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Experimental Investigation of Two Phase Closed Thermosyphon Using Propylene Glycol As A Working Fluid

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***Abstract*— In the present study the heat transfer characteristic of two phase closed thermosiphon (TPCT) using Propylene Glycol (PG) is analysed experimentally and compared with De-ionized (DI) water for different inclinations and heat input. For the experimentation, two copper thermosyphon of same dimensions are designed. Both are filled with equal fill volume ratio. One TPCT is charged with de-ionized water and the other with aqueous solution of Propylene Glycol with 50% purity. The experimental results indicate that the Propylene Glycol thermosyphon works better at higher heat inputs and the optimum inclination angle for PG thermosyphon is between 20°-30° and that for DI water is 10° to 20°.**

Keywords—Two phase closed thermosiphon, Working Fluid, Inclination angle, Heat inputs

I. INTRODUCTION

Organization of heat in industrial and residential applications is becoming more and more important as we attempt to improve the efficient use of energy. Heat transfer fluids have been an integral part of this process for many years. Presently, one of the most intensively discussed options is the usage of high heat carrying fluids. The high thermal conductivity of these fluid leads to an increased overall heat carrying capacity of TPCT.

The TPCT is an efficient heat transfer device due to their high heat transfer capabilities with no exterior power requirement. It transfers a large amount of heat with very small temperature difference. It is vertically oriented with liquid pool at bottom. 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 and 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 are being used in many applications such as heat exchangers, cooling of electronic components, solar energy conversion systems, spacecraft thermal control, cooling of gas turbine rotor blades, waste heat recovery etc. [1]. Heat transfer characteristics of TPCT have been investigated by many researchers for various types of fluids like alcohols, glycols, refrigerants etc. but most of the investigations have been limited to either low or high temperature ranges [2]. Ethylene Glycols are used for high temperature application as discussed in [5], [6] and [9]. Propylene Glycol shows the similar properties as that of ethylene glycol, so it usages in TPCT is needed to be investigated. Therefore, there exists a necessity to study the moderate temperature performance of TPCT using Propylene Glycol as a working fluid.

II. LITERATURE REVIEW

M. Karthikeyan et al. [3] 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. M. Kannan et al. [4] 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 to 70 °C, the maximum heat transport capability is also increased from 425 to 650 W for water. A. Nuntaphan et al. [5] 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. [6] 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. In this experiment, the thermosyphon exhibits the highest performance at the angle of about 60°. Park et al. [7] 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. [8] 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 [9] 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.

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

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. [10] 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%.T. Payakaruk et al. [11] describes the effect of dimensionless parameters like Bond numbers, Froude numbers, Weber numbers and Kutateladze numbers and experiments are conducted to find out their effects on the heat transfer rate and on the total thermal resistance. The working fluid is found to be affected at the inclination angles of 20˚ to 70˚. S Lips et al. [12] 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˚.

In the present study, propylene glycol is employed as working medium for TPCT to investigate the thermal performances of TPCT. The results obtained are compared with the thermal performance of the TPCT filled with DI-water.

III. EXPERIMENTAL SETUP

Experimental setup for studying the thermal performance of a TPCT for moderate temperature application is shown in Fig. 1. For conducting the experimentation a TPCT of copper tube is designed. Both the TPCT are charged with equal fill volume ratio. The working fluid is filled inside the tube 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 1 KW heater to heat the water. 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 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 both the sections. The surface temperature distribution of the TPCT

