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Article

An experimental investigation of the thermal analysis of a two-phase closed thermosyphon including an internal semi-circular finned condenser

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ABSTRACT

Extended fins play an important role in improving the thermal performance of many engineering applications. This manuscript studies the effect of hemi circular cross sectional longitudinal internal fins on the wickless heat pipe performance. The experimentally studied along the length of the internal section in the thermosyphon's condenser part, six hemi circular cross-section extended internal fins with a 4 mm radius circle are formed. Water is used as the working fluid in the internally finned thermosyphon at filling ratios of 20%, 50%, and 80%. Experiments are conducted at different powers: 100, 150, 175, 200, and 250 watts. The results showed that using hemispherical internal fins decreased the thermal resistance for filling ratio of 50%. The thermal resistance of finned Two phase closed thermosyphon also enhanced by 39% at low heat input.

Keywords

Thermosyphon, wickless heat pipe, internal semicircular fins, water, thermal resistance, experiment, filling ratio, internal fins, and condenser fins.

1. Introduction

One of the greatest troubles that face engineers is the higher rates of heat generation in many engineering applications. Thermal control of engineering devices plays an essential role in maintaining its best performance. Several cooling techniques are used for controlling thermal devices temperature like natural, forced convection, cooling by thermosyphon, and heat pipes.

The TPCT is used in many applications for transferring heat from one side to another side. Thermosyphons and heat pipes have been used for many applications for the purpose of waste heat energy recovery in many engineering applications as ventilation, air conditioning (HVAC) and heating. Water heating systems, electronic cooling, nuclear reactors and heat exchangers.

The thermosyphon has an extremely high thermal conductivity. The thermosyphons are referred as superconductors as they can transport a very high amount of thermal energy between two sides one is an evaporator and other is a condenser with a small temperature difference and over a small distance. It can transport Avery large quantities of heat with a small difference of temperature depending on the latent heat of the liquid inside the thermosyphon.

The TPCT consists of a tube inside which a quantity of liquid is inserted and the air inside it is evacuated, it is sealed. The lower portion of the tube is heated causing the liquid to vaporize and the vapor moves to the upper tube portion, at the top of the tube the vapor is condensed and returns back to the lower section by gravitational force. The lower portion of the thermosyphon is called the evaporator, the upper portion is the condenser part, and adiabatic section separates upper and lower parts (Evaporator and Condenser). The fluid inside the thermosyphon is called working fluid.

The main differences between the thermosyphons and the heat pipes are that heat pipes working fluids are returned to the evaporator by different methods. While TPCT by the gravity, no restriction to the evaporator position in heat pipes and it can operate in various orientations. For thermosyphons the evaporator must be at the lower part while for heat pipes with wick no restriction for the evaporator position, Figure 1 shows thermosyphon different parts.

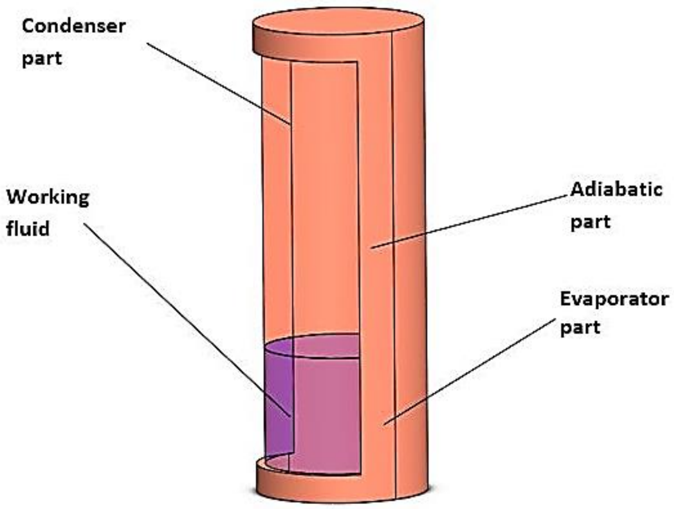

Figure 1: Thermosyphon different parts.

The thermosyphon has many advantages as it has excellent reversibility, high efficiency and simple design. Many researches have studied factors affecting the TPCT and improving its performance. The factors affect the TPCT performance are (Working fluid, Input power, Operating temperature. Inner surface roughness., Dimensions, orientation, diameter, Geometry and Filling ratio).

