Comparative Study of Two Phase Closed Thermosyphon with Different Fluids and Fill Volume Ratio

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Abstract: *In this paper an experimental study was performed to observe the effect of fill volume ratio, inclination angle and heat input supplied to understand the heat transfer characteristics of a two phase closed thermosyphon (TPCT) charged with glycol and water. For the experimentation purpose four copper TPCT's of same dimensions were designed which are filled with aqueous solution of Propylene Glycol (PG) with 50% purity and De-ionized (DI) water with fill volume ratio of 40% and 60% and are heated with hot water in evaporator jacket from 60°C to 90°C. TPCT's were also tested for the inclination of 0° to 50° from vertical. Temperature distributions along the length of TPCT's were noted, heat supplied to evaporator along with heat removed from condenser section were also measured. The experimental results indicate that the PG TPCT works better at higher heat inputs and its optimum inclination angle is between 20° to 30° and that for DI water TPCT is 10° to 20°. Efficiencies of TPCT's were found to increase with respect to increase in heat input but are less affected with fill volume effect.*

Keywords: *Efficiency, Fill Volume Ratio, Heat Inputs, Inclination Angle, Two Phase Closed Thermosyphon.*

I. Introduction

In the today's world, the scientific community is striving for effective utilization of energy. As we all know energy can neither be created nor be destroyed but it can be used effectively so that we can use it more efficiently. In an attempt of effective utilization of energy, the fluids used in the heat transfer felid hold the great potential in improving the thermal performance of the system.

At present [1], one of the most intensively discussed options is the usage of high heat carrying fluids in thermal systems. The high thermal conductivity of these fluid leads to an increased overall heat carrying capacity of thermal systems. The TPCT is one of the thermal systems considered in this work whose thermal performance is evaluated by using suitable working fluid. The TPCT is an efficient heat transfer device. It transfers a large amount of heat with very small temperature difference. It is vertically oriented with liquid pool at bottom filled under negative pressure. Heat is given to evaporator section and vapour forms rises up to the condenser section where it condense heat to the surrounding and return to the evaporator section along with the tube wall due to gravitational force. The main benefit of TPCT is that it requires no mechanical pumping furthermore which makes it inexpensive and reliable. Hence it is widely used because of its simple structure when compared to other types of heat exchangers. TPCT's [2] are being used in wide variety of applications depending upon their heat transfer ability such as solar energy utilization, geothermal conservation, die casting and injection molding, heat cooling of batteries, waste heat recovery, spacecraft application, computer electronics etc.

The heat transfer characteristics of TPCT have been investigated by many researchers for various types of fluids like water, alcohols, refrigerants etc. but most of the investigations have been limited to either low or high heat inputs [3]. S H Noie et al. [4] experimentally studied the effect of the inclination angle on the thermal performance of a TPCT with different filling ratios under normal operating conditions. A series of experiments were carried out for inclination angle range of 5° to 90° and filling ratios of 15%, 22%, and 30%. The results show that the TPCT has the highest thermal performance in the inclination angle range of 15° to 60° for 30% filling ratio. M. Karthikeyan et al. [5] determines the heat transfer coefficient of evaporator of aqueous solution of n-butanol is nearly 55% higher than that of DI water for 75° inclination and 80 W heat input. The thermal resistance of aqueous solution of n-butanol is less than the de-ionized water for all the variables. A. Nuntaphan et al. [6] in his research found that the use of TEG–water mixture can extend the heat transport limitation compared with pure water and higher heat transfer is obtained compared with pure TEG at high temperature applications. R Park et al. [7] used working fluids as water-ethanol, water-ethylene glycol and water-glycerol. The results obtained shows the overall heat transfer coefficient was found to increase considerably with increasing adiabatic temperature. The thermosyphon exhibits the highest performance at the angle of about 60°. H. Mirshahi et al. [8] studied the effect of the heat flux, cooling water flow rate, fill ratio and extra volume on the overall performance of a partially vacuumed thermosyphon. It was seen that the thermosyphon loses its performance as the trapped gas occupies the whole condenser. Due to the existence of the trapped gas,

increasing the heat load to the evaporator of the thermosyphon, increase of cooling water flow rate decreases the performance of the thermosyphon and to access the maximum performance of a thermosyphon when employing it for transferring heat at lower temperature, more vacuum should be established inside it.

M. Kannan et al. [9] studied the performance of a TPCT for various input heat of 0 to 1000 W and for various working fluids such as distilled water, ethanol, methanol and acetone. The maximum heat transport capability shows an increasing trend with increasing operating temperature. Maximum heat transport capability was found to strongly depend on the operating temperature. As the operating temperature is increased from 40°C to 70 °C, the maximum heat transport capability is also increased from 425 to 650 W for water. Park et al. [10] investigated the heat transfer characteristics of two phase thermosyphon to the fill charge ratio. For small fill charge ratio the dry out limitations occurs and large fill charge ratio flooding phenomenon was observed. M Rahimi et al. [11] used water as a working fluid with 75% as fill volume and tested for 44 power inputs. The results show that it will be possible to increase the average thermal performance by15.27% and decrease the thermal resistance by 2.35 times compared with the plain thermosyphon. N Zhang [12] suggests an innovation of heat-pipe system by using new working fluids, using dilute aqueous solutions of long chain alcohols to replace water as the working fluid for their unusual surface tension characteristics. Water can be replaced by a dilute aqueous solution of long-chain alcohols. Because of the unusual characteristics of surface-tension gradient with temperature of the new working fluids, the capillary limit and the boiling limit of the heat pipe systems are increased significantly, and consequently, the more large heat load can be reached. K Joudi et al. [13] studied the effect of TPCT orientation on temperature distribution at positive inclination angles ranging from 90° to 22.5°and for different heat pipe lengths. When the heat flux was increased from 26 kW/m^2 to 31.8 kW/m^2, the optimum inclination was 45° for all different lengths of pipe. The presence of the adiabatic separator in TPCT resulted in a marked increase in heat transfer coefficient by 35%. S Lips et al. [14] conducted experiments in a smooth inclined tube for the whole range of inclination angles. R134a at a saturation temperature of 40°C was used working fluid. An optimal inclination angle that leads to the highest heat transfer coefficient can be found, the increase of heat transfer can be up to 20% for an inclination angle of 75°. A. K. Mozumder et al. [15] design, fabricate and test a miniature heat pipe with a thermal capacity of 10 W. Experiments were conducted for different thermal loads to assess the performance of heat pipe. The working fluids chosen were water, methanol and acetone. The temperature distribution across the heat pipe was measured. The performance of the heat pipe was quantified in terms of thermal resistance and overall heat transfer coefficient. The amount of liquid filled was varied as 35%, 55%, 85% and 100% of the evaporator volume and the variation of the performance is observed. The fill ratio of working fluid is shown to have minimum effect on the performance of heat pipe with respect to the temperature difference when water and methanol are used as working fluids. For acetone as the working fluid, 100% fill ratio of evaporator volume shows the best result with minimum temperature difference across the evaporator and condenser. In general, fill ratios of working fluid greater than 85% of volume of evaporator show better results.