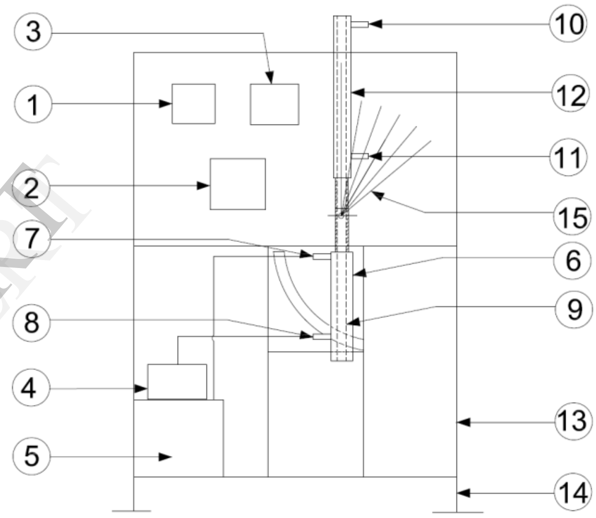


Fig. 1. Experimental Setup

TABLE I. EXPERIMENTAL SET UP SPECIFICATION

No.	Specification	No.	Specification
1	Energy Meter	8	Hot Water Outlet
2	PID Controller	9	TPCT
3	Temperature Indicator	10	Condenser Outlet
4	Motor	11	Condenser Inlet
5	Hot Water Tank	12	Condenser Jacket
6	Evaporator Jacket	13	Main Frame
7	Hot Water Inlet	14	Base Stand
15	Inclination Angle Marking’s		

is measured with eight copper constantan (K type) thermocouples as shown in Fig.2. Three thermocouples are installed on evaporator section; three are on condenser and two on adiabatic section.

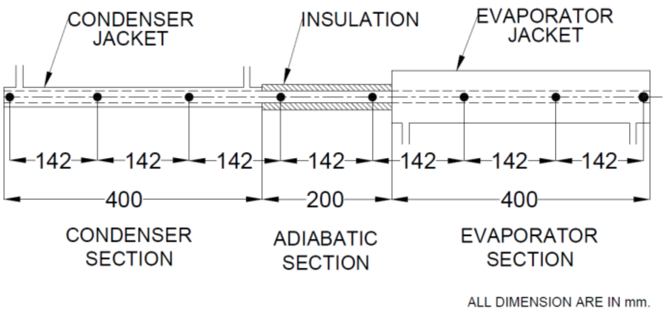


Fig. 2. Position of Thermocouples

TABLE II. PARAMETERS AND VALUE FOR TPCT

Parameters	***Values***
Working fluid	De-ionized Water, Propylene Glycol (50% purity)
Inner diameter of the pipe	17 mm
Outer diameter of the pipe	19 mm
Length of evaporator section	400 mm
Length of adiabatic section	200 mm
Length of condenser section	400 mm
Fill Volume	60%
Flow rate	0.033 kg/sec
Inclination angle	0˚, 10˚, 20˚, 30˚, 40˚, 50˚ (From Vertical)
Heat input	60˚C, 70˚C, 80˚C, 90˚C
Thermocouple	K type

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 is provided to adiabatic section, evaporator jacket and hot water tank to avoid the heat loss to the surrounding. An energy meter is provided to measure energy consumption while conducting the experimentation. Angle holder slot is provided for getting the inclination of 60°.The experimental procedure consists of two identical TPCT of same dimensions as mentioned above. One is charged with de-ionized water and other with propylene glycol with 50% purity. Initially heater is on and water is allowed to get heated in hot water tank. This hot water is continuously circulated in the evaporator jacket with the help of motor which ensures uniform temperature achievement in evaporator jacket. PID controller is provided to cut the heater, when the desired temperature is reached in evaporator jacket. The cold water is allowed to circulate through condenser jacket. As the desired uniform temperature is achieved in evaporator jacket the temperatures at different locations are measured at regular time intervals for the given inclination angle. After that the inclination angle of TPCT is changed. The same procedures of heating were followed with varying the inclination. Thus the TPCT is tested for its performance for different heat inputs and for different inclination angles. The energy balance method is applied to measure the input and output heat transfer rate from the evaporator and condenser section.

IV. DATA ANALYSIS

The 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. For maximum reading the Karl Pearson Correlation exists positive. The probable error in the measured correlation is 0.56.