Several researches have studied fins effect on TPCT performance , Some researches that studied the different factors affecting TPCT performance are Kannan et al,[1] studied the TPCT performance with an electrical heater at bottom of evaporator portion. Four different working fluids (acetone, methanol, water, and ethanol.) were used at different fill ratios. At operating temperatures over than 40 °C, water had heat transfer ability higher than that of other fluids.

Jouhara et al , [2] Experimentally investigated small copper thermosyphons performance. The thermosyphons were charged with four different liquids water, FC-3283, FC-84, and FC-77. The choice of FC-3283, FC-84, and FC-77 as their wide thermophysical properties range and being dielectric fluids. For power larger than 40 watt the best used fluid was water, but below 40W the other used working fluids FC-77 and FC-84 offered adequate thermal performance.in addition to being dielectric that may be beneficial in some applications.

Engin Gedik, [3] Experimentally investigated three different liquids effect (water, ethylene glycol and ethanol.) for different operating conditions as coolant flow rate, heat inputs, and inclination angle on TPCT performance. Heat input and inclination angle had a significant effect on TPCT performance, best performance of working fluid differed according to heat input and coolant flow rate, no working fluid was the best at all conditions. For 200 watt heat input and the 10 L/h coolant flow rate water gave the best performance.

H.Z.abou-ziyan et al, [4] studied the TPCT performance under stationary and vibrated conditions. They used Water and R134a working fluids, Experiments performed for different conditions of liquid filling ratios, input heat flux, adiabatic part length, and vibration frequency. The TPCT vibration with R134a above the boiling limit enhanced by about 250% to the stationary state.

Rafal Andrzejczyk [5] studied TPCT charged with (water, SES36, and ethanol) performance. The TPCT heat transfer resistance was noticed to be affected by aspect ratio, input power, filling ratio, and working fluid type.

K.S. Ong, Md. Haider-E-Alahi [6] Experimentally determined fill ratio and temperature difference between condenser portion and bath. The results showed that heat flux transferred by TPCT is increased by increasing the coolant flow rate, working fluid fill ratio, and temperature differential between the bath and condenser sections.

T. Kiatsiriroat et al ,. [7] studied the TPCT performance using different binary fluids TEG-Water and water-ethanol mixture. This study studied three parameters affecting TPCT thermal performance (the heat pipe diameter, the mixture content and the working temperature). It was observed that the presence of TEG in the combination raises the crucial TPCT heat flux. The ethanol-water mixture had a higher heat transfer rate than water and was nearly as efficient as pure ethanol at low heat source temperatures.

S.H. Noie, [8] Experimentally investigated filling ratio, input rate of heat transfer and the evaporator length effect on TPCT performance. It was conducted that Maximum heat transfer rates for each aspect ratio take place at unique filling ratios.

Patil Aniket , Dr. Yarasu Ravindra [9] investigated the different factors affecting the TPCT performance The focus of the review was on the TPCT filling ratio, heat load, mass flow rate, inclination angle, aspect ratio, and heat transfer augmentation techniques such as ultrasonic wave and resurfacing.

M. R. SARMASTI EMAMI et all, [10] studied the impacts of fill ratio, aspect ratio, and inclination angle on TPCT performance. The oriented TPCT performance with a 60° inclination angle was extremely enhanced. It was also discovered that between 30 and 45 degrees, the heat transfer coefficient of condensation was maximum for all studied aspect ratios.

V. Dube et al, [11] Theoretically and experimentally investigated the NCG (NON-CONDENSABLE GASES) effects on the loop thermosyphon performance, the optimum reservoir installing location to trap the non-condensable gases and minimize their adverse effect on the effectiveness.

Qi Baojin [12] Experimentally studied TPCT characteristics made of two different materials. One made of commercially pure titanium while the other one material was copper.

V.M.Aguiar et all,.[13] Experimentally studied the TPCT with external circular fin performance, air forced convection cooled TPCT condenser section. Using fins improved the TPCT thermal performance.

Naresh. Y, Balaji. [14] Experimentally studied TPCT performance with internal rectangular fins; six internal rectangular fins were placed along condenser section length. The fins were 1mm and 5mm in terms of thickness and width respectively. Both water and acetone were used for 20, 50, and 80% filling ratios. Best performance occurs for 50% filling ratio. TPCT performance was improved by 17% as a term of temperature reduction and by 35.48% as a reduction of thermal resistance.

Naresh. Y, Balaji. [15] Studied TPCT with internal rectangular fins. Refrigerant134a was used as the TPCT working fluid. R134a charged internally finned thermosyphon heat transfer performance was superior compared to water charged TPCT.