From the available literature survey it has been observed that a lot of experimental work had been done on the performance evaluation of TPCT's for fluids like alcohols and refrigerants. However, there is a scarcity of literature available which highlights on the usage of glycols and there it requires a need to gain a better insight in to the usage of such fluids in TPCT's. An investigation to see the effects of fill volume ratio is also needed. This study is carried out to see whether TPCT's charged with different fill volume of PG can enhance heat transfer and thermal performance for different inclinations and heat inputs given and results obtained are compared with the TPCT's charged same fill volume of DI water.

II.   Experimental Setup and Procedure

Experimental setup for studying the thermal behavior of a TPCT using PG and DI water as a working fluid with varying fill volume ratio is shown in Fig. 1. For conducting the experimentation four copper TPCT's of same dimensions (L = 1000 mm, ID = 17 mm and OD = 19 mm) were designed. TPCT's are charged with fill volume (the ratio of liquid volume filled to the total volume of evaporator section) of 40% and 60% with respective working fluids filled under the pressure of 10^{-2} Torr. The set up consists of hot water tank, evaporator jacket and condenser jacket along with measuring instruments. The hot water tank is used to heat up the water and this hot water is circulated in evaporator jacket with electric motor pump of 0.25hp. The tank is incorporated with 1000 W heater to heat the cold water in the hot water tank. Evaporator jacket is a rectangular tank in which TPCT is placed. The hot water from hot water tank is allowed to enter in the evaporator jacket, which heats up the evaporative section of TPCT. Condenser jacket is made up of PVC pipe of 31.25 mm ID; it acts as a cooling water jacket and is used to remove the heat from the condenser section. The TPCT has the ability to transfer large amount of heat. As a result of which, a sudden rise in the wall temperature would damage the TPCT when the heat is not released correctly at the condenser end. Therefore, cooling water is dispersed first through the water jacket before supplying the heat to evaporator section. Flow rate of water is kept constant at 0.033 kg/sec in both the sections and it is measured by the amount of the water flows over an

Fig: 1. Actual photograph of the experimental setup

Table 1:- Specifications of experimental setup

Sr. No.	Specification	Sr. No.	Specification	Sr. No.	Specification
1	Energy Meter	2	PID controller	3	Temperature Indicator
4	Motor	5	Hot Water Tank	6	Evaporator Jacket
7	Hot Water Inlet	8	Hot Water Outlet	9	Two Phase Closed Thermosyphon
10	Condenser Inlet	11	Condenser Outlet	12	Condenser Jacket
13	Main Frame	14	Base Stand	15	Inclination Marks

interval of time. Digital temperature indicator of 12 channels is used to measure the temperature. The surface temperature distribution of the TPCT is measured with eight copper constantan (K type) thermocouples with an accuracy of $\pm 1°C$ as shown in Fig.2.

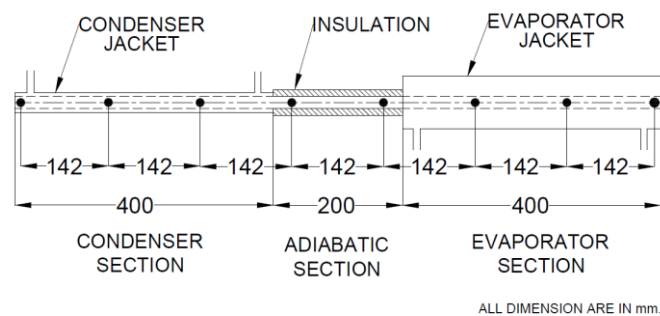**Fig: 2.** Location of Thermocouples on TPCT [1]

Three thermocouples are installed on evaporator section (Le = 400 mm); three are on condenser (Lc = 400 mm) and two on adiabatic section (La = 200 mm). In addition to that, two thermocouples are placed at hot water tank and condenser jacket inlet and outlet. A PID controller is used to cut off the heater by sensing evaporator jacket temperature. This thermocouple makes the assurance of desired temperature achievement in evaporator jacket. The hot water is continuously circulated from hot water tank to evaporator jacket so as to achieve uniform temperature in evaporator jacket. Glass wool insulation of 12mm thickness is provided to adiabatic section, evaporator jacket, hot water tank and piping systems to avoid the heat loss to the surrounding. An energy meter is provided to measure energy consumption while conducting the experimentation. An angle holder slot is provided for giving tilt to TPCT from 0° to 60° inclination with a step size of 10° from vertical. The experimental procedure is already explained in author's previous work [1].

III. Statistical Data Analysis
The [1] enormous experimental data obtained is verified statistically, in which the measure of central tendency, dispersion, asymmetry and relationship is determined. The data obtained shows closeness to mean value. Dispersion obtained shows standard deviation is between 0.4 - 3 but for most readings it is close to 1. Skewness obtained with Pearson method is between − 1.2 to +1.2 but for the majority of the readings it is closed

to 0 and for maximum reading the Karl Pearson Correlation exists positive. The probable error in the measured correlation is 0.56.

