

Parametric Study of a Two-Phase Closed Thermosyphon Loop

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ABSTRACT

A theoretical and experimental investigation was carried out to study the behavior of a two-phase closed thermosyphon loop (TPCTL) during steady-state operation using different working fluids. Three working fluids were investigated, i.e., distilled water, methanol, and ethanol. The TPCTL was constructed from an evaporator, condenser, and two pipelines (riser and downcomer). The driving force is the difference in pressure between the evaporator and condenser sections and the fluid returns to the heating section by gravity. In this study, the significant parameters used in the experiments were filling ratios (FR%) of 50%, 75%, and 100% and heat-input range at the evaporator section of 215-860.2 W. When the loop reached to the steady-state, the wall-temperature was recorded at various positions along the thermosyphon loop. Results showed that the thermal performance with water was better than methanol and ethanol with same condition. The experimental values of the heat transfer coefficient at the evaporator section were measured for the three working fluids. The results were estimated with the nucleate boiling correlation using engineering equation solver (ESS) program. In addition, a comparison between the experimental ($h_{e,exp.}$) and theoretical ($h_{e,theo.}$) values of heat transfer coefficient in the evaporator section showed good agreement with a maximum difference of 16%.

Keywords: Thermosyphon loop, Filling ratio, Working fluid.

دراسة استدلالية لمنظومة سيفون حراري ثنائي الطور

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الخلاصة

دراسة عملية ونظرية للأداء الحراري لمنظومة السيفون الحراري باستخدام موائع عمل مختلفة. حيث تم استخدام ثلاثة سوائل عمل وهي الماء والميثانول والإيثانول في هذه الدراسة. يتكون السيفون الحراري من أربعة أجزاء رئيسية جزيئين رئيسيين

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هما المبخر والمكثف ومرتبطة مع بعضها بواسطة خطين من الأنابيب (خط لنقل البخار والأخر للسائل) ومائع التشغيل المستخدم في المنظومة يعود الى المبخر بواسطة الجاذبية بدون استخدام أي مضخة. أن نسبة الشحن المستخدمة للمائع 50%، 75% و100% وتعتبر عامل أساسي ومهم في هذه التجربة، مقدار الطاقة المسلطة من المصدر الكهربائي على منطقة المبخر تتراوح ما بين 215 الى 860.2 واط. تم وضع ثمانية ثرمو كبلات في مناطق مختلفة من الترموسايفون لقياس درجة حرارة الجدار للأجزاء الرئيسية في حالة المستقرة غير معتمدة على الزمن. الدراسة النظرية تتمثل باستخدام نموذج نظري لحساب قيم معامل انتقال الحرارة للموائع الثلاثة من خلال برنامج الحل للمسائل الهندسية (EES) وهذه القيم تم مقارنتها مع القيم العملية. أظهرت النتائج أن معامل انتقال الحرارة يكون بالقيمة العظمى عند استخدام الماء النقي كمائع عمل واقل قيمة له في الميثانول. بالإضافة إلى ذلك تم مقارنة النتائج العملية لمعامل الانتقال الحراري مع القيم النظرية ووجد أنها مقبولة مع اعلى فرق يصل الى من 16%.

الكلمات الرئيسية: السيفون الحراري، نسبة الشحن، مائع العمل

1. INTRODUCTION

The two-phase natural flow loops have important engineering applications due to their easiness, great heat transfer capacity (Haider, S., et al., 2002; Ezzat and Ghashim, 2019). TPCTL can operate in a steady state and a sporadic heat transfer approach under gravitation and anti-gravitation states (Filippeschi, S., 2006). The heating section TPCTL is placed at the lowest vertical side of the loop, while the cooling side is situated above the heating section. As the condition of the fluid inner the loop, six protruding regions have been recognized initiating from the heating section, see figure .1 and Table.1. It is implicit that the fluid density was depended merely on the temperature. The viscosity of working fluid dissipation and axial heat transfer affects were insignificant (Rao, N., et al., 2006).

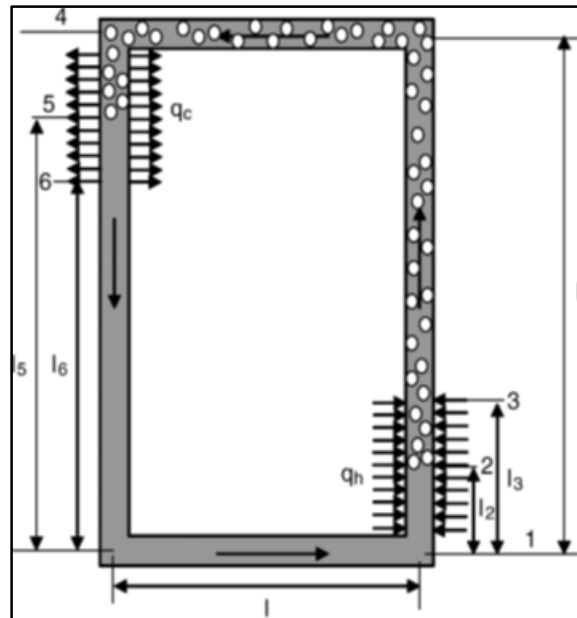


Figure.1 Schematic diagram of a two-phase natural circulation loop.

**Table.1** The regions of two-phase natural circulation.

Sections	Regions
1-2	Sub-cooled heating
2-3	Vaporization
3-4	Adiabatic two phase(Vapor line)
4-5	Condensation
5-6	Sub-cooled cooling
6-1	Adiabatic single phase(Liquid line)

(Kang, S., et al., 2010), studied the effect of filling ratios on the heat transfer performance of TPTL, the experiments were carried out for filling ratios (5, 10, 20, 30, 40, and 50) % at different temperatures range of (20, 30, 40 and 50) °C. Water and Methanol were used as working fluid. (Franco and Filippeschi, 2013), analyzed experimentally of TPCTL for energy system. The experiments have been worked at different heat loads (0-1700) W and the operating pressure(0.1-1) bar, the FR% of the liquid in the evaporator section (H/L) between (0.2-0.32). The results show that the \dot{m}'_{max} seems to be effected by operating pressure and on the mixture between FR% and pressure. (Kannan, M., et al., 2014), Performed thermal performance of a thermosyphon designed with dimensions ID =6.7 mm ,OD = 8 mm and length 1000 mm. The investigation tests were carried out for various filling ratios of (30% - 90%) and heat load (0-1200) W the methanol was found to have better heat transfer if the driving temperature was less than 30 °C. (Zhang, P., et.al, 2015), studied experimentally the TPTL with partly full liquid in riser and with fully filled in the same section. The refrigerant was (R134a) as a working fluid. The result shows the driving force of TPTL was relative to the liquid height in the downcomer. (Eidan, A., et al., 2017). (Hamad and Yasser, 2019), studied the experimental and theoretical analysis to investigate the two- phase boiling heat transfer coefficient using R-in evaporator section. The experimental results has revealed that, the enhancement in heat transfer coefficient at higher heat flux was about 38% compared with another lower value at constant operating condition. Also, investigated numerical and an experimental of the TPCT charged with working fluids (ethanol, acetone, butanol, water, R-134a, and methanol) and filling ratios (40% to 100%). (Adeeb, A., et al., 2021), investigated the thermal performance of CLT with various evaporator geometry. The water was used only as a working fluid, with different FR=50,70 and 100 %. The heat load and cooling flow rate were constant with magnitudes (185 W, 2 L/min.) receptively. The studied results show that the evaporator with helical coil, d=50 mm was better than the other types of evaporator which had high heat transfer rate and low thermal resistance. The main objective of the present work is to investigate, theoretically and experimentally, the various parameters affecting the thermal performance of a two-phase thermosyphon system charged with different working fluids, filling ratio, and heat input load in evaporator section. There are basic concepts of TPCTL as shown below:

a. Working fluid

A working fluid is a fluid inside a closed system that facilitates its function, such as heating, cooling or electricity generation. The main important factor in the selection of working fluid is a range of



operating temperature for vapor. The essential properties for working fluid are computability with material of thermosyphon and geometries, such as boiling point, thermal conductivity, low vapor and liquid viscosities and densities, latent heat and surface tension ... etc. Table(1.2) indicates boiling point for many working fluids which may be used in thermosyphon (**David and Peter, 2006**).

b. Filling ratio (FR%)

The filling ratio which is defined as the volume ratio of the charged liquid to the whole two-phase thermosyphon loop (**Jiao, B., et al., 2008**). It is an important effect on the thermal performance of the device. In most of the cases, the input working fluid is overfilled so that the liquid pool remains during the thermosyphon operation (**Shabgard, H., et al., 2014**). The optimal filling liquid is determined for every operating temperature when the overall thermal resistance of the thermosyphon is minimal (**David, A., et al., 2014**).

2. Mathematical model

A model describing both thermal and phase flow of the closed two-phase thermosyphon loop has been performed. The theoretical model provides an accurate description of the behavior of our experimental setup based on experimental observations. This model presents a theoretical investigation of the thermosyphon loop behavior in steady regime. A computer simulation program based on the method was developed to estimate temperatures of the thermosyphon loop. This program can be considered as a simple tool for modeling and designing TPCTL shown in the figure.2.