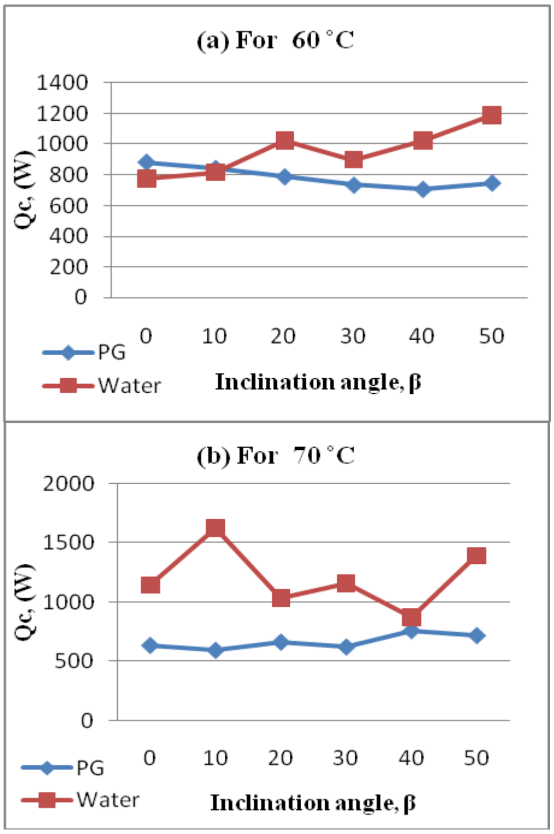
V. RESULTS AND DISCUSSION

A. *Effect of the inclination angle on the heat transfer rate*

The quantity of heat transferred to the coolant water can be calculated from inlet and outlet water temperature difference, taking into account the water mass flow rate and specific heat as equation (1)

$$Q = mc\ Cp\ (To - Ti) \quad (1)$$

To compare the improvement in heat transfer rate the TPCT filled with PG and DI water is tested. The experimental results clearly show the effect of working temperatures on heat transfer rate.



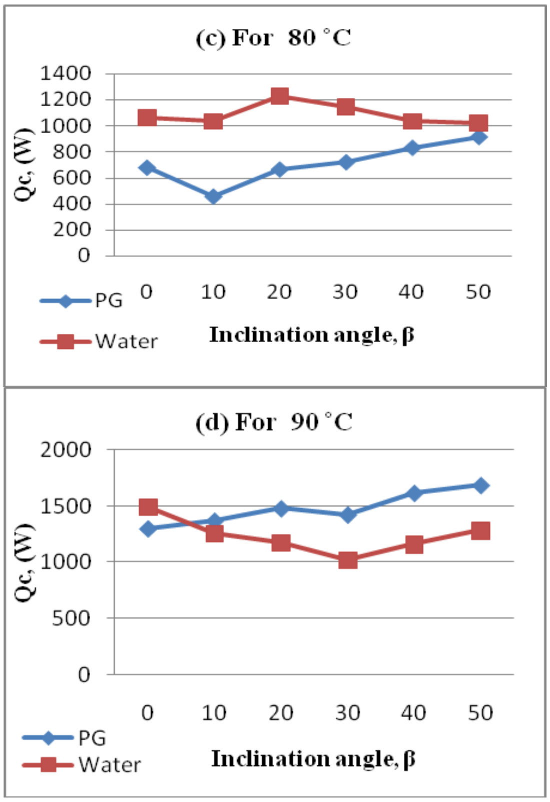


Fig. 3. *(a–d)* Heat transfer rate (Qc) for different inclination angles (β) at various heat inputs.

For higher heat input of 90°C, the PG pipe is having higher heat transfer rate as compared to DI water pipe. There exists a 30% improvement in heat transfer for the PG TPCT compared to DI water TPCT at 90°C heat input over all inclination angles.

B. Effect of the inclination angle and on the evaporation heat transfer coefficient

The heat transfer capacity of evaporator section for TPCT is determined by heat transfer coefficient (he) is determined by using the equation (2),

$$he = \frac{Qe}{\Pi d_i L_e(\Delta T_e - \Delta T_a)} \qquad (2)$$

Where, Qe is the rate of heat absorbed from hot water to the evaporator section and is obtained from the equation (3) as mentioned below,

$$Qe = m_e \, C_p \, (T_{eti} - T_{eto}) \qquad (3)$$

From the graphs it is observed that the evaporative heat transfer coefficient is affected with the inclination for the various heat inputs. As shown in the fig. 4. (a-d), the PG shows highest evaporation heat transfer coefficient for higher heat inputs up to 30° inclination angle. For 80°C the PG shows, good increasing heat transfer coefficient for the higher inclination angles. For 70°C heat input the PG shows minimum heat evaporation heat transfer coefficient over all inclinations. And for lower heat inputs, the DI water holds better heat transfer capability compared to PG. The heat transfer coefficient of evaporator for PG is nearly 66% higher than that of DI water in 30° inclination and 90°C heat input.