IV. Experimental Results and Discussion

A series of experiments were conducted to find the effect of variable parameters on the thermal performance of an inclined TPCT charged with different fluids and fill volume ratio for different heat inputs. The temperature distribution along the length of TPCT, evaporative and condenser heat transfer coefficients, heat transfer, thermal resistance and efficiency were examined.

4.1. Temperature Distribution along the TPCT surface

The temperature variation along the length (outer surface) of TPCT is monitored and recorded carefully with the help of thermocouples provided in the respective evaporator, adiabatic and condenser sections. From Fig 3(a-d), Fig 4(a-d) and Fig 5(a-d) we can observe the temperature variation on the PG and DI water TPCT's charged with different fill volumes, for an inclination of 0°, 30° and 50° from vertical with respect to different heat inputs supplied. The heat absorption and rejection capacity of PG and DI water TPCT's are found to be varying with respect to change in variable parameters. From Fig. 3(a-d), when the TPCT's are at 0° inclination, the effect of fill volume ratio is not observed clearly for most of the heat inputs.
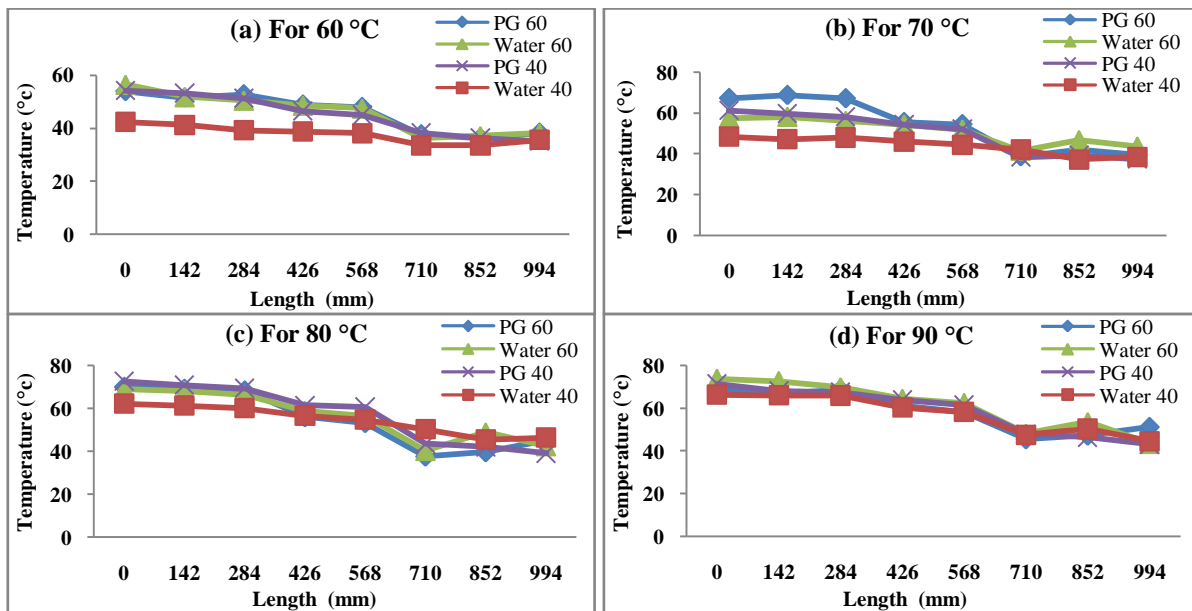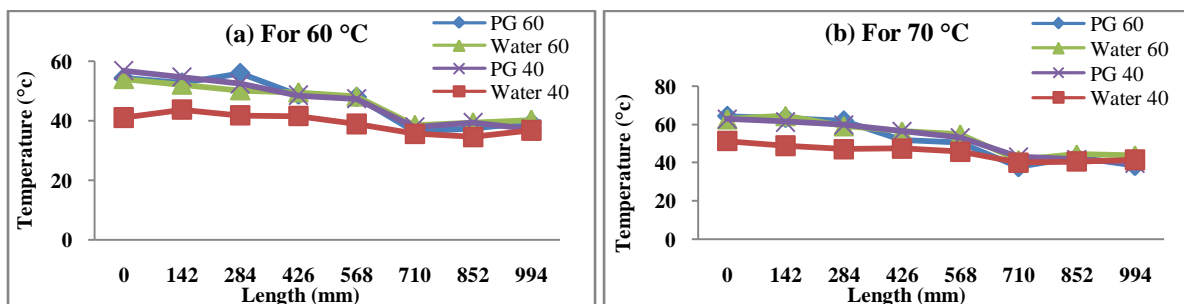

Fig: 3. (a-d) Temperature distribution for 0° inclination

For heat input of 70°C, the TPCT charged with PG 60% is having higher surface temperature and TPCT charged with water 40% is having low surface temperature when compared with other TPCT's for all heat inputs.

The change in TPCT's surface temperature distribution is observed clearly in Fig. 4(a-d), when TPCT's were tilted at 30° inclination angle. The surface temperature on PG 60% TPCT is found to be decreased with increase in a heat supplied. TPCT charged with water 60% is having high surface temperature for all heat inputs. For lower heat input of 60°C the PG40% and PG60% TPCT's show better surface temperature distribution but for higher heat input of 80°C and 90°C, water 60% TPCT is having higher surface temperature distribution.
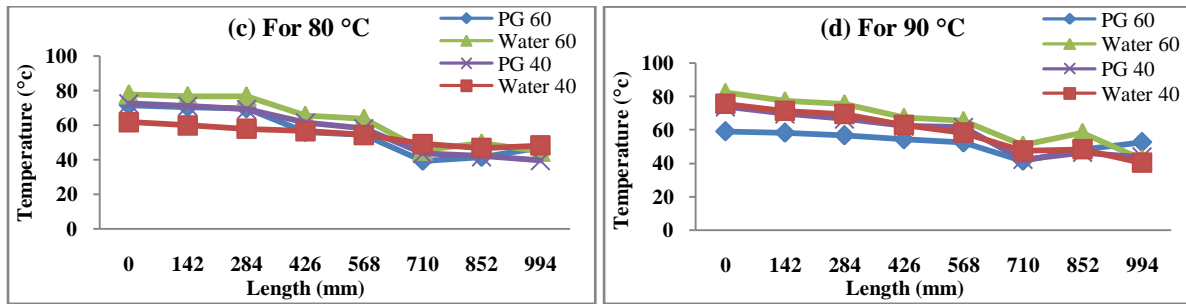
Fig: 4. (a-d) Temperature distribution for 30° inclination