RohitS Nair, C. Balaji [16] Added extended surfaces inside the condenser of TPCT ,Developed a numerical model that studied varying internal fins number effect on the thermal performance of wickless heat pipe.

M.ALIZADEH, D .D , Ganji, [17] studied TPCT with external longitude fins on the condenser parts ,Empirical correlations were developed to expect heat coefficients of both evaporator portion and condenser section as functions of thermosyphon different parameters as number of fins, filling ratio, coolant rate, and heat input.

The literature review indicated that many researches have studied the different factors affecting TPCT performance but a few researches have studied the internal fins effect, The internal fins are expected to enhance condensation rate due to increasing the inner surface area of the condense which leads to increasing the performance of TPCT. The fins effect at the condenser effect hasn’t been well studied no researches have studied the effect of semi-circular internal fins which is the scope of our study.

The novelty of the internally finned thermosyphon is that using the internal semicircular fins increases the condensation area and hence increasing the condensation rate by using the new profile of internal fins (semicircular longitudinal fins) along the condenser part caused the enhancement of the TPCT performance by lowering the TPCT thermal resistance.

2. Experimental setup and procedures

2.1. Experimental setup

A setup is constructed at heat transfer lab at mechanical department of engineering ZAGAZIGE University. A copper TPCT with semi-circular internal fins is tested. The working fluid used is water. The internally finned TPCT thermal performance is tested for varied fill ratios (the ratio between liquid pool volume to evaporator section volume.), and different input power. The evaporator is heated using an electrical heater that supplies heat required to evaporate the liquid pool, Thermocouples were used to measure temperature of the working fluid along TPCT length. The different parts forming this experiment are the thermosyphon pipe, the condenser jacket, Evaporator heating system, The Condenser cooling system, charging and evacuating tools, and Measuring devices. Figure two shows a schematic diagram of the different parts of the test reg.

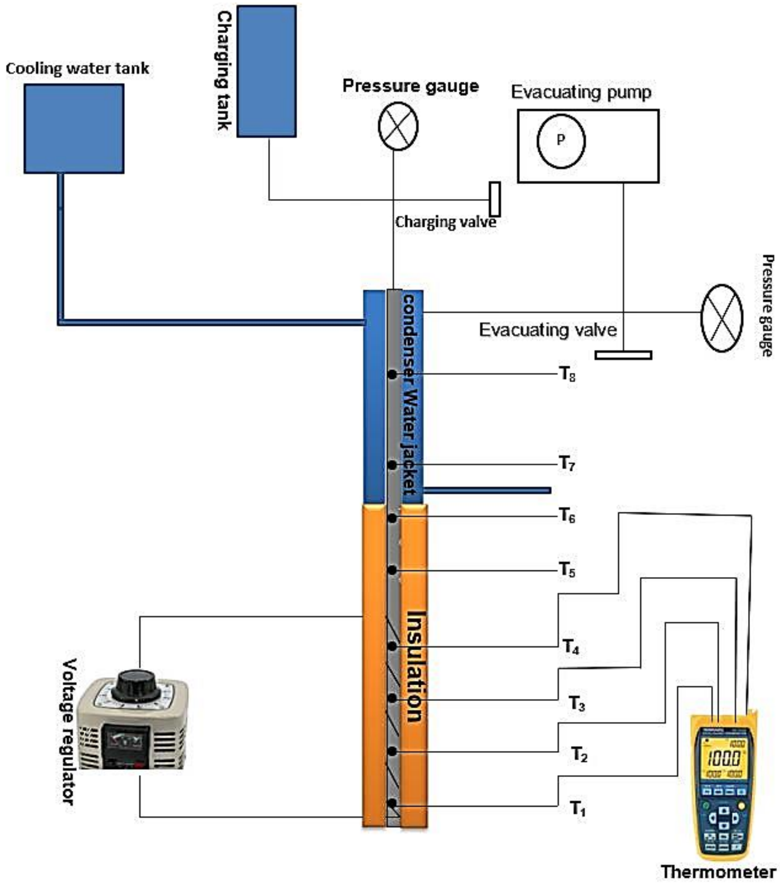

Figure 2: A diagram of the different parts of the test reg.

2.1.1. Thermosyphon and condenser jacket

Thermosyphon is made of a 500 mm length and 28 mm diameter copper bar. The tube is machined into two parts. The first part which is 30 cm is holed a through all longitude hole of inner diameter 24 mm using a press, the other part is machined using a wire cutting machine to form the internal longitude semicircular fins. The two parts are connected together by the thread on each part of them thermal O-rings are used in order to prevent leakage from the thermosyphon.