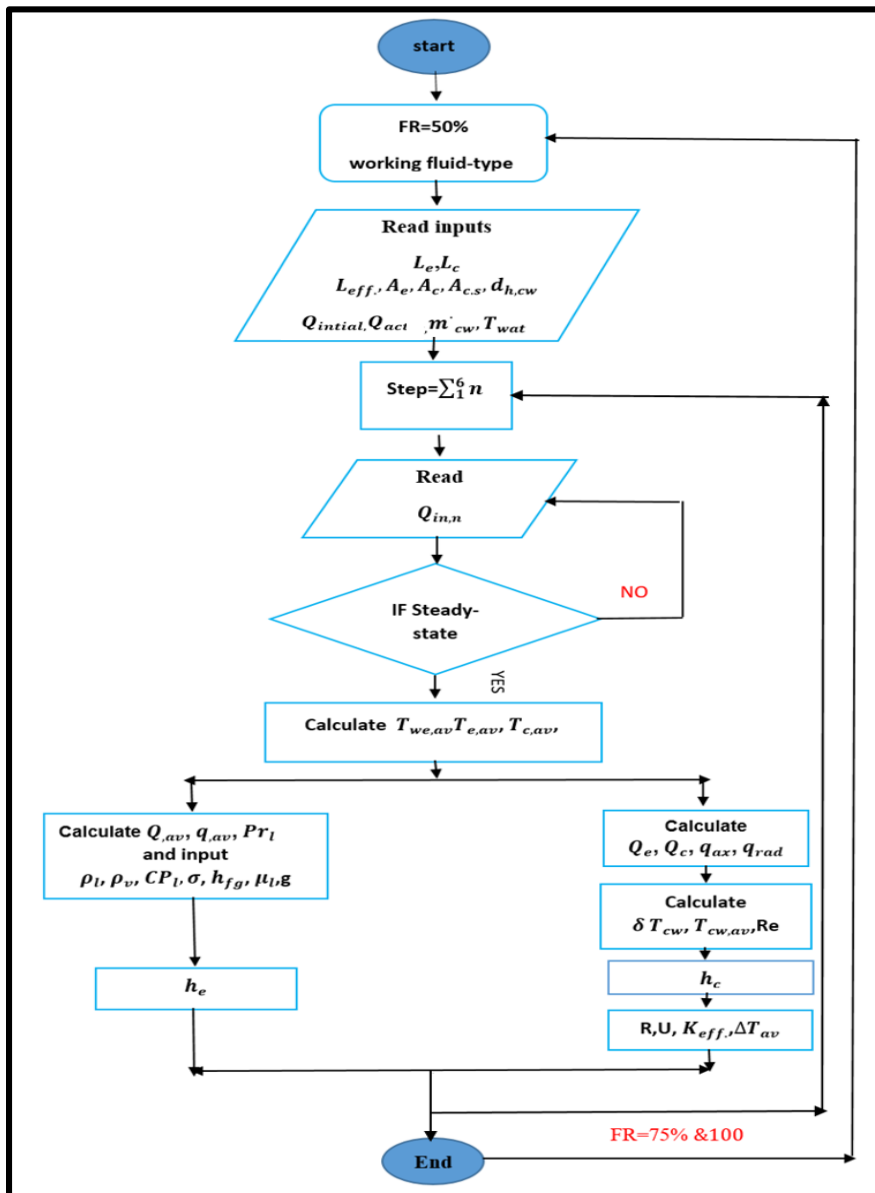


Figure.2 Flow chart of a TPTL model.

3. Experimental setup

The thermosyphon loop is divided into four sections: evaporator section (heating region) of 300mm in length, riser section of 950 mm length, condenser section of 500mm in length, and the downcomer with length of 1200 mm. All sections are made of copper tube with inner (ID) and outer diameters (OD) of 9.5 mm 12.7 mm, respectively. The cooling-water jacket in the condenser section has an outer diameter of 25 mm. To reduce the heat losses to the environment, the heater in the evaporator section was rapped with multi-layer thermal insulation, which consists of fiber glass wool. These layers form an average thickness of about 50 mm. All pipes are connected by solder-welded to each other in the TPCT as shown in the table.2. A two valves were placed in the system, first valve at the bottom of the system for charging the working fluid as well as for



discharging while second valve linked to the vacuum pump at the highest point of the system. The heater temperature varies between 36 to 110 °C on the evaporator zone. The process starts from the outer surface in the evaporator section is heating, then the working fluid inside evaporator boiled upward the riser and enter the condenser which make the fluid from condensation, finally it can be back to the bottom of thermosyphon loop by liquid line (downcomer) as shown the figures 3 and 4.

Table.2 Specifications of TPCTL.

Sections and Details	Specifications
Evaporator	One pipe $L_e = 300$ mm ID= 9.5 mm OD= 12.7 mm
Condenser	Double pipe $L_c = 500$ mm ID= 12.7 mm, OD= 25 mm
Riser	$L_r = 950$ mm ID= 9.5 mm OD= 12.7 mm
Downcomer	$L_d = 1200$ mm ID= 9.5 mm OD= 12.7 mm
Distance between evaporator and condenser	900 mm
Working fluids	Water (PH=7), Ethanol (Assay 99.9%, 0.01 water) and Methanol (Assay 98.9%,0.02 water)
Material	All pipes made of copper
Insulator of evaporator section	Fiber glass wool, t= 50mm

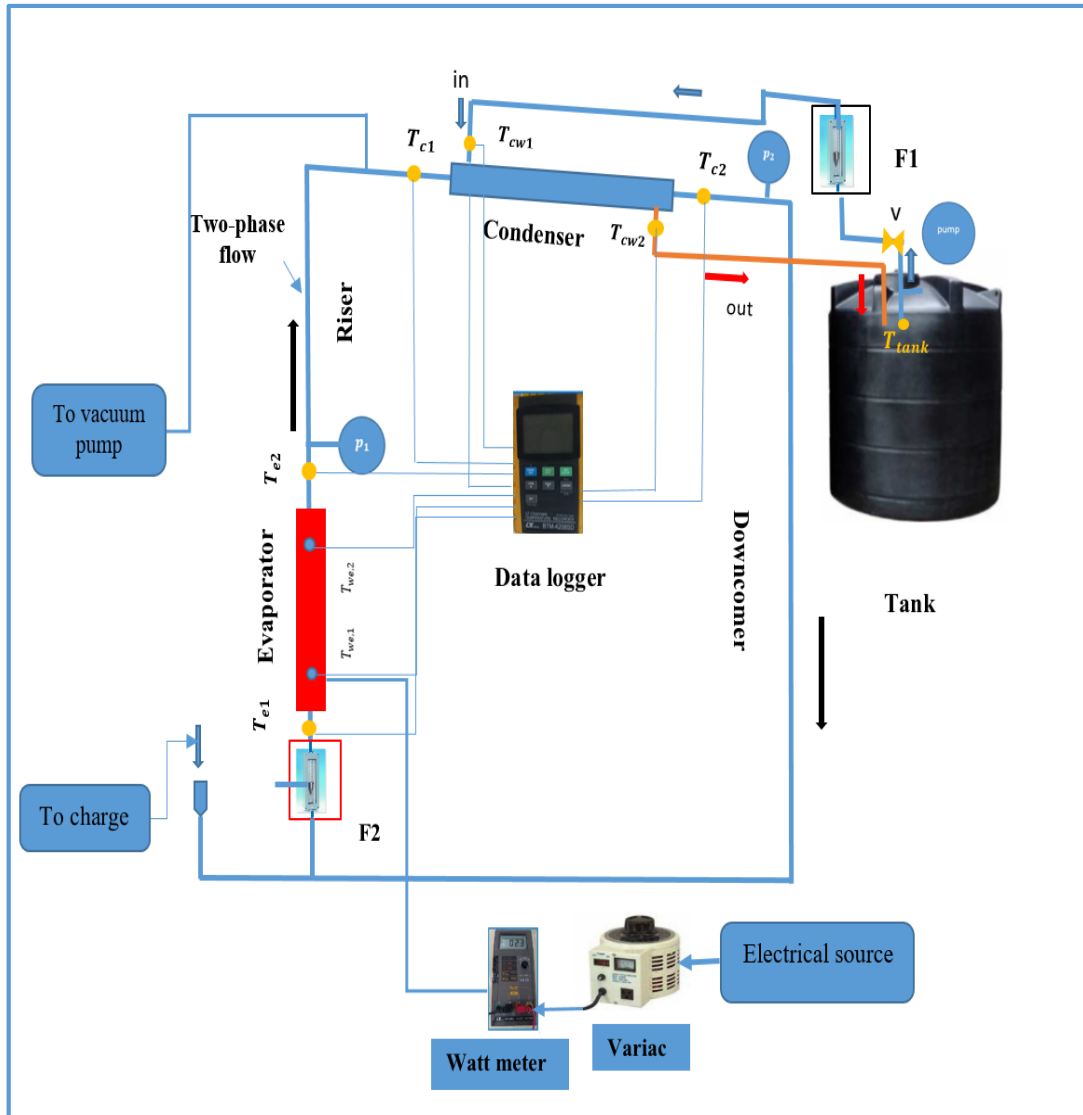


Figure. 3 Schematic of the test rig used in the present research.

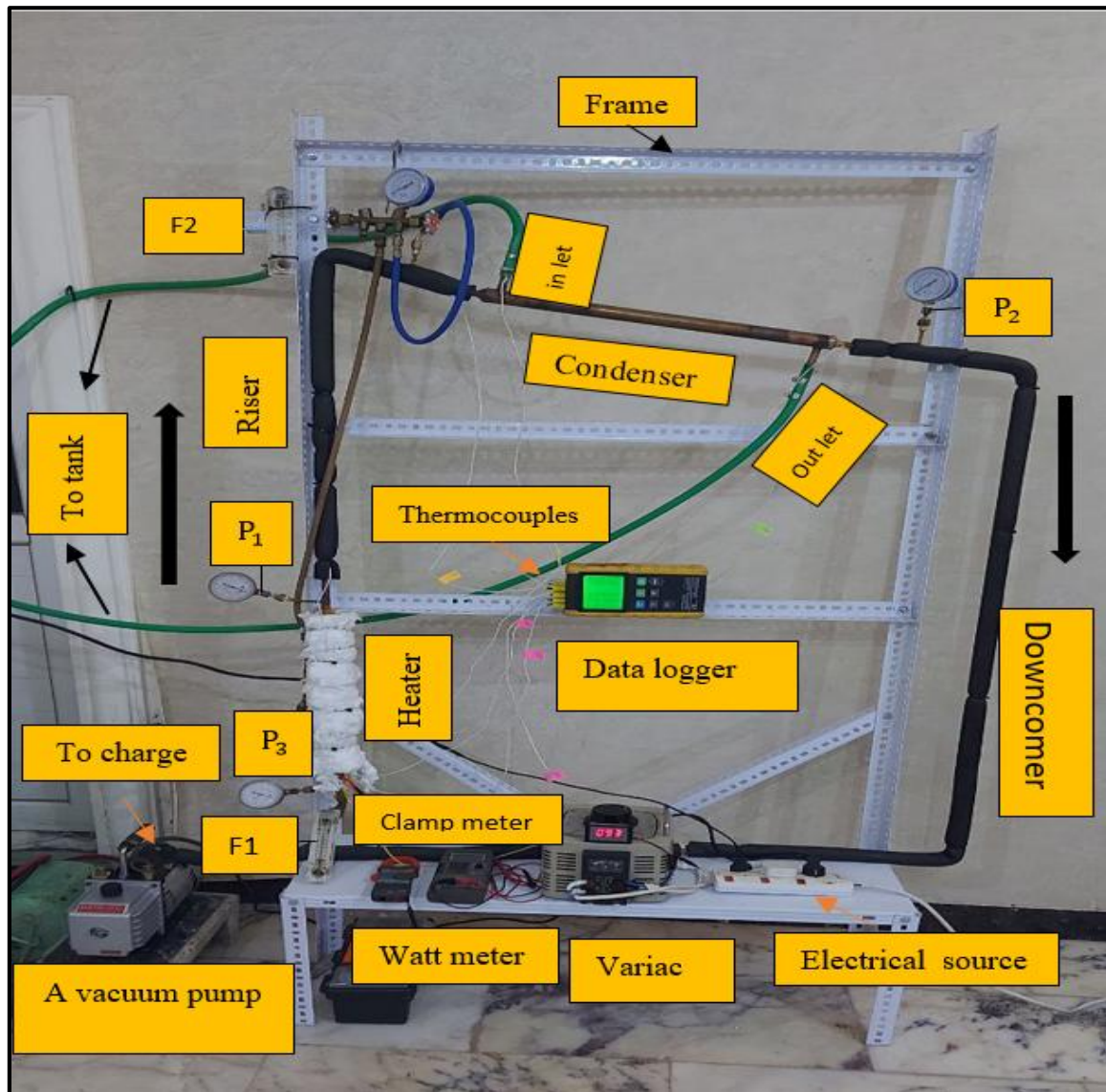


Figure.4 Picture of the test rig used in the present research.