The effect of maximum inclination angle is shown in Fig. 5(a-d) where TPCT's were tilted at an inclination of 50°. TPCT charged with higher fill volume ratio shows better surface temperature distribution compared to TPCT charged with lower fill volume. The behavior of PG 40% and 60% TPCT's were almost same for all heat inputs. For higher heat inputs of 80°C and 90°C all TPCT's shows the similar type of temperature distribution irrespective of their fill volume ratios.
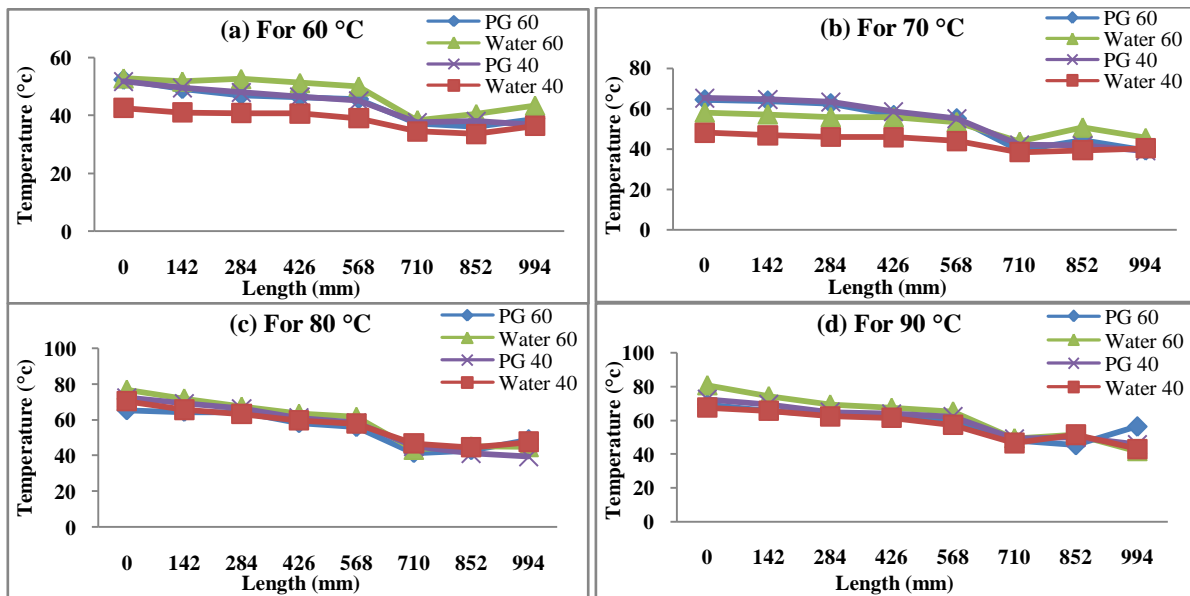

Fig: 5. (a-d) Temperature distribution for 50° inclination

From the above figures we can conclude that uniform heat absorption is observed in evaporator section and the constant adiabatic temperature is observed for all the heat inputs. The effect of temperature drop in the condenser section at the entrance of cold water in condenser jacket is also noted. Insignificant increase in condenser surface temperature is noted in condenser section which is due to the accumulation of non condensable gases in this section. From the above observations it is possible to differentiate the performance of water TPCT's on the fill volume ratio but for the PG TPCT such differentiation is not possible.

Table 2:- Slope values of Temperature distribution along the length of TPCT

Heat Input	60° C			70° C			80° C			90° C		
Inclination	0°	30°	50°	0°	30°	50°	0°	30°	50°	0°	30°	50°
PG 60	-2.76	-2.86	-2.25	-4.92	-4.27	-4.11	-4.97	-4.85	-3.47	-3.52	-1.17	-2.86
Water 60	-2.93	-2.33	-1.98	-2.38	-3.42	-1.89	-4.29	-5.54	-5.13	-4.47	-5.37	-5.35
PG 40	-3.08	-3.07	-2.32	-3.92	-3.72	-4.35	-5.40	-5.41	-5.20	-4.39	-4.79	-3.98
Water 40	-1.24	-1.15	-1.20	-1.65	-1.57	-1.37	-2.63	-2.25	-3.74	-3.42	-5.15	-3.46

If we try to obtain a straight line fit through the above temperature distribution curves then the following temperature gradient (slope) were observed as shown in Table 2, for the various inclination and heat inputs. The negative sign indicates the decrease in temperature with increase in a length of TPCT. For the zero slopes we can assure to have uniform heat transfer from one point to another point. From the above data we can observe the minimum slope shown by water 40% TPCT for all heat inputs and TPCT with PG60% shows better surface temperature distribution for heat input of 90°C.