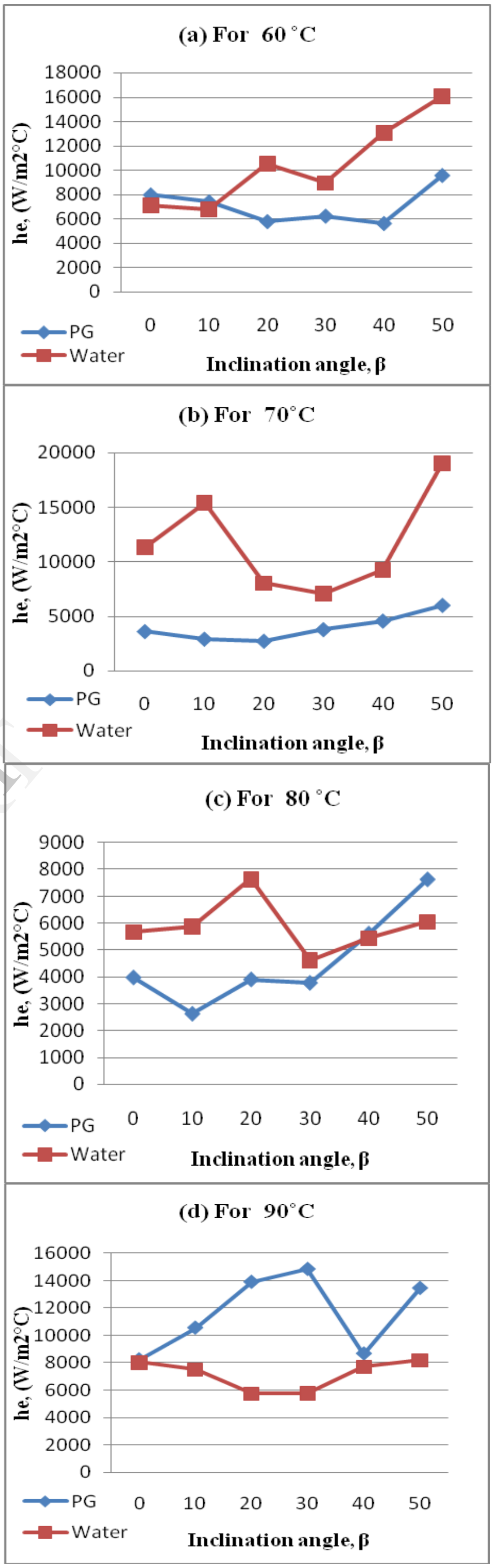


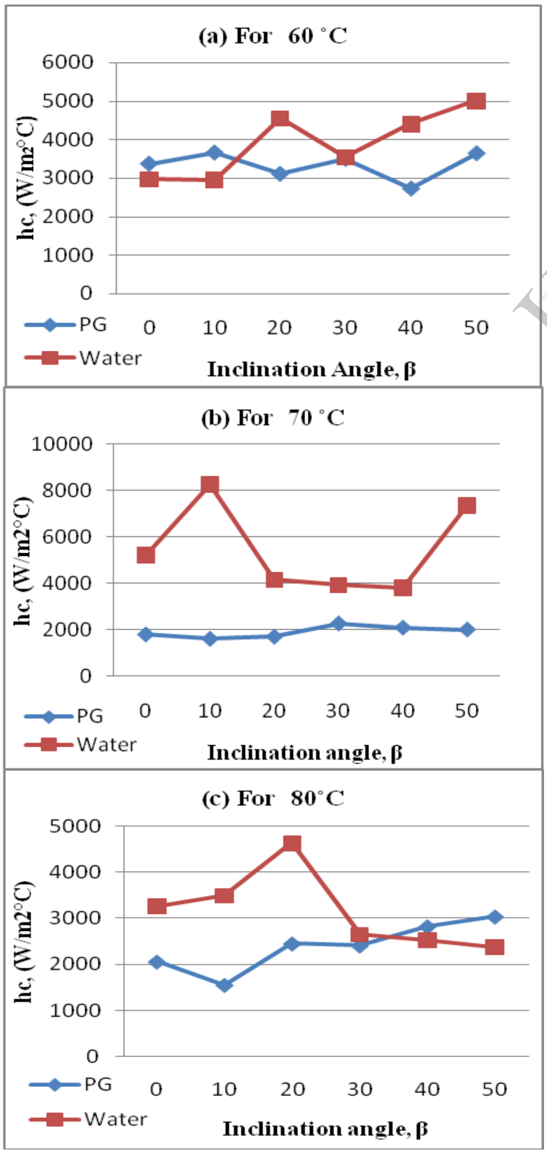
Fig. 4. (a–d) Evaporation heat transfer coefficient (he) for different inclination angles (β) at various heat inputs.

