	683.3	30.13	50.86
145.00	0.41529	921.7	0.44643	610.8	2740.2	189.3	13.82	4.300	2.265	682.8	30.85	49.81
150.00	0.47572	917.1	0.39287	632.3	2746.4	182.5	13.99	4.312	2.299	682.1	31.59	48.75
155.00	0.54299	912.3	0.34681	654.0	2752.3	176.2	14.16	4.325	2.335	681.1	32.35	47.68
160.00	0.61766	907.5	0.30709	675.6	2758.0	170.3	14.34	4.338	2.374	680.0	33.12	46.60
165.00	0.70029	902.6	0.27270	697.4	2763.3	164.8	14.51	4.353	2.415	678.6	33.92	45.51
170.00	0.79147	897.5	0.24283	719.3	2768.5	159.6	14.68	4.369	2.460	677.1	34.74	44.41
175.00	0.89180	892.3	0.21679	741.2	2773.3	154.7	14.85	4.386	2.507	675.3	35.58	43.31
180.00	1.0019	887.1	0.19403	763.2	2777.8	150.2	15.02	4.403	2.558	673.4	36.44	42.20
185.00	1.1225	881.7	0.17406	785.4	2782.0	145.9	15.20	4.423	2.612	671.2	37.32	41.08
190.00	1.2542	876.1	0.15650	807.6	2785.8	141.8	15.37	4.443	2.670	668.8	38.23	39.95
195.00	1.3976	870.5	0.14102	829.9	2789.4	138.0	25.54	4.465	2.731	666.2	39.15	38.82
200.00	1.5536	864.7	0.12732	852.4	2792.5	134.4	15.71	4.489	2.797	663.4	40.10	37.68
205.00	1.7229	858.9	0.11517	875.0	2795.3	130.9	15.89	4.515	2.867	660.3	41.08	36.54
210.00	1.9062	852.8	0.10438	897.7	2797.7	127.6	16.06	4.542	2.943	657.1	42.07	35.39
215.00	2.1042	846.6	0.09475	920.5	2799.7	124.5	16.23	4.572	3.023	653.5	43.10	34.24
220.00	2.3178	840.3	0.08615	943.5	2801.3	121.6	16.41	4.604	3.109	649.8	44.15	33.08
225.00	2.5479	833.9	0.07846	966.7	2802.4	118.7	16.59	4.638	3.201	645.7	45.24	31.91
230.00	2.7951	827.2	0.07155	990.0	2803.1	116.0	16.76	4.675	3.300	641.4	46.35	30.75
235.00	3.0604	820.5	0.06534	1013.5	2803.3	113.4	16.94	4.715	3.405	636.9	47.51	29.58
240.00	3.3447	813.5	0.05974	1037.2	2803.0	110.9	17.12	4.759	3.519	632.0	48.70	28.40
245.00	3.6488	806.4	0.05469	1061.2	2802.1	108.5	17.31	4.806	3.641	626.8	49.94	27.23
250.00	3.9736	799.1	0.05011	1085.3	2800.7	106.2	17.49	4.857	3.772	621.4	51.22	26.05
255.00	4.3202	791.5	0.04596	1109.7	2798.8	103.9	17.68	4.912	3.914	615.6	52.57	24.88
260.00	4.6894	783.8	0.04219	1134.4	2796.2	101.7	17.88	4.973	4.069	609.4	53.98	23.70
265.00	5.0823	775.9	0.03876	1159.3	2793.0	99.6	18.07	5.039	4.236	603.0	55.47	22.52
270.00	5.4999	767.7	0.03564	1184.6	2789.1	97.5	18.28	5.111	4.418	596.1	57.04	21.35
275.00	5.9431	759.2	0.03278	1210.1	2784.5	95.5	18.48	5.191	4.617	588.9	58.72	20.17
280.00	6.4132	750.5	0.03016	1236.1	2779.2	93.6	18.70	5.279	4.835	581.4	60.52	19.00
285.00	6.9111	741.5	0.02777	1262.4	2773.0	91.6	18.92	5.377	5.077	573.5	62.47	17.84
290.00	7.4380	732.2	0.02556	1289.1	2765.9	89.7	19.15	5.485	5.345	565.2	64.59	16.68
295.00	7.9952	722.5	0.02354	1316.3	2757.8	87.8	19.39	5.607	5.644	556.6	66.91	15.52
300.00	8.5838	712.4	0.02167	1344.1	2748.7	85.9	19.65	5.746	5.981	547.7	69.49	14.37
310.00	9.8605	691.0	0.01834	1401.2	2727.0	82.2	20.21	6.084	6.799	529.0	75.61	12.10
320.00	11.279	667.4	0.01548	1461.3	2699.7	78.4	20.84	6.542	7.898	509.4	83.59	9.88
330.00	12.852	641.0	0.01298	1525.0	2665.3	74.6	21.60	7.201	9.458	489.2	94.48	7.71
340.00	14.594	610.8	0.01079	1593.8	2621.3	70.4	22.55	8.238	11.865	468.6	110.20	5.64
350.00	16.521	574.7	0.00881	1670.4	2563.5	65.9	23.81	10.126	16.110	447.6	134.65	3.68
360.00	18.655	528.1	0.00696	1761.0	2482.0	60.4	25.71	14.690	25.795	427.2	178.01	1.89
370.00	21.030	453.1	0.00499	1889.7	2340.2	52.3	29.57	41.955	78.751	428.0	299.38	0.39
373.99c	22.064	322.0	0.00311	2085.9	2085.9	43.1	43.13	∞	∞	∞	∞	0

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