4.2. Effect of the inclination angle on the heat transfer rate
      The amount of heat transferred by condenser section to the surrounding cold water in condenser jacket is calculated by considering the mass flow rate and specific heat and inlet and outlet temperature difference of water, as given in equation (1)

$$Qc = mc * Cp * (To - Ti) \qquad\qquad (1)$$

      From Fig. 6. (a–d) we can observe the heat transfer rate is get affect by the variable parameters. For lower heat input of 60°C and 70°C, water 60% TPCT excel the heat transfer phenomena but for higher heat input of 80°C and 90°C, PG 60% TPCT is having higher heat transfer rate for all inclination angles. For 0° inclination heat transfer ability of water 40% TPCT is found to increase for all heat inputs whereas TPCT with PG 60% holds good heat transfer ability for the extreme inclination of 50°.
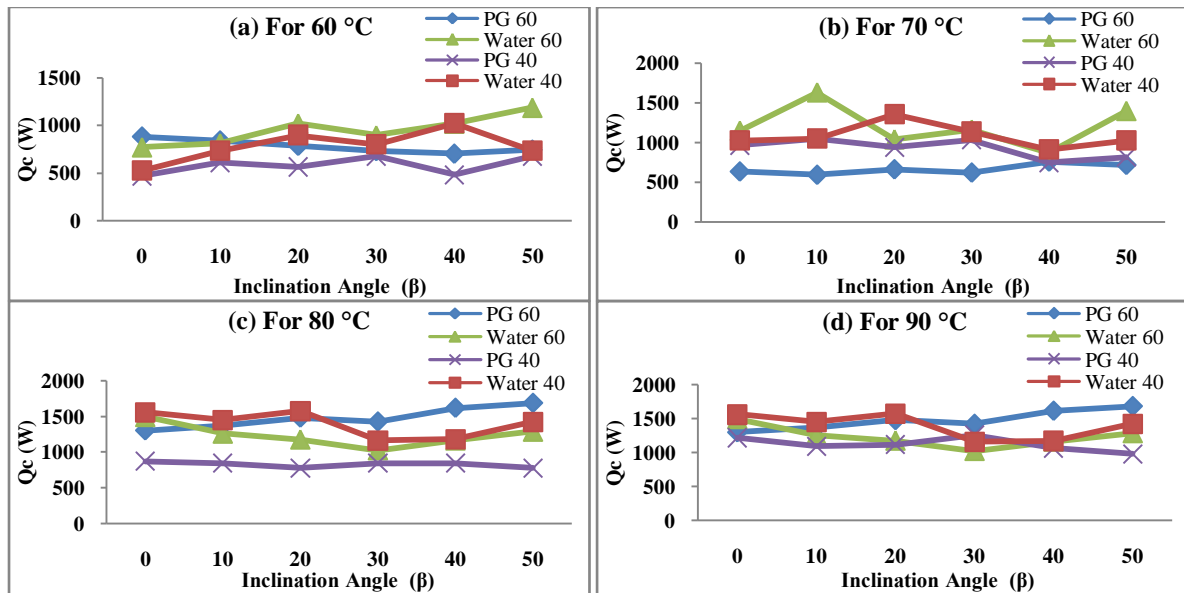

Fig: 6. (a–d) Heat transfer rate (Qc) for different inclination angles (β) at various heat inputs.

Table 3:- Slope values for heat transfer rate

Heat Input	60° C	70° C	80° C	90° C
PG 60	-33.16	24.87	75.00	75.00
Water 60	73.42	-26.05	-42.24	-42.24
PG 40	22.1	-45.00	-11.84	-31.97
Water 40	51.71	-18.16	-55.26	-55.26

      From the above slope values we found that the heat transfer rate for PG 60% TPCT is of increasing nature which means the TPCT bears a good heat transfer capability for all inclination angles compared to other TPTC's.

4.3. Effect of the inclination angle and on the evaporation heat transfer coefficient
      The heat absorption capacity of evaporator section of TPCT is determined by heat transfer coefficient (he) which is given by equation (2),

$$he = \frac{Qe}{\pi * di * Le * (\Delta Te - \Delta Ta)} \qquad\qquad (2)$$

where, Qe is the rate of heat absorbed by the evaporator section of TPCT from the hot water of the evaporator jacket and is obtained from the equation (3) as mentioned below,

$$Qe = me * Cp * (Teti - Teto) \qquad\qquad (3)$$

      As shown in the Fig. 7. (a-d), highest heat absorption ability is observed in water 40% TPCT for 0° and 50° inclination angles and at all heat inputs. TPCT charged with water 60% shows increasing trend of heat absorption for all inclination and heat inputs. TPCT's charged with PG 40% shows low heat absorbing capacity for all inclinations and heat inputs.
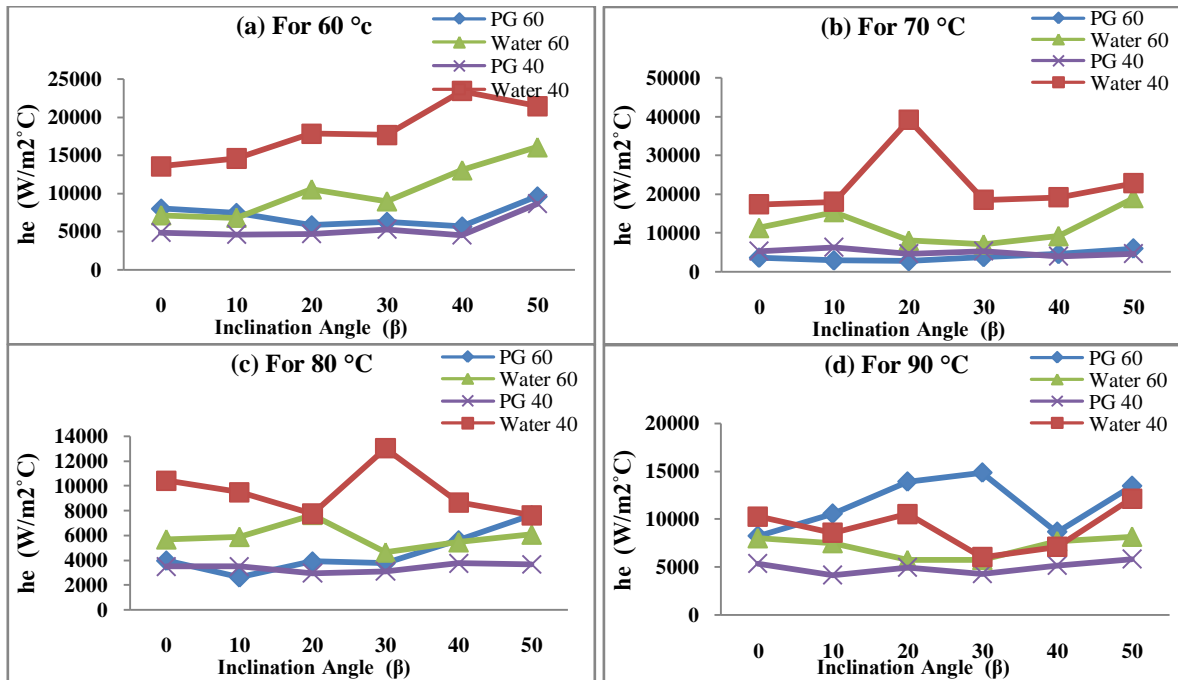
Fig: 7. (a–d) Evaporator heat transfer coefficient (he) for different inclination angles (β) at various heat inputs.