4. Experimental measurement apparatus

4.1 Temperature measurement

The following instruments were used to measure the temperatures on TPCTL:

1. Thermocouples

All temperature measurements were executed using calibrated K-type thermocouples. Nine data-points for temperature measurements were considered. Nine thermocouples were soldered to the outer surface of the thermosyphon loop. Two thermocouples to measure the axial temperature of the pipe-surface before and after the evaporator section and two thermocouples on heater region. Where two of thermocouples were attached for the cooling water to measure inlet and outlet of the jacket. For the condenser, two thermocouples were installed to measure the inlet and outlet temperatures. The last thermocouple put inside the tank to measure the water temperature. The



Thermocouple was employed in this test K-type made of Nickel-Chromium (Ni-Cr), which is naturally magnetic as shown in the figures(5.a),(5.b). K-Type thermocouple work very well in oxidizing ambient at temperatures up to 1250°C and its acceptance grade is ± 1 °C between -270 and 1320 °C (Cole-Pramer, 2001/2002).

2. Data logger (Temperature recorder)

Temperature data logger recorder model BMT-4208 SD was used in the present experimental work. One data logger was used to read and record the temperatures of heat source, riser and heat sink. Data logger has 12 channel thermocouples as shown in the figure (5.c).

4.2 Power supply measurement

The following instruments were used to measure the electric power consumed by the heater:

1. Variable voltage transformer (Variac)

A manual Voltage Regulator (Variac) type (TDGC2) for the heater was used in the present investigation. To get a vast range of temperature gradients, the voltage regulator capacity from 0 to 250 V with 50 Hz oscillation as shown in the figure (5.d). The electric power is measured the voltage (V) and the current (I) of AC(Salem, M., 2010):

$$Q_{elec.} = V.I \quad (1)$$

2. Clamp meter

AC clamp meter model KT-3288 was used to measure the current supplied to the heater with reading accuracy of 1% for readings less than 20 A as shown in the figure (5.e).

3. Watt meter

AC Watt meter model DW-6060 was used to measure the power supplied to the heater with reading accuracy of 1% for readings less than 1000 Watt. It can also be used to measure voltage as shown in the figure (5.f).

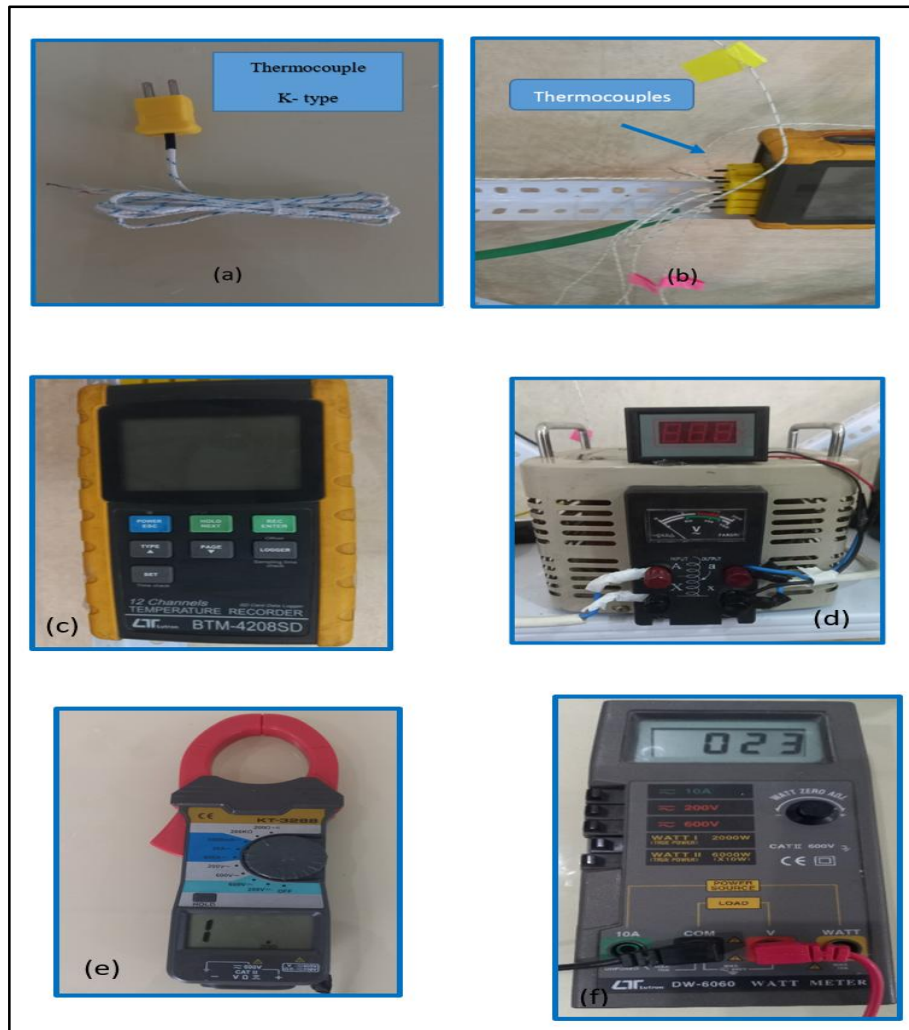


Figure.5 Pictures for measurement devices and apparatuses a) K-type thermocouple b) Set of thermocouples c) Variable voltage transformer (Variac) d) Data logger 12 channels e) Clamp meter f) Watt meter.

4.3 Heating system

The heater used for the heating system consisted of an electrical resistance wire (1040 W), with 46.5Ω , length of 6 m and diameter of 0.3 mm. This heater wire can be used at temperatures up to 1320°C . The heater was wrapped around the outer surface of the evaporator section, before that the pipe is insulated with an electrical insulator (Kapton polyimide tape) with a working range of temperatures -269 to $+400^{\circ}\text{C}$. Then, heater poles were connected to the power supply as shown in the Fig.6.

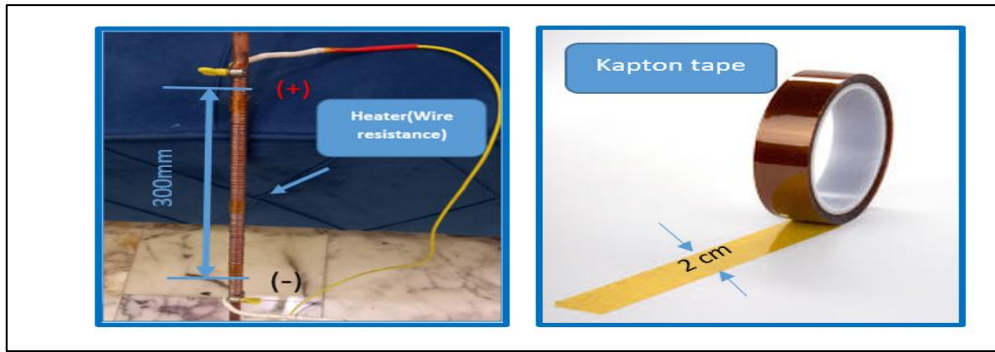


Figure.6 Pictures of the heater and Kapton tape.

4.4 Charging and evacuation system

Before starting the charging process of the working fluid with the adapted filling ratio, the thermosyphon system must be connected to the rotary vacuum pump to evacuate it from any non-condensable gases. The rotary vacuum pump can produce a maximum vacuum pressure needed of 39.99 KPa (30 cm Hg).

The charging process includes two steps : first step, Measure all pipe lengths to calculate the volume of liquid to be filled into the system with the addition of a volume of the evaporator according to the filling ratio. Second step, From total volume could be measured the weight of the required working fluid, by using a high-accuracy sensitive balance, then it is charged by charging valve on the bottom of the downcomer.

4.5 Rotary flow meter

The rotary Flow meter is one of the oldest and mature principles in flow measurement with its simple design: a float rises inside a conically shaped glass tube as the flow increases and its position on a scale can be read off as the flow rate. Since this measuring method is purely mechanic, it as simple as it is reliable.

5. Calibration of the measuring devices

Calibration processes were carried out for the temperature, cooling-water flow meter and power devices as shown below:

1. Thermocouple

The calibration of thermocouples was done by using four liquid; water, for boiling and freezing point, ethanol for boiling point (78°C) and methanol for boiling point (65°C) at the atmospheric pressure. The curve was obtained for the thermocouples by fitting the collected data. The calibrated data is respect with agreement with the standard values, where the standard deviation range ± 0.34 .

2. Rotary flow meter

The rotary flow meter required for the cooling-water flow rate measurement was calibrated using a constant control volume (4 liters). The calibration process of rotary flow meter was performed by calculating the time required to completely filling the control volume. The cooling flow rate is determined 3 Lit. and 4 Lit. divided by filling time in seconds, where the standard deviation range ± 0.001 for the 3- Lit./min. flow meter and ± 0.003 for the 4-Lit./min. flow meter.



3. Variable voltage transformer

The variable voltage transformer (Variac) calibration involves volt and current. The calibrated curve values measured by clamp ammeter were compared to the actual values. The deviation for this device is ± 0.01 .

6. Experimental procedure

After completing of the preparation processes, the thermosyphon loop is ready for operation. To attain safe operation without troubles that may damage the thermosyphon loop, the procedure for performing the test runs could be summarized as:

1. Before starting experimental test, a vacuum pump is turned on until pressure inside the system 39.99 kPa(30 mHg) which is used to remove air from the thermosyphon loop ; however, All the valves are closed in vacuum.
2. After shutting down the vacuum pump, the loop is charged with the designed quantity of the working fluid from the charging valve on the bottom of the system.
3. Water charge into the system through a charging valve with 50% filling ratio from volume of evaporator section, repeat this step for (75% and 100%).
4. Supply a heat load at evaporator section where is adjusted to the desired value start from 215 W to 860.2 W.
5. When all the temperature reading reached steady state values, after around 15-20 min, then the temperatures were recorded.
6. The above steps are repeated for ethanol and methanol with above mentioned parameters, moreover must be evacuated the system from old FR% and charge with a new FR%.