Figure 3: The internal fins and the cap with two opening at the condenser section.

These two parts forming TPCT tube, the tube forms the three TPCT parts, the evaporator portion which is the lower thermosyphon section, the adiabatic portion above evaporator section and the condenser where the internal fins are formed. A jacket around the condenser part made of plastic tube and the two ends of the jacket had two oil seals to prevent leakage of the flowing cooling water. The jacket had two openings one for the inlet of the flowing cooling water while the other for the purpose of discharge. The thermosyphon had two caps at each end made of steel to close TPCT tube, one of the caps is completely closed while the other cap had two openings, one where the pressure gauge is fitted and is used for charging the thermosyphon and the other had a valve for the purpose of evacuating the TPCT with the working fluid as shown in figure 3.

2.1.2. Evaporator heating system

The evaporator wall is heated by the heating system. Heat transfer occurs from the heating system to the evaporator wall then to the working fluid pool inside the evaporator. The heating system consists of an electrical heating wire which wraps the total length of the evaporator part. The electrical heater is connected to a VARIAC (electrical voltage controller). The VARIAC is used to control the input heating power to the heating wire. The wall of the evaporator is insulated by a thick layer of glass wool and a mica strip layer that covers the evaporator and the glass wool.

2.1.3. Condenser cooling system

A plastic jacket that wraps the condenser part is used to remove heat from the condenser part. Water flows inside the jacket to cool the condenser section and causes the working fluid inside the condenser to condense it. The cooling system consists of a tank where cooling water is suctioned, and a flow control valve. The tank has a float to keep the level of the water in the tank constant. The tank has a suction port where water passes from it to the water pump where it passes the condenser jacket passing through the flow control valve. The flowing water extracts heat from the condenser then flows outside the jacket. The temperature of the flowing water before entering and after leaving the jacket is measured by two thermocouples.

2.1.4. Charging and evacuating tools

At the end cap of the thermosyphon two ports with threads on it are made for the purpose of charging and evacuating of the thermosyphon. The first port has a vacuum gauge with a valve and a port where the vacuum valve is connected, in order to evacuate the thermosyphon tube to avoid the bad effects of the non-condensable gases. A one stage vacuum pump with an ultimate vacuum pressure of 5 pascal was used to evacuate the thermosyphon tube. The second port is used for the purpose of charging the thermosyphon with the working fluid.

2.1.5. Measuring devices

Measuring devices are used for the purpose of measuring temperature of the thermosyphon wall, the input power and the flowing water.

2.1.5.1. Temperature measurement devices

The wall of the thermosyphon temperature is measured to predict the performance of the thermosyphon eight k-type thermocouples are fixed on the surface of the thermosyphon at different positions. The thermocouples are fixed using adhesive epoxy. Four thermocouples are fixed at the evaporator wall, the thermocouples are inserted a way from the heating wire, two thermocouples are fixed at the adiabatic part, two thermocouples are fixed on the condenser tube part. In addition to the thermocouples fixed on the wall of the thermosiphon, two thermocouples are used at the inlet and the outlet of the flowing water and two thermocouples were inserted inside the glass wool insulation which wraps the evaporator. The thermocouples temperature is measured using (TENMARS 747DU device). The steady state temperature of the thermocouples is recorded for two working fluids. Figure four indicates the positions of thermocouples along the length of TPCT.

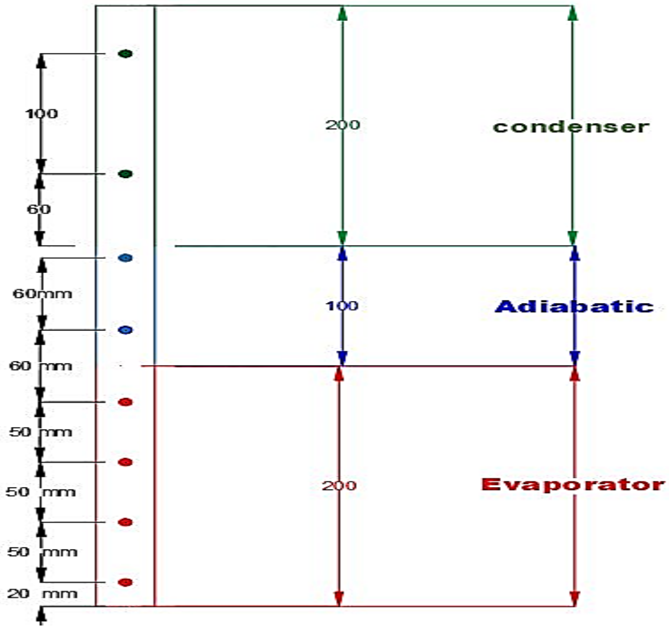

Figure 4: Position of thermocouples along the length of the thermosyphon.