Similar trend is observed for PG 60% TPCT up to 80°C. For heat input of 90°C the PG 60% TPCT surprisingly absorbs more amount of heat from evaporator for all inclination angles. The heat transfer coefficient of evaporator for PG 60% TPCT is nearly 66% higher than that of DI water 60% TPCT in 30° inclination and 90°C heat input.

Table 4:- Slope values for evaporator heat transfer coefficient

Heat Input	60° C	70° C	80° C	90° C
PG 60	89.14	512.6	772.8	609
Water 60	176.6	541.5	-68.54	40.16
PG 40	551.7	-271	51.87	135.6
Water 40	1881	279.8	-317.4	9.565

From the above slope values we found that the evaporator heat transfer coefficient for PG 60% TPCT shows an increasing trend for all heat inputs which means the TPCT bears good heat absorption ability for all inclination angles compared to other TPTC's.

4.4. Effect of the inclination angle on the condensation heat transfer coefficient
The heat transfer capacity of condenser section for TPCT is determined by heat transfer coefficient (hc) which is evaluated by using equation (4)

$$hc = \frac{Qc}{\pi * di * Lc * (\Delta Ta - \Delta Tc)} \tag{4}$$

Where, Qc is the rate of heat rejected from the condenser section to the surrounding cold water. From Fig. 8. (a–d), we can observe the similar trends of heat rejection as that of in heat absorption. TPCT charged with water 40% shows highest heat rejection for the 0° and 50° inclinations. TPCT's charged with PG 40% shows low heat rejection capacity for all inclinations and heat inputs. For lower heat input of 60 °C and 70 °C the water 40% TPCT shows improvement in rejection up to 30° inclination beyond which this heat rejection rate gets decreased. Similar improving trend is observed for PG 60% TPCT for higher heat input of 80°C for all inclination angle but for 90°C this improvement trend breaks ahead of 30°. It is also observed that the heat transfer coefficient of condenser section is slightly lower than that of the heat transfer coefficient of evaporator section for all the heat inputs and inclination angle. This is due to accumulation of non condensable gases in the condenser section of the TPCT which resists the heat transfer from vapor to TPCT wall. The heat transfer coefficient of condenser of PG 60% TPCT is nearly 70% higher than that of DI Water 60% TPCT for 30° inclination at 90 °C heat input.
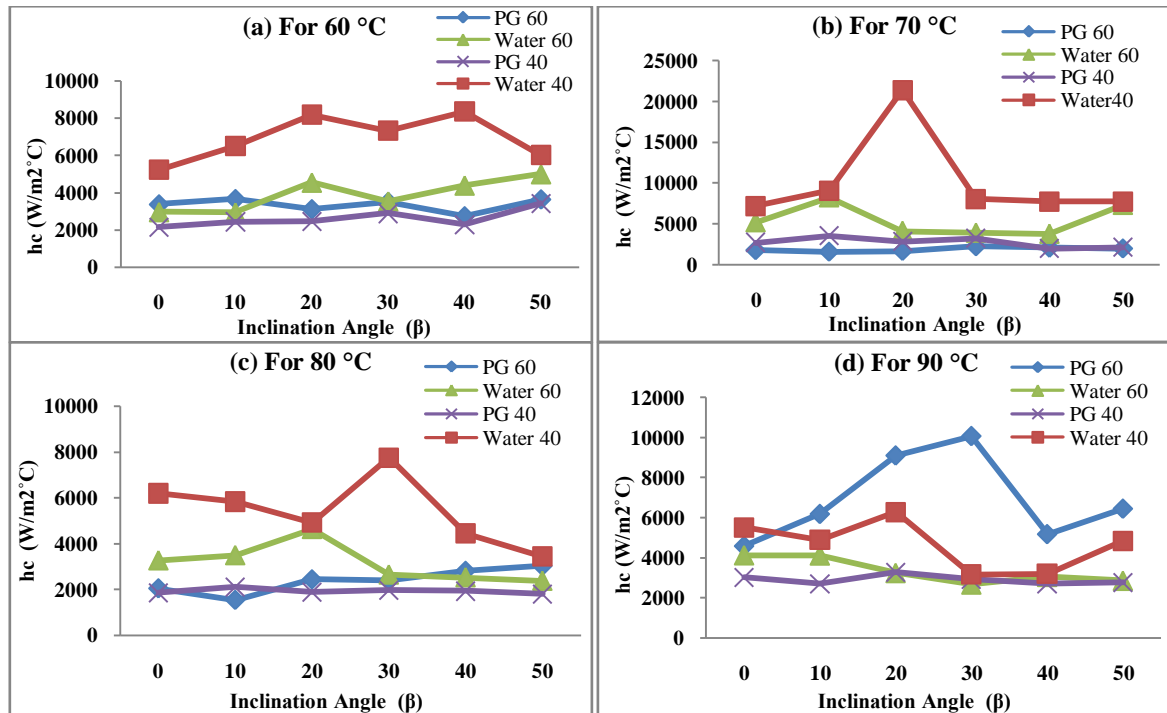
Fig: 7. (a–d) Condenser heat transfer coefficient (hc) for different inclination angles (β) at various heat inputs.