C. 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)

$$hc = \frac{Qc}{\Pi diLc(\Delta Ta - \Delta Tc)} \quad (4)$$

Where, Qc is the rate of heat rejected from the condenser section to the cold water. Experimental results of DI water and PG at different inclination in condenser are plotted and compared. As shown in the Fig. 5. (a–d), the values of hc for DI water TPCT decreases with the increment in inclination angle whereas the heat transfer coefficient of PG TPCT shows improvement of heat transfer coefficient with respect to increasing inclination angle. For higher heat inputs of 80 °C and 90°C the effect of non condensable gases is found to be minimum on PG TPCT over all inclination angles due to which we can observe the improvement in heat transfer coefficient. 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



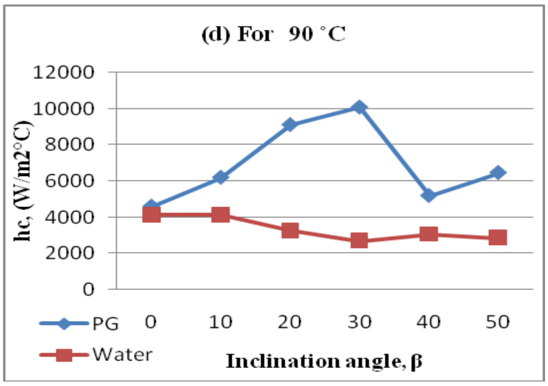


Fig. 5. (a–d) Condensation heat transfer coefficient (hc) (W/m^2-K) for different inclination angles (β) at various heat inputs.

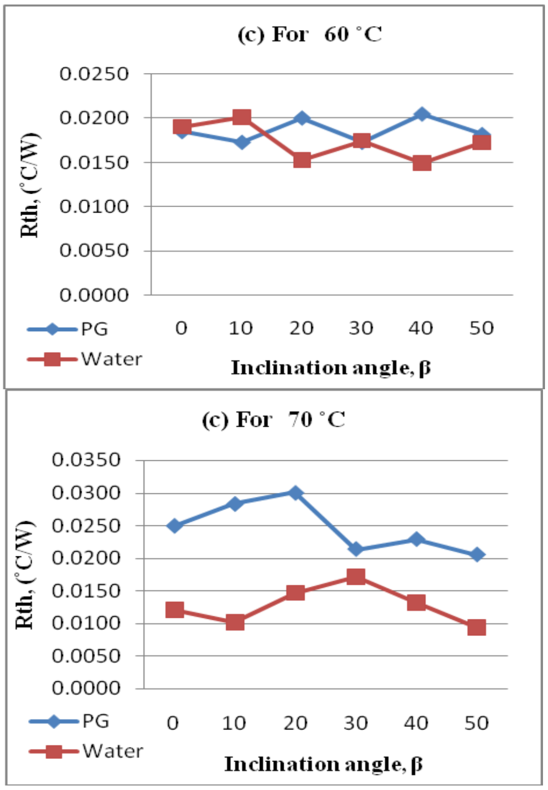
and inclination angle. This is due to accumulation of non condensable gases in the condenser section of the TPCT which resists the heat transfer from vapor to TPCT wall. The heat transfer coefficient of condenser of PG is nearly 70% higher than that of DI Water for30° inclination and 90 °C heat input.

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

The thermal resistance of the TPCT is calculated by using the following expression (5),

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

A noteworthy observation can be drawn from the above graphs that thermal resistance is very much lower for the PG pipe for higher heat input of 90°C and for 80°C the thermal resistance decreases beyond 10° of inclination.