The energy transported by the thermosyphon can be measured by measuring the heat transferred to the flowing cooling water by the thermosyphon. The heat transferred to the cooling water is measured by measuring the mass flow rate of the cooling water, the temperature difference between the inlet and the outlet cooling water temperature, the inlet and outlet temperature is measured by thermocouples. The heat rate transferred to the cooling water is calculated from equation 1:

$$\dot{Q}_{\mathrm{c}} = \dot{m}_{\mathrm{c}}\, C_p (T_{\mathrm{cwo}} - T_{\mathrm{cwin}}) \tag{1}$$

2.1.5.2. Power measurement devices

A voltage regulator (VARIAC) controls the power input to the evaporator heating coil. The voltage regulator input is connected to an electric AC current of 220 V, the output of the VARIAC (voltage regulator) is connected to the heating wire. Digital multimeter is used to measure the electrical voltage and electrical current.
The electric power is calculated from the relation:

$$P = V \times I \tag{2}$$

P Input power, V voltage difference, I electrical current.

2.1.6. Calibration

The thermocouples used during the experiments are calibrated using a thermostatic device. The calibration system for thermocouples consists of a thermostatic heater, thermometer and stirring device. The ten thermocouples are calibrated from 0 °C to 100 °C. The calibration process showed good agreement with the standard value. A deviation ranges of 1% occurs which is acceptable.

2.2. Pre experiment Preparation

A thermosyphon leakage test is performed before starting the experiment of finned TPCT performance. Air is supplied to the thermosyphon by an air compressor through the charging valve then the valves are closed and the thermosyphon valves are completely closed after that pressure up to 7 bar is stored inside the thermosyphon tube. The air is left inside the thermosyphon for 48 hours to make sure that no leakage occurs from the TPCT pipe. The pressure inside the TPCT tube is held constant and this makes sure that no leakage occurred. After that the air is evacuated from the tube. Another leakage test is performed for the water jacket leakage of the flowing water by flowing water in the condenser jacket and noticing the water leakage by the eye. The leakage openings are closed by epoxy. The thermocouples connections are examined before starting the tests. The coolant flow rate is set to a desired value. The flow rate of water inside the jacket on the condenser remained constant during the experiments.

2.3. Experiment Procedures

After the leakage test is performed, the thermosyphon test rig is prepared and the thermosyphon heating wire is connected to the VARIAC output, the input of the voltage controller is connected to the AC current source. The cooling jacket inlet is connected to the water pump outlet passing through the inline rotameter. Then the outlet of the water jacket is connected to the discharge line. The vacuum pump is connected to a port at the cap at the end of the condenser part. The working fluid (water) is charged to the thermosyphon tube through the charging valve. The vacuum pump is turned on to evacuate the thermosyphon from the non-condensable gases. The vacuum valve is closed, the pump is turned off when the pressure inside the pump reaches 1 kg/cm^2 which is the desired required operating pressure.

The thermosyphon is fixed over an iron structure. At the first test the various voltage regulator (VARIAC.) is set to 100 watt, the charged working fluid volume is 20% of the TPCT pipe, cooling water is allowed to flow to the water jacket. The TPCT tube temperature is recorded by using TENMARS 744DU device. The test is repeated three times to make sure of the results. After the first test results are recorded, the input power is changed to 150, 175, 200, and 250 watts for the same fill ratio, same coolant flow, and all the tests are also performed for vertical position. The results are recorded for each test at steady state condition (the TPCT temperature is constant at same points and don't change with time but change from one position to the other.).

The TPCT is then evacuated again. It is charged again; water volume is 50% of the evaporator section (filling ratio is 50%). The input power is set to 150 watt, the tests are performed also for different power inputs. The temperature of thermosyphon tube is measured and the TPCT thermal resistance is calculated for each case.

3. Results and discussion

The TPCT with internal longitudinal hemispherical fins charged with water is studied for different filling ratios and different input power. The filling ratios studied are (20%, 50%, and 80%). Water is chosen as a working fluid due to its good thermophysical properties and its high latent heat of vaporization and condensation.