Table 5:- Slope values for condenser heat transfer coefficient

| Heat Input	60° C	70° C	80° C	90° C
PG 60	-29.89	88.66	249.6	207.3
Water 60	387.2	-85.26	-267.2	-287.8
PG 40	179.2	-208.2	-22.41	-43.98
Water 40	246.7	-420	-432.7	-328.2

From the above slope values we found that the PG 60% TPCT shows an improving trend of heat transfer coefficient for all heat inputs along the all inclinations which means the PG TPCT holds good heat rejection ability angles compared to other TPTC's.

4.5. Effect of the inclination angle on total thermal resistance of the TPCT

The thermal resistance of the TPCT is the average temperature difference between the evaporator and condenser to the amount of heat absorbed by TPCT which is calculated by expression (5),

$$R = \frac{(\Delta Te - \Delta Tc)}{Qe} \qquad (5)$$

It is the resistance to the flow of heat from one point to the other, for better heat transfer the thermal resistance has to be on a lower side. An observation can be drawn from Fig. 9 (a-d), the water 40% TPCT shows a low thermal resistance up to 80 °C heat input for all inclination angles and for 90 °C the PG 60% TPCT have the minimum thermal resistance. The PG 40% TPCT shows a higher resistance to all heat inputs. For maximum inclination of 50° for all heat inputs the thermal resistance is found to be decreased compared to 0° inclination.
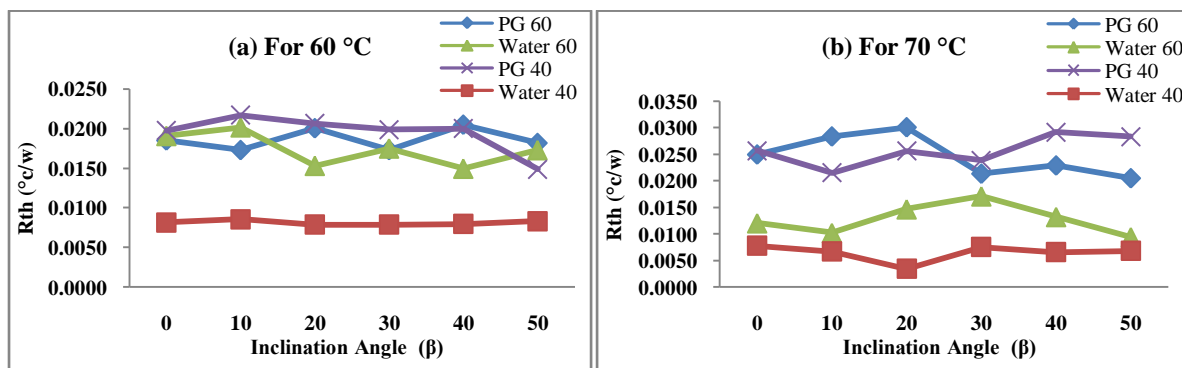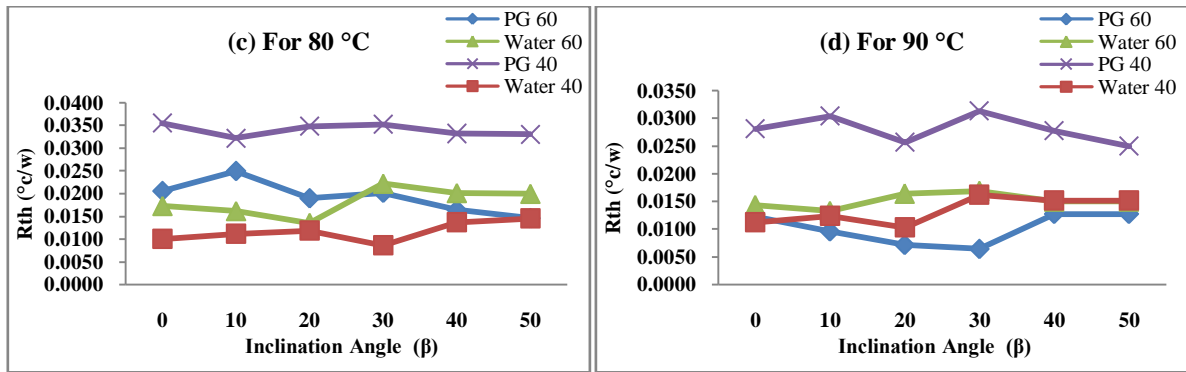
Fig: 8. (a–d) Thermal resistance (R_{th}) for different inclination angles (β) at various heat inputs

Thermal resistance of all TPCT is found to be decreased for all inclination angles for higher heat input of 90°C. For all variables the majority of the readings for slope values for the thermal resistance are coming to zero which means the value of thermal resistance is unaffected with inclination effect.