7. Experimental analysis and uncertainties

The equations as below used for calculation the heat transfer coefficient at evaporator section (Adeeb, A., et al., 2020):

$$h_{e,exp} = q_{av.} / (T_{we,av.} - T_{v,av.}) \tag{2}$$

$$q_{av.} = Q_{av.} / A_e \tag{3}$$

$$Q_{av.} = Q_{in} + Q_{out} \tag{4}$$

$$Q_{out} = m'_{cw} * cp_{cw} (T_{cwo} - T_{cwi}) \tag{5}$$

$$A_e = \pi d_e L_e \tag{6}$$

And the equation coloration used to calculate the heat transfer coefficient of boiling nucleate pool in the evaporator section:

$$h_{NPB} = \frac{q^{2/3}}{\frac{C_{sf} h_{fg}}{cp_l}} / \left[\frac{1}{h_{fg} \mu_l} \times \left(\frac{\sigma}{g(\rho_l - \rho_v)} \right)^{1/2} \right]^{0.33} pr_l^n \tag{7}$$

Where:

q= heat flux, W/m²

C_{sf}= experimental constant, dependent on the combination of surface and fluid



Pr =Prandtl number
 n =Prandtl Exponent (Rohsenow Correlation)

The thermal resistance and the overall heat transfer coefficient are mostly calculated from the following equations (Salem, M., 2010):

$$U = \frac{q_{ax}}{\Delta T_{(e-c),av.}} \tag{8}$$

$$R_{thermal} = \frac{1}{UA_{c.s}} = \frac{\Delta T_{av}}{q_{ax}.A_{c.s}} \tag{9}$$

The uncertainty in the computed results is approximated on the basis of the uncertainties in the primary measurements. The result (F) is given perform of the self-governing variables $x_1, x_2, x_3, \dots x_n$; thus (Holman, J., 2001)

$$F = F(x_1, x_2, x_3, \dots x_n). \tag{10}$$

Let UF be the uncertainty in the result and U1, U2, ...Un be the uncertainties in the independent variables. If the uncertainties in the independent variables are all given with the same odds, then the uncertainty in the result has this relation:

$$U_F = [(\frac{\delta F}{\delta x_1} U_1)^2 + (\frac{\delta F}{\delta x_2} U_2)^2 + (\frac{\delta F}{\delta x_3} U_3)^2]^{1/2} \tag{11}$$

Therefore, the uncertainty of the heat transfer coefficient measurement is:

$$U_h = [(\delta h \frac{\delta h}{\delta I} U_I)^2 + (\delta h \frac{\delta h}{\delta V} U_V)^2 + (\delta h \frac{\delta h}{\delta d} U_d)^2 + (\delta h \frac{\delta h}{\delta L} U_L)^2 + (\delta h \frac{\delta h}{\delta T_{we,av.}} U_{Te})^2 + (\delta h \frac{\delta h}{\delta T_{v,av.}} U_{Tv})^2]^{1/2} \tag{12}$$

For example :The certainty of heat input calculated as below

Minimum heat input (Q_{in})=215 W

Voltage (V) = 100 volt

Current (I) = 2.15 A

$$U_Q = [(\frac{\delta Q}{\delta I} U_I)^2 + (\frac{\delta Q}{\delta V} U_V)^2]^{1/2} \tag{13}$$

$$\frac{\delta Q}{\delta I} = V = 100 \text{ volt}, U_V = 0.01 * 100 = 1 \text{ volt}$$

$$\frac{\delta Q}{\delta V} = I = 2.15 \text{ A}, U_I = 0.01 * 2.15 = 0.0215 \text{ A}$$

$$U_Q = [(100 * 0.0215)^2 + 2.15 * 1^2]^{1/2} = 3.04 \text{ W}$$

Therefore; the uncertainty of Q = 3.04 /215= 1.41 %



Table.2 The uncertainties of test parameters.

Variables	Units	Uncertainties
Flow meter m'_{cw}	L/min	± 0.001
Thermocouple	$^{\circ}\text{C}$	± 0.34
current	I	± 0.01
voltage	V	± 0.01
Heat input (Q_{in})	W	1.41%
$h_{e,exp}$	$\text{W}/\text{m}^2\cdot^{\circ}\text{C}$	5.75%

8. Results and Discussions

The experimental and theoretical data are describing the thermal performance of a TPCTL during steady-state operation. The parameters investigated in the present work were heat inputs 215,336,452,585.5, 658.6 and 860.2 W and filling ratios of 50%,75% and 100% using three different working fluids, which are water, methanol and ethanol influence of the previous parameters on TPCTL features and performance are studied including differences of wall temperatures, evaporator and condenser heat transfer coefficients, average heat transfer coefficient, effective thermal conductivity of the thermosyphon and thermal resistance.

8.1 The influence of input heat rate on heat transfer coefficient of TPCTL

The heat transfer capacity of evaporator is characterized by heat transfer coefficient. The influence of changing the heat input under constant filling ratio shows in Figures.7, 8 and 9 illustrate that the transfer coefficient ($h_{e,exp}$) increase with increment of heat input heat rate or the a heat flux in the evaporator section for the filling ratios (50%,75% and 100%) using three working fluid. The maximum heat transfer coefficient is obtained 5582 $\text{W}/\text{m}^2\cdot^{\circ}\text{C}$ for water, FR=75% and the minimum value of ($h_{e,exp}$) 1074 $\text{W}/\text{m}^2\cdot^{\circ}\text{C}$ for methanol, FR=100% because of the latent heat for water is higher than ethanol and methanol.

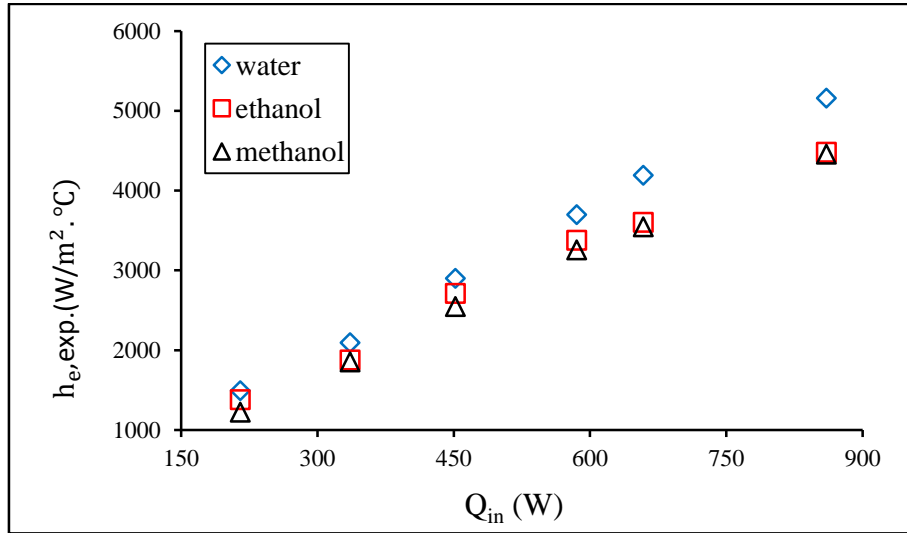


Figure. 7 Heat transfer coefficient of the evaporator section for various heat inputs at FR of 50% using three working fluids.

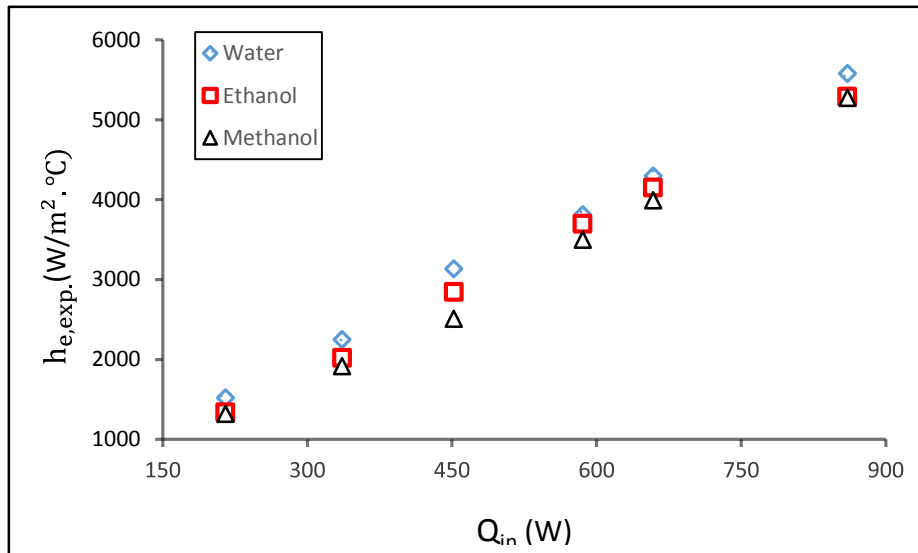


Figure.8 Heat transfer coefficient of the evaporator section for various heat inputs at FR of 75% using three working fluids.

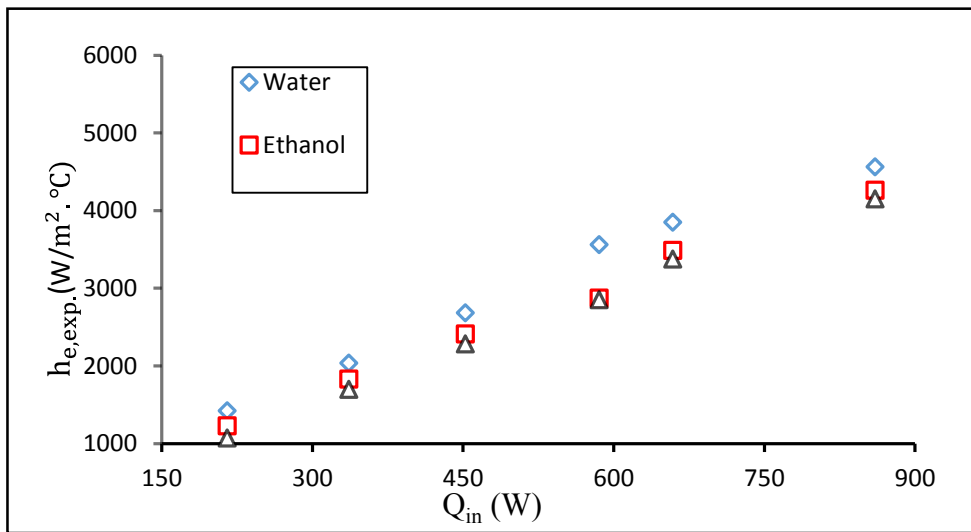


Figure. 9 Heat transfer coefficient of the evaporator section for various heat inputs at FR of 100% using three working fluids.