After evacuating the thermosyphon and charging it with water. The water volume in the pool at the lower section is 20% of the evaporator (20% filling ratio). Power is applied to the heating rope and heat transfers to the TPCT external wall by conduction then heat transfer to the liquid. The temperature of the water heats up, when water reaches the boiling temperature, it evaporates. The vapor rises up where it loses heat to the flowing cooling water and gets condensed. The condensed water returns back to the evaporator. The TPCT temperature is measured since the power is applied to the heating rope. The results are recorded when the temperature is constant at each point (the temperature variation doesn't exceed 0.1^0C). The thermosyphon temperature is recorded at eight points for three filling ratios (20%, 50%, and 80%). The TPCT evaporator length is 200 mm where four thermocouples measure the evaporator temperature (T_1, T_2, T_3, T_4) according to the experimental results for 20% and 50% fill ratio the temperature of first and second thermocouples (T_1, T_2) is approximately equal, Third and fourth thermocouple temperature is nearly equal for 50% Filling ratio and power levels of 100,150 watts. Figure 5, 6, and 7 show temperature variation along the TPCT for filling ratio of 20%, 50%, and 80%.

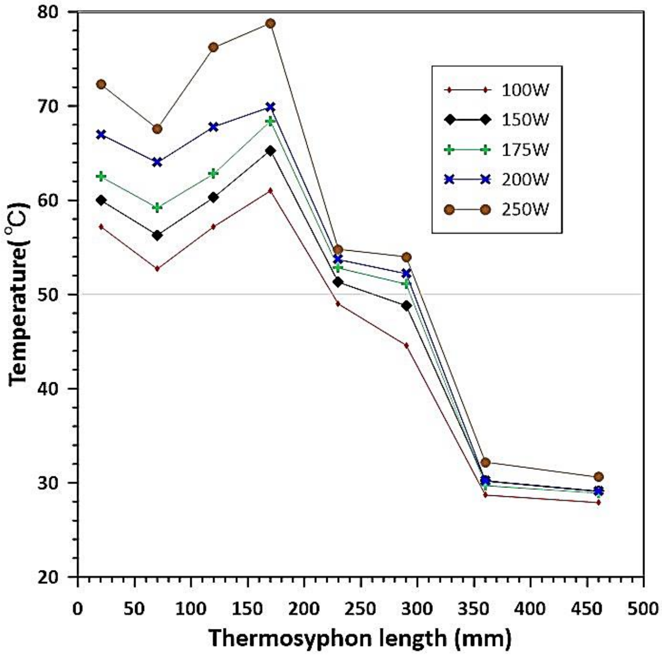

Figure 5: Temperature variation along the length of the thermosyphon for 20% filling ratio.

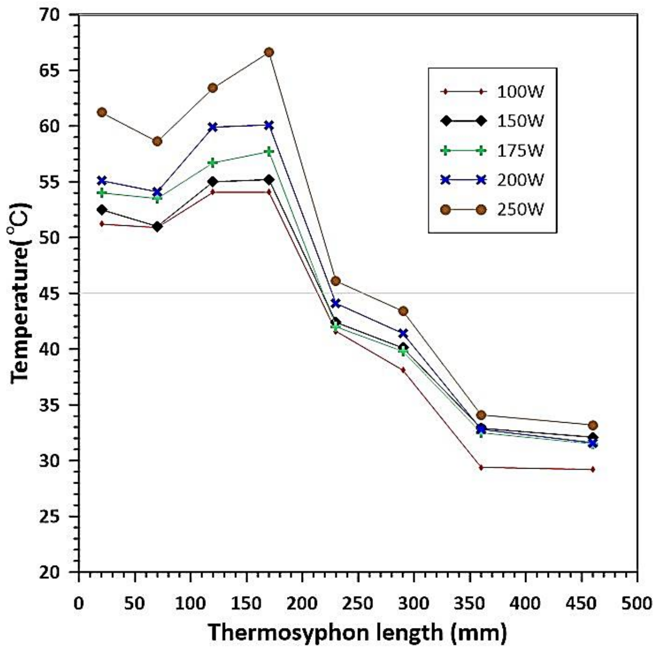

Figure 6: temperature variation along the length of the thermosyphon for 50% filling ratio.