4.6. Effect of the inclination angle on Efficiency

The efficency of TPCT is calculated as the ratio of amount of heat rejected (hc) by the condenser to the amount of heat absorbed (he) by the evaoporator section of the TPCT.
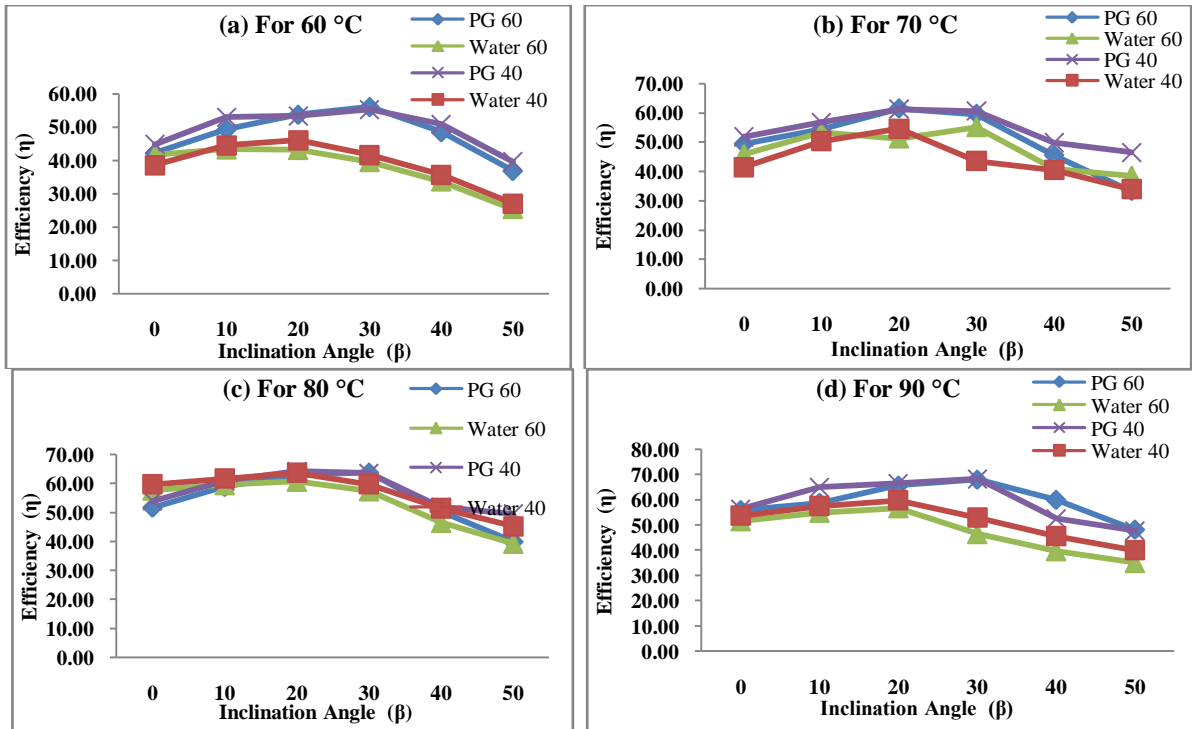

Fig: 9. (a-d) Efficiency (η) of TPCT for different inclination angles (β) at various heat inputs

From the following plots we can observe the efficiency of PG TPCT is higher than the DI water TPCT for all heat inputs over all inclination angles. From Fig. 10 (a-d), for all the heat inputs the efficiency of vertical TPCT's for all fill volume ratio remains same but with the increase in the inclination angles the efficency of PG TPCT remains on higher side compared to DI water TPCT. Between 20° to 30° of inclination PG TPCT's with different fill volume ratio have maximum efficiency of 67% for all heat inputs & at 20° water TPCT is having maximum efficiency of 64%. The effect of fill volume ratio on the efficiency of TPCT is observed to some extent.

From the slope values of efficiency the following observations can be made. The lower sope values are obtained by PG TPCT's. For $60°$ C and $90°$ C the PG 60% having lower slope value but for $70°$ C and $80°$ C it is the PG 40% TPCT with lower slope values for all incilation angles. Based on above remark we can say that PG TPCT works better than water TPCT.

Table 6:- Slope values for efficiency of TPCT

Heat Input	60° C	70° C	80° C	90° C
PG 60	-0.77	-3.12	-2.83	-0.94
Water 60	-3.25	-2.01	-3.83	-3.93
PG 40	-0.86	-1.37	-1.41	-2.26
Water 40	-2.54	-2.24	-3.05	-3.16

V. Conclusion

This following study were conducted with an aim of investigating whether the use of Propylene Glycol in TPCT can enhance heat transfer characteristics compared to DI water TPCT's. The PG TPCT's were tested for two fill volume ratios, four heat inputs and six inclination angles and the results obtained are compared with DI water TPCT based on which following conclusion can be made. The temperature distribution along the length of TPCT surface is found to be varying with change in inclination angle for all heat inputs. The PG TPCT shows better temperature distribution compared to water TPCT for 50° inclination. For 0° inclination heat transfer ability of water 40% TPCT is found to increase for all heat inputs whereas TPCT with PG 60% holds good heat transfer ability for the extreme inclination of 50°. The evaporative heat transfer coefficient of PG 60% TPCT is nearly 66% higher than that of DI water 60% TPCT for 30° inclination and 90°C heat input. The heat transfer coefficient of condenser section is slightly lower than that of the heat transfer coefficient of evaporator section for all the heat inputs and inclination angle. TPCT charged with water 40% shows a lower thermal resistance for all inclination angle compared to PG TPCT charged with different fill volume. The efficiency of PG TPCT found to be higher than the water TPCT. Maximum efficiency of 68% is observed for PG TPCT between 20° to 30° of inclination for 90°C heat input and for water TPCT it is up to 63% for 80°C heat input.For the given heat input insignificant effect of fill volume ratio is observed on the TPCTs performance.

VI. Future Work

Every research work will always have a definite scope of further research. It is an enduring process of research that the present status of the system can be changed by having certain amendment, enhancement, improvement, etc. The PG TPCT can be investigated for its 100% purity along with this it is possible to investigate its performance for higher heat inputs. Alteration with material of TPCT is also possible. Further part of this project work will be making analysis with the help of computational solver.

Nomenclature:

C specific heat, (J/kg°C)
di inner diameter of heat pipe, (m)
hc condensation heat transfer coefficient, (W/m²-°C)
he evaporation heat transfer coefficient, (W/m²-°C)
Le length of evaporator section, (m)
Lc length of condenser section, (m)
m mass flow rate of water, (kg/s)
Q heat transfer rate, (W)
R Thermal resistance, (°C /W)
Ti cold water inlet, (°C)
To hot water outlet, (°C)
Ta adiabatic temperature, (°C)
Tc condenser temperature, (°C)
Te evaporator temperature, (°C)
Tet evaporator tank temperature, (°C)
   Suffix
e evaporator section
a adiabatic section
c condenser section
i inlet
o outlet
t hot water tank
   Greek symbols
Δ Average
β Inclination angle
η Efficiency

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