8.2 The influence of filling ratio on average heat transfer coefficient ($h_{av,exp.}$) of TPCTL at average heat input rate

The average heat transfer coefficient of closed thermosyphon loop in the evaporator section with water is higher than ethanol and methanol at all filling ratios. The maximum average heat transfer coefficient is $3433.55 W/m^2 \cdot ^\circ C$ with water at FR= 75%, while the minimum value = $2567.96 W/m^2 \cdot ^\circ C$ for methanol because of the difference temperatures between evaporator wall and adiabatic section (riser) is lower than the difference temperatures using the ethanol and methanol at same average heat input as shown in the Fig.10. There is validate with (Adeeb, A., et al., 2021), using FR=50%,70% and 90% as shown in Fig.11.

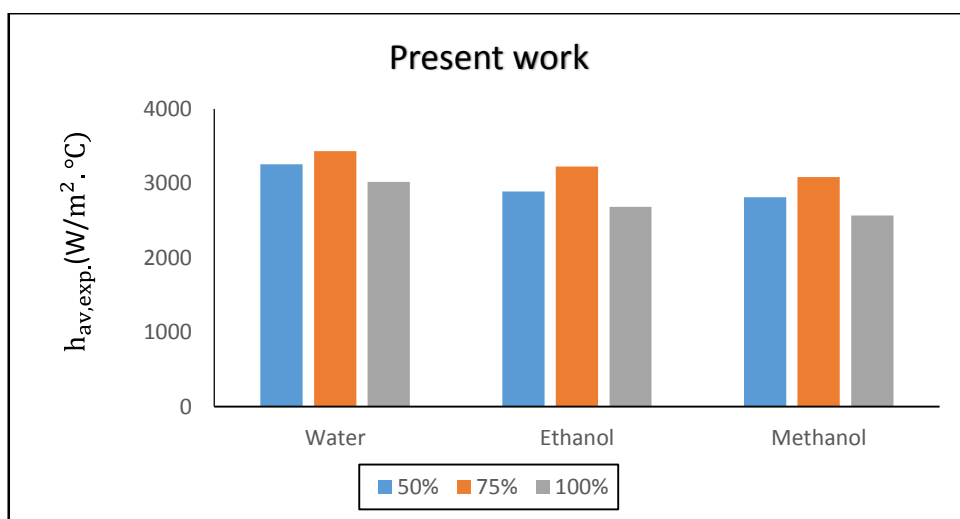


Figure.10 Average heat transfer coefficient for various FR= (50%,75% and100%) with three working fluids.

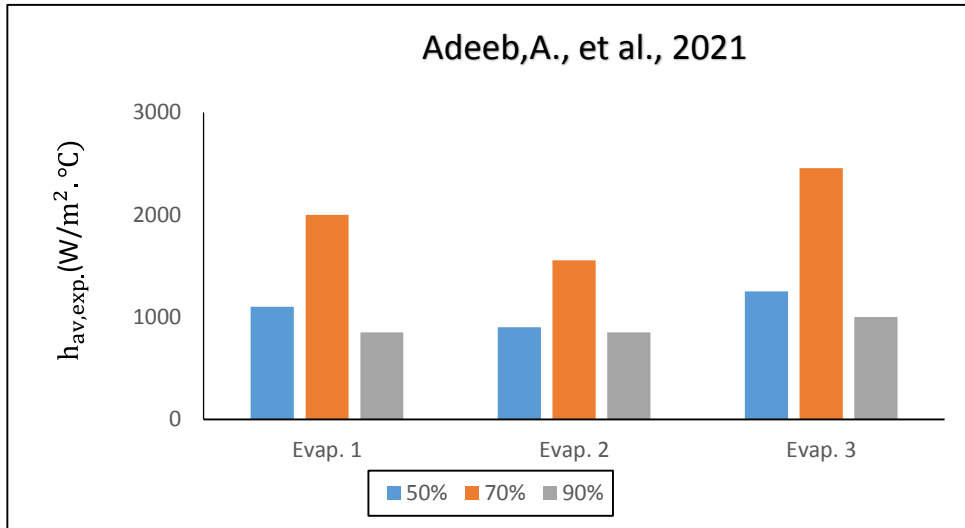


Figure.11 Average heat transfer coefficient for various FR= (50%,70% and 90%) with three different evaporators.

8.3 The influence of input heat rate on effective thermal conductivity($K_{eff.}$) of TPCTL

The effective thermal conductivity of TPCTL is summarized and plotted in figures. 12, 13 and 14 which are show that the effective thermal conductivity increases significantly with increases in the heat input rate. High effective thermal conductivity can be achieved by employing water to transport heat from the evaporator to the condenser sections, which the maximum value is 1732 W/m.°C at FR = 75%.

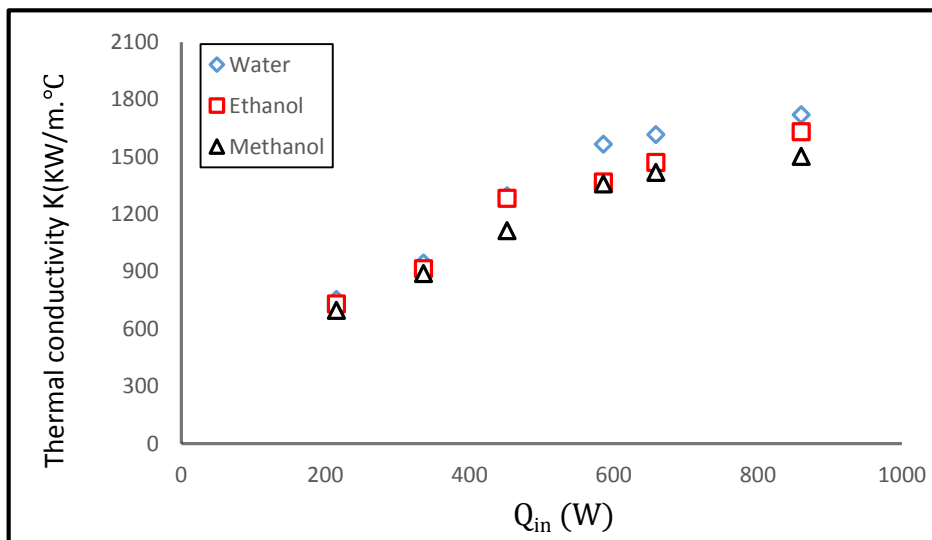


Figure. 12 Thermal conductivity for various heat inputs at FR= 50%. using three working fluids.

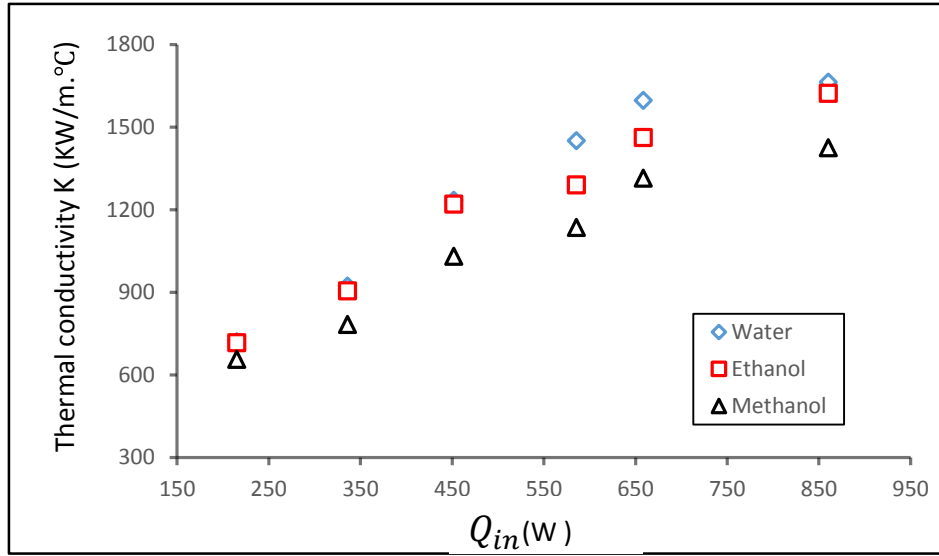


Figure. 13 The thermal conductivity for various heat inputs at FR= 75% using three working fluids.

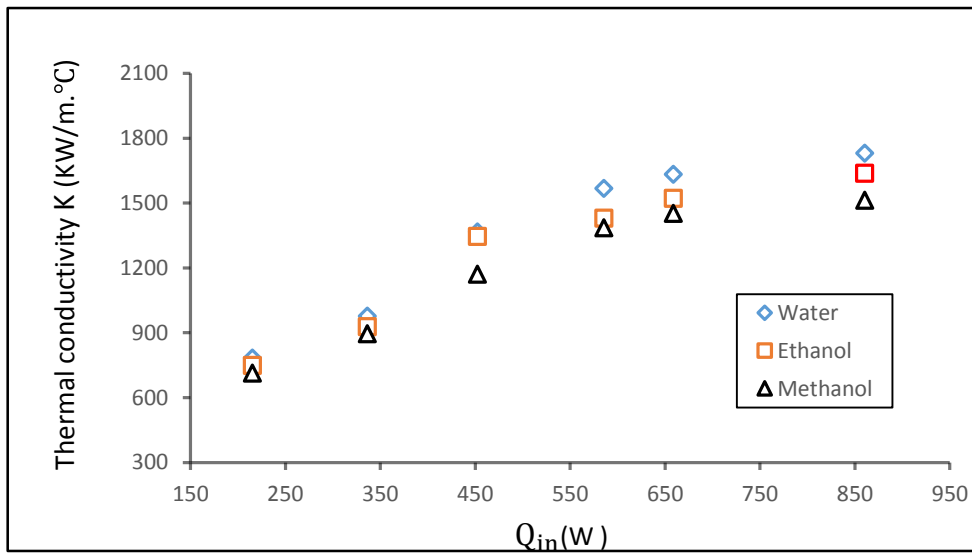


Figure.14 The thermal conductivity for various heat inputs at FR= 100% using three working fluids.



8.4 The influence of filling ratio on average effective thermal conductivity ($K_{av,exp.}$) of TPCTL

To assess the heat output of the thermosyphon filled with the working fluid, transfer capacity is treated as an equal- size, solid pipe. This solid pipe has a thermal conductivity as specified for the thermosyphon. The figure.15 illustrate shows that the average thermal conductivity for water is higher compared to ethanol and methanol because of the water has high latent heat (h_{fg}). The maximum value of the thermal conductivity for water at FR = 75% = 1343.75 W/m.°C while the minimum value ($K_{av,exp.}$) using methanol at 100% = 1058.54 W/m.°C. It can be observed the value of ($K_{av,exp.}$) between methanol and ethanol is approximately equal because of Cp and h_{fg} at bulk temperature are not much variation. These results of present work agreement with the results of (Adeeb, A., et al., 2021), at different parameters shown the figure.16.