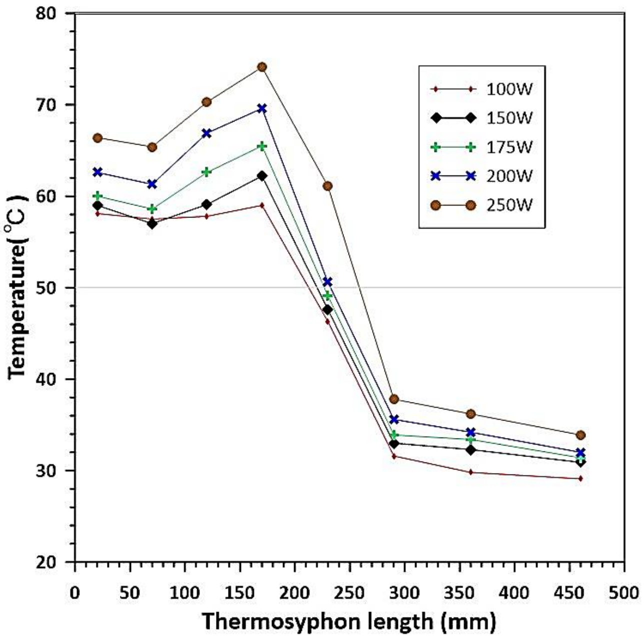

Figure 7: temperature variation along the length of the thermosyphon for 80% filling ratio.

The TPCT evaporator average temperature for 20%, 50%, and 80% filling ratio are 57.03 °C, 46.8 °C, and 28.3 °C at power level of 100 watt. Figures 8, 9, and 10 indicate the average temperature for different thermosyphon parts at different filling ratios for different input power level.

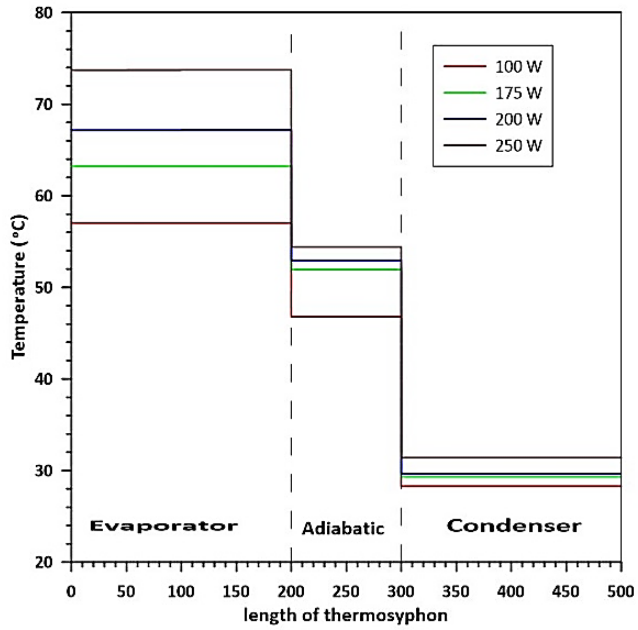

Figure 8: Average temperature of TPCT for 20% filling ratio.

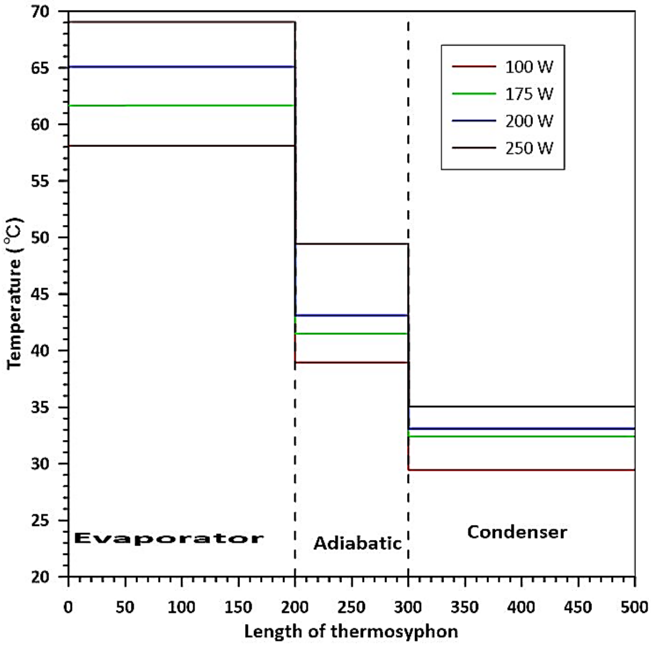

Figure 9: Average temperature of TPCT for 50% filling ratio.