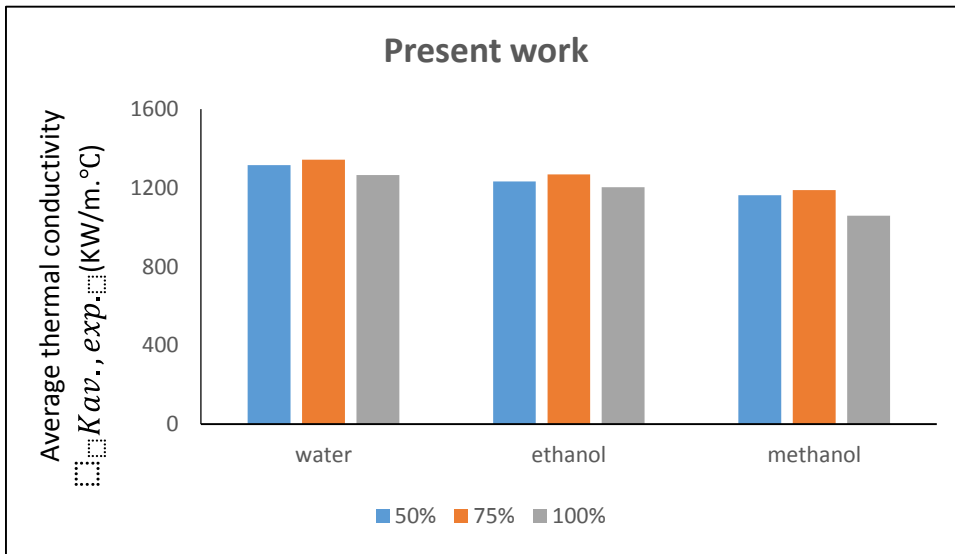


Figure.15 The average thermal conductivity for various FR= (50%, %75and100%) using three working fluids.

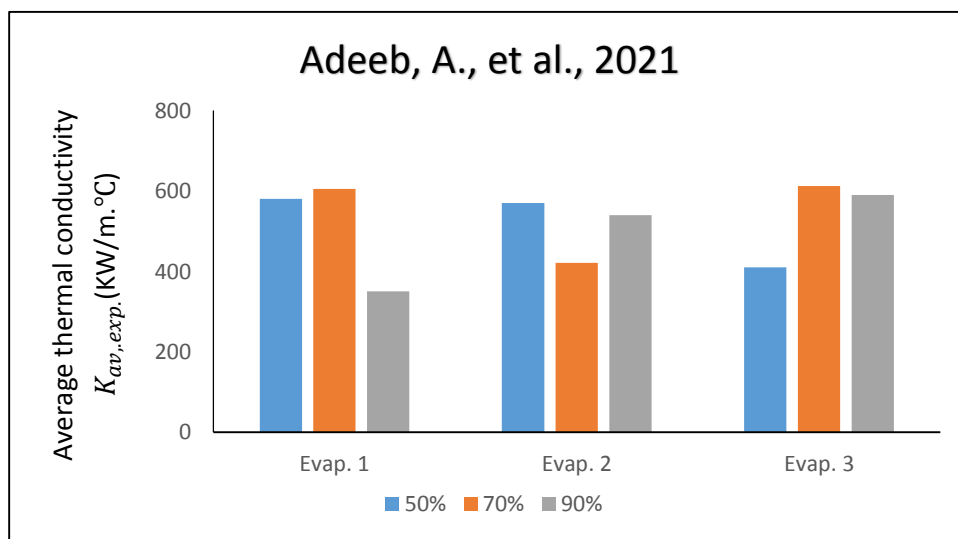


Figure.16 The average thermal conductivity for various FR= (50%, %70 and 90%) using three different evaporators.



8.5 The influence of heat input rate on overall thermal resistance ($R_{thermal}$) of TPCTL

Figs. 17, 18 ad 19 illustrate that the increasing the heat input rate causes a decrease in the overall thermal resistance $R_{thermal}$ at all filling ratios and using three working fluids. This is mainly due the change in the heat transfer mechanism in the evaporator section. At low heat input rate may be a liquid exists in the evaporator section and hence the heat transfer take place by convection for the liquid and evaporation in the thin film region at the wall. At higher heat input rate the height of the liquid decrease due to boiling rate increase leading to an increase in heat transfer area in the evaporator. The results show that TPCTL at low thermal resistance = 0.0111 °C /W has a high heat transfer coefficient using water at FR% = 75% and maximum $Q_{in} = 860.2$ W.

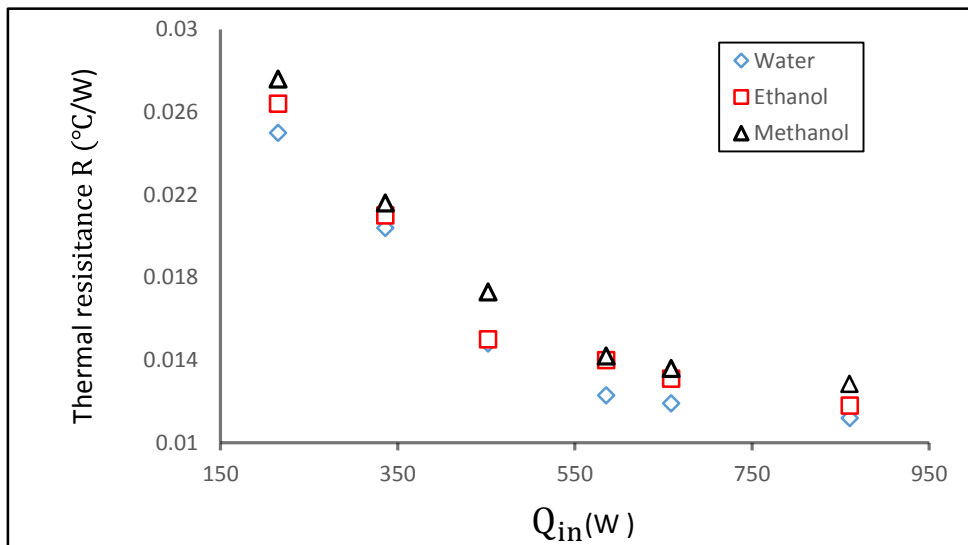


Figure.17 The thermal resistance for various heat inputs using three working fluids at FR= 50%.

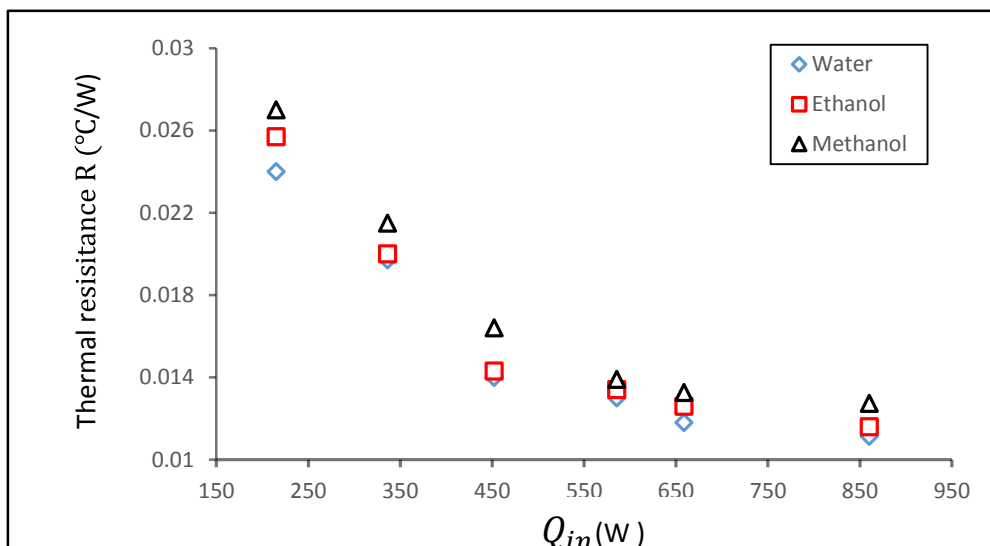


Figure.18 Thermal resistance for various heat inputs at FR= 75% using three working fluids.

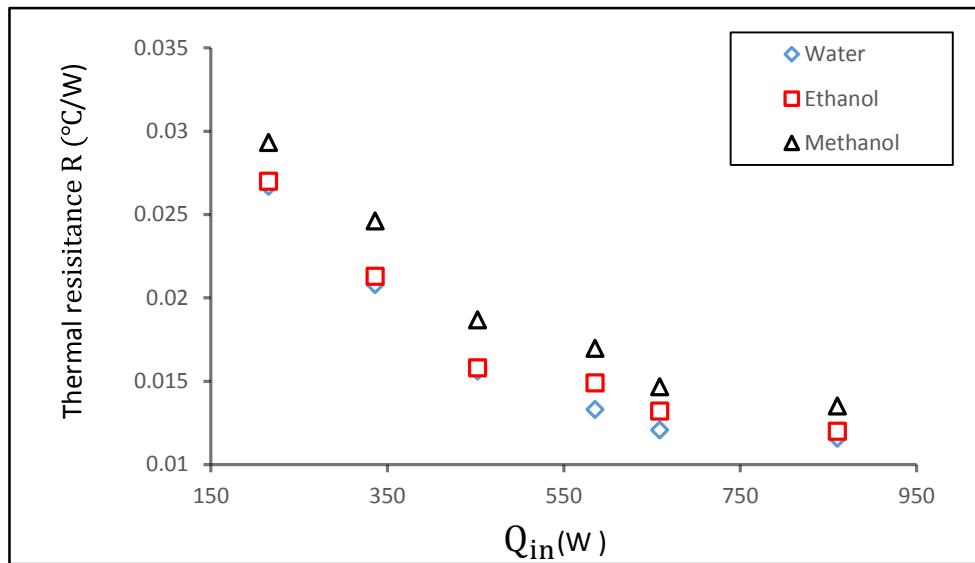


Figure.19 Thermal resistance for various heat inputs at FR= 100% using three working fluids.

8.6 The influence of filling ratio on average overall thermal resistance (R_{av}) of TPCTL

Fig.20 illustrate that the average overall thermal resistance slowly decrease with the increase in the filling ratio, even reaching to 75% filling ratio and then it gradually increase to reach FR =100%. The TPCTL has the smallest valve of thermal resistance at FR=75% with water and has greater thermal resistance for ethanol and methanol at same filling ratio, which increase the temperatures difference between the evaporator section and the condenser section, since the heat transfer coefficient is reduced. There is acceptable with (Adeeb, A., et al., 2021), as shown in the Fig.21.

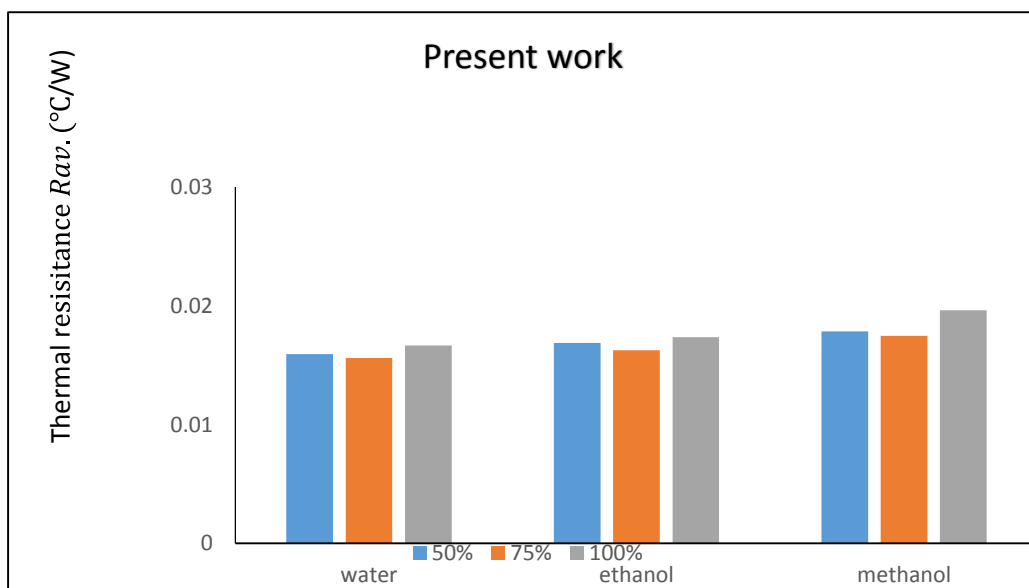


Figure.20 Average thermal resistance for various FR= (50%, %75 and100%) using three working fluids.

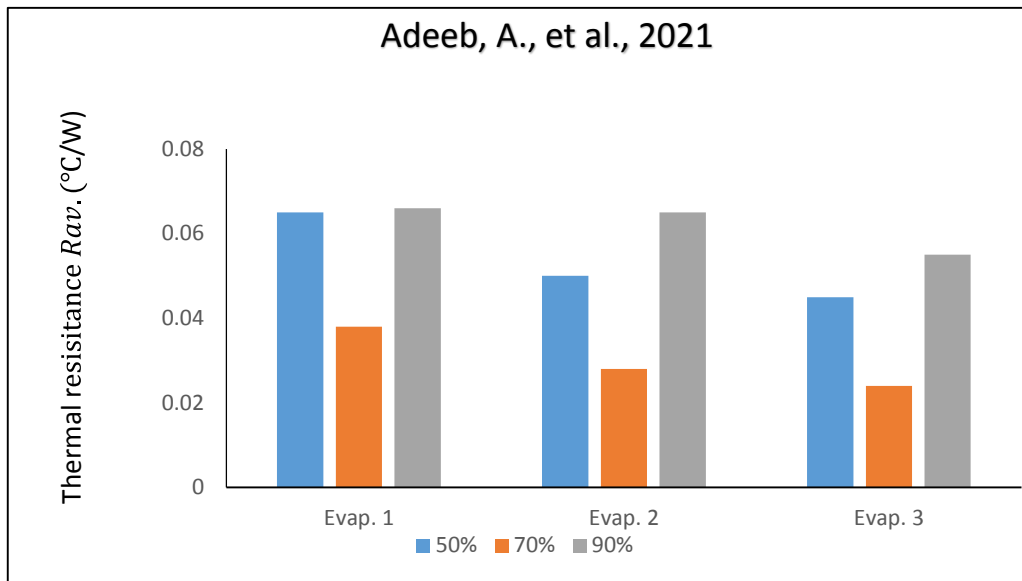


Figure.21 Average overall thermal resistance for various FR= (50%, %70 and90%) using three different evaporators.

8.7 The influence of filling ratio on overall heat transfer coefficient (U) of TPCTL

The influence of FR% on overall heat transfer coefficient investigation on the figures 22, 23 and 24 illustrate and indicate the U is increased with increasing of the heat input. As can be seen the overall heat transfer coefficient for water larger than for ethanol and methanol due to low overall thermal resistance between the evaporator and condenser. In other hand heat is conducted through over a series of resistant mediums, however in this study the water-thermal resistance is smaller lead to the value of the overall heat transfer coefficient is larger.

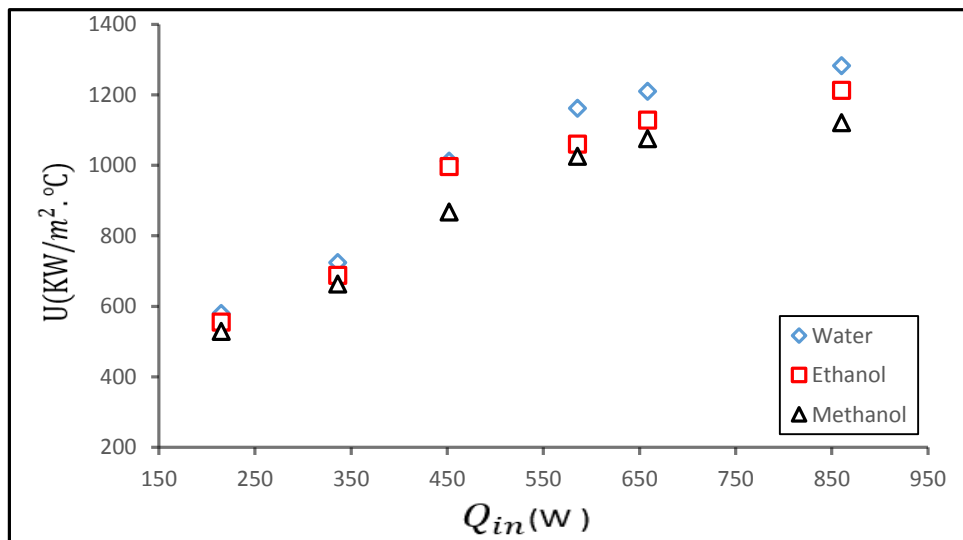


Figure. 22 Overall heat transfer coefficient for various heat at FR= 50% inputs using three working fluids.

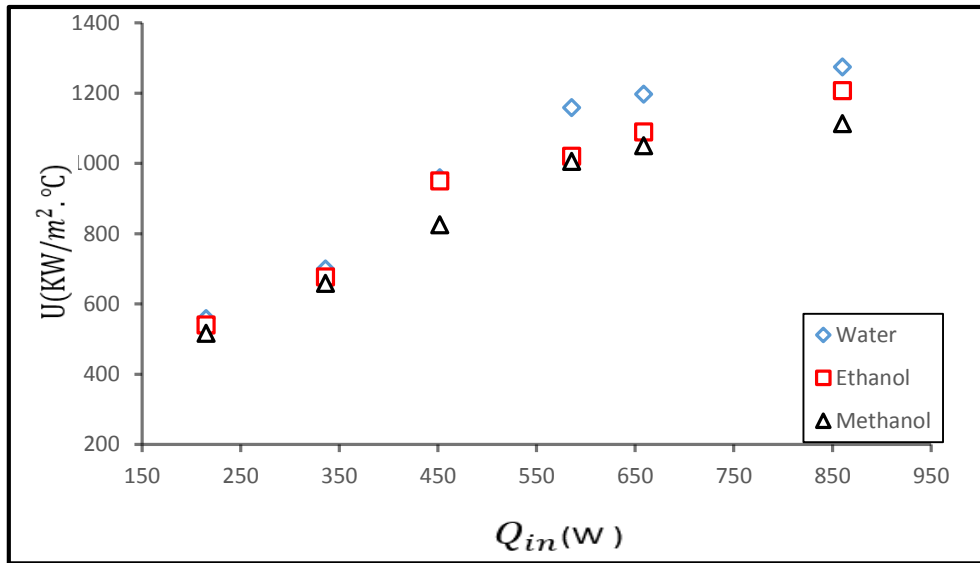


Figure.23 The overall heat transfer coefficient for various heat inputs at FR= 75% with three working fluids.

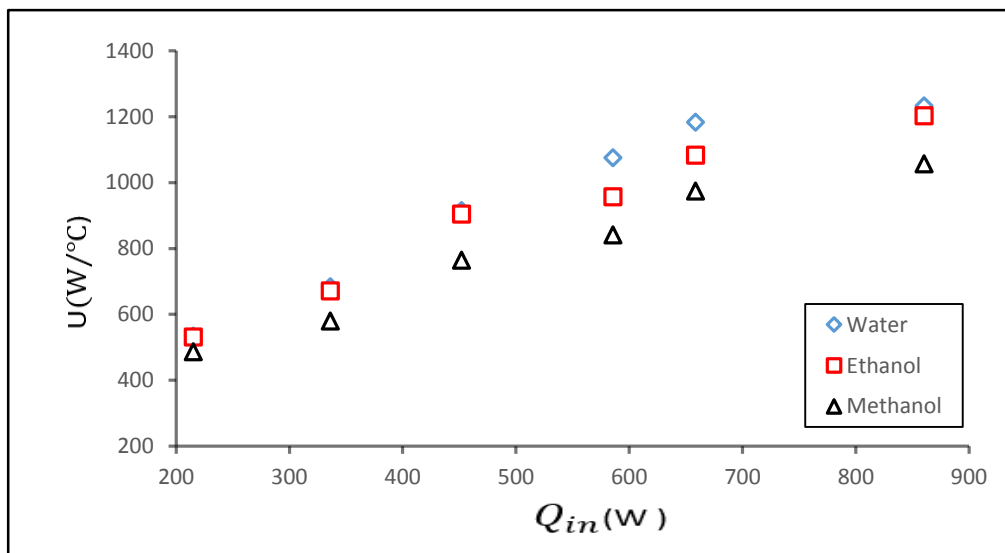


Figure.24 Overall heat transfer coefficient for various heat inputs with at FR= 100% three working fluids.