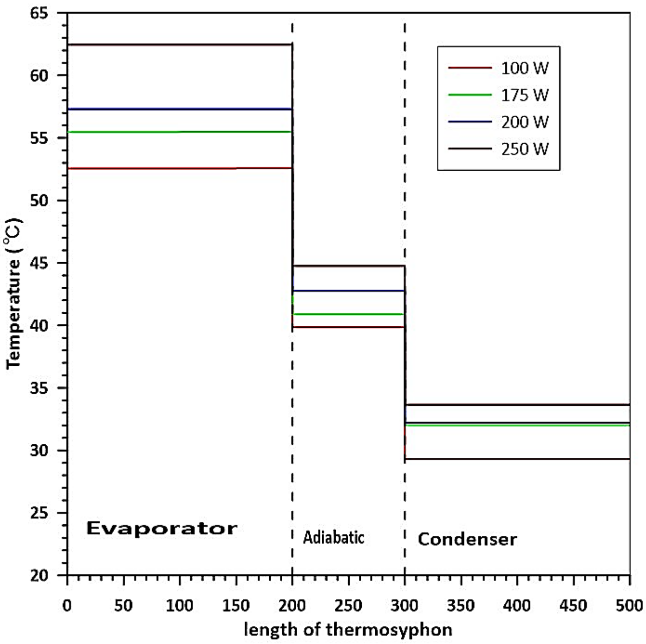

Figure 10: Average temperature of TPCT for 80% filling ratio.

The TPCT with fins thermal resistance is calculated from the relation

$$R_{th} = \frac{\Delta T_{avg}}{\dot{Q}} \tag{3}$$

Where, ΔT_{avg} is the average TPCT temperature difference between the TPCT evaporator and condenser.

Figure 11 indicates The TPCT with semi-circular fins Thermal resistance, the results showed that the lowest thermal resistance of the thermosyphon occurred at 50% filling ratio, Results showed the higher heat input the lower TPCT thermal resistance occurs, the worst thermal resistance occurred at filling ratio of 80% due to the overfilling of the thermosyphon. Form results a 39% thermal resistance enhancement for power level of 100 watt at 50% water fill ratio when compared with literatures [14].

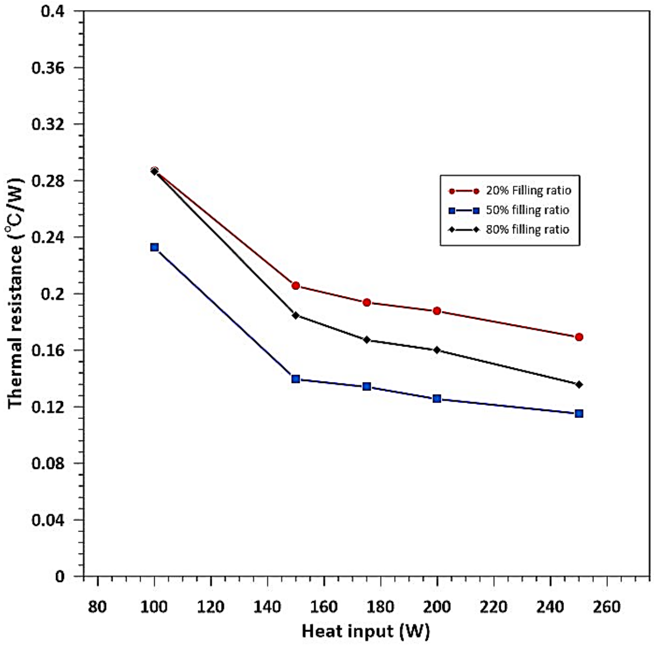

Figure 11: Thermosyphon thermal resistance variation for different filling ratio.

4. Conclusion

A two-phase closed thermosyphon is manufactured to include internal semi-circular fins, the thermosyphon material is copper, Water is used as the working fluid for different filling ratios of 20%, 50%, and 80% and input power levels of 100, 150, 175, and 200 watts. The thermal performance of the TPCT is studied experimentally, the main conclusions of this experimental work are, The greatest performance of the finned thermosyphon was achieved at a filling ratio of 50% of the evaporator portion, with a thermal resistance lowering of 39% when compared to previously research work. The worst thermal performance occurred at filling ratio of 20% and power input level of 100 watt.

Nomenclature

$\dot{m}_c$	Cooling water mass flow rate, kg/s
$\dot{Q}$	Heat rate, W
R_{th}	Thermal resistance, ℃/W
T_{cwin}	Cooling water temperature at the inlet, ℃
T_{cwo}	Cooling water temperature at the outlet, ℃
TPCT	Two-phase closed thermosyphon.

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