8.8 The influence of filling ratio on average overall heat transfer coefficient ($U_{av.}$) of TPCTL

Generally, The overall heat transfer coefficient is influenced by the thickness and thermal conductivity of the mediums through which heat is transferred. The figure.23 shows that the influence of FR% on average overall heat transfer coefficient ($U_{av.}$), where can be observed for water is higher compared to ethanol and methanol because the water has low average thermal resistance ($R_{av.}$). The maximum value of the $U_{av.} = 69.22 \text{ W/m}^2 \cdot ^\circ\text{C}$ for water at FR = 75%, while the minimum $U_{av.} = 55.04 \text{ W/m}^2 \cdot ^\circ\text{C}$ for methanol at 100%. The $U_{av.}$ is increased even reach to



the FR=75% where the values of U_{av} are decreased when the FR % increase. An increase in the filling ratio does not mean an improvement in thermal performance of thermosyphon loop.

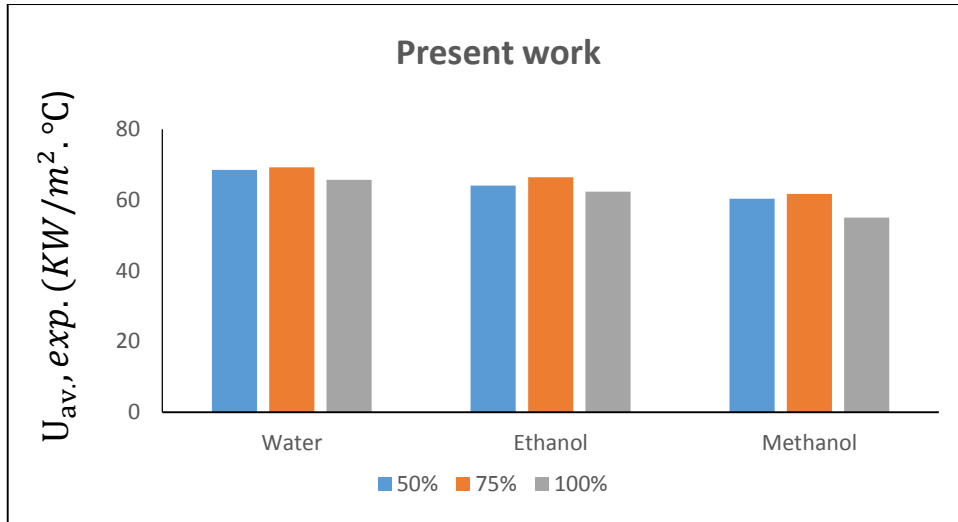


Figure.25 Average overall heat transfer coefficient for various FR= (50%, %75 and100%) using three working fluids.

8.9 Comparison theoretical and experimental heat transfer coefficient values with different heat input at optimum FR=75%

The heat transfer coefficient is a significant element for explaining the thermal performance. Figures.24, 25 and 26 illustrate the comparison between theoretical and experimental results for heat transfer coefficient (h). This comparison has been taken with optimum FR of 75% using water , ethanol and methanol. From these figures can be observed that the deviation range of heat transfer coefficient for water is between 215W to 450 W and it is not exceed max. of 5.9 % , while for ethanol and methanol their deviations are larger than water because the heat loss and different capacity of working fluid. The results show that the theoretical values of heat transfer coefficients of TPCTL are higher than experimental values because of the error coming from heat losses and environmental conditions effects. These two measurements show a good agreement, as the deviaton are within less than ± 16 for each value.

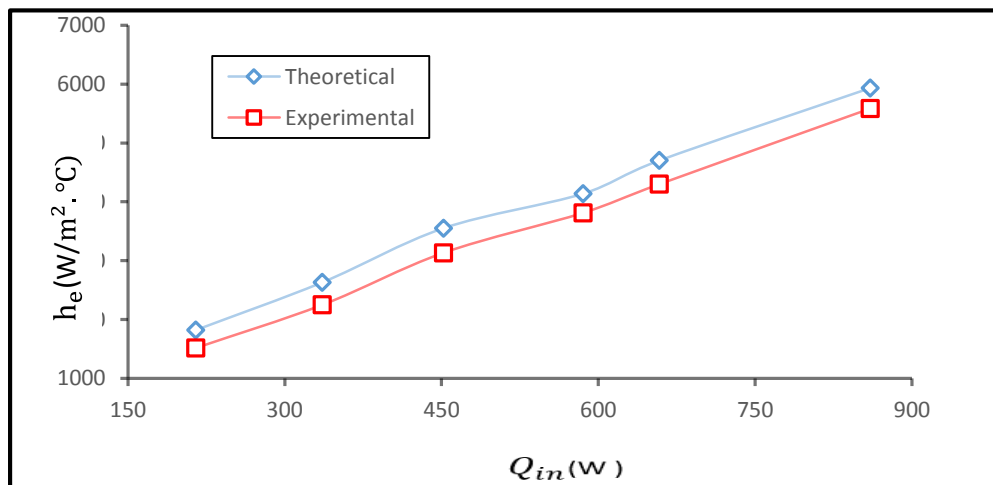


Figure.26 Theoretical and experimental heat transfer values with heat input at optimum filling ratio = 75% for Water.

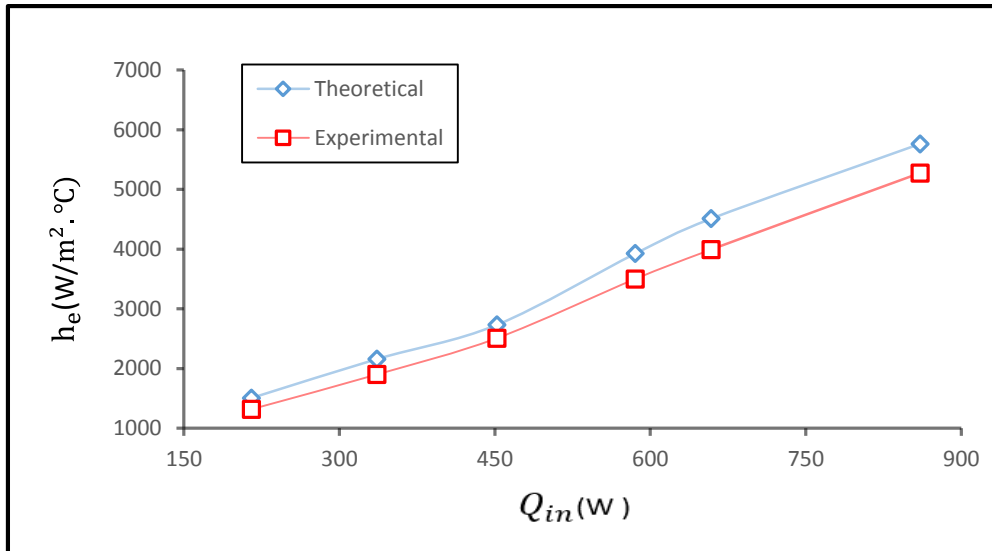


Figure.27 Theoretical and experimental heat transfer values with heat input at optimum filling ratio = 75% for Ethanol.

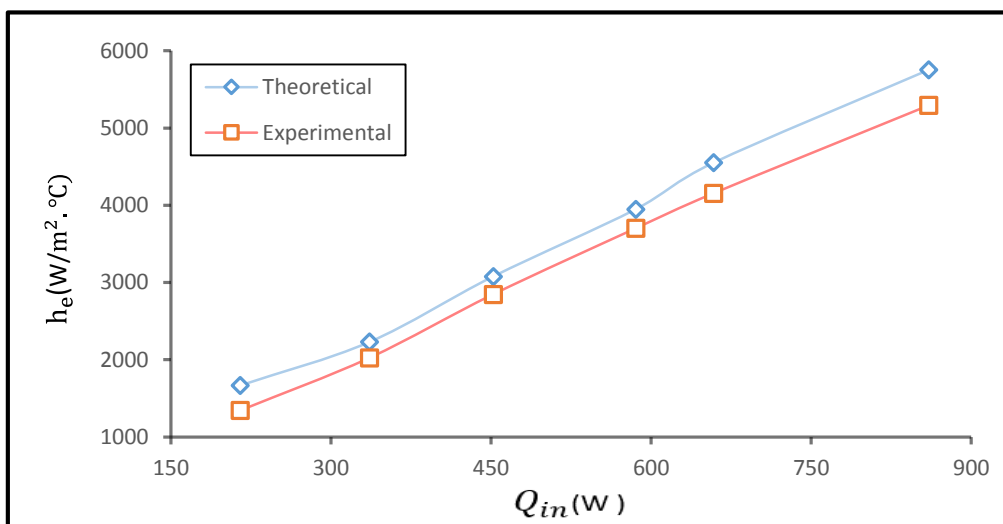


Figure.28 Theoretical and experimental heat transfer values with heat input at optimum filling ratio = 75% for Methanol.

7. CONCLUSIONS

1. The heat transfer coefficient for water is higher than ethanol and methanol for the same filling ratio and heat input because the water have a high latent heat.
2. The highest heat transfer coefficient is (5582 W/ m².°C) for water at filling ratio 75%.
3. It is found that when the boiling heat transfer occurs in the evaporator section with water , the temperature difference of the loop is lower and a high heat flux resulting a high heat transfer coefficient because the water have a high latent heat compared with ethanol and methanol.
4. The minimum value of the thermal resistance in the evaporator section is (0.0111 °C /W) with water and the highest effective thermal conductivity is for the same working fluid is (784.16 KW/ m. °C) using filling ratio 75%. This explain the maximum heat transfer in the evaporator section using water.



5. From above conclude the optimum filling ratio in this test is 75% and the thermal performance for water better than ethanol and methanol under the same different parameters

NOMENCLATURES

FR= filling ratio %
ID= inner diameter, mm
OD=outer diameter, mm
H= height of working fluid, mm
L= vertical distance between evaporator and condenser, mm
h= heat transfer coefficient, $W/m^2 \cdot ^\circ C$
 $Q_{elec.}$ = electrical power, W
 Q_{in} = heat input, W
 Q_{out} = heat removed, W
 $q_{av.}$ = heat flux at evaporator, W/m^2
 $T_{we,av.}$ = average wall temperature at evaporator, $^\circ C$
 $T_{v,av.}$ = vapor temperature at evaporator, $^\circ C$
 $T_{sat.}$ = saturation temperature, $^\circ C$
 m'_{cw} = mass flow rate for cooling water, L/min.
 cp_{cw} = specific heating for cooling water, KJ/kg. $^\circ C$
 A_e = surface area of evaporator, m^2
 C_{sf} = experimental constant
K= thermal conductivity, W/m. $^\circ C$
U= overall heat transfer coefficient, $KW/m^2 \cdot ^\circ C$
R= thermal resistance, $^\circ C/W$
 L_e = length of evaporator, mm
 L_c = length of condenser, mm
 σ = surface tension, N.m
 μ = dynamic viscosity, kg/m.s
 ρ = density, kg/m^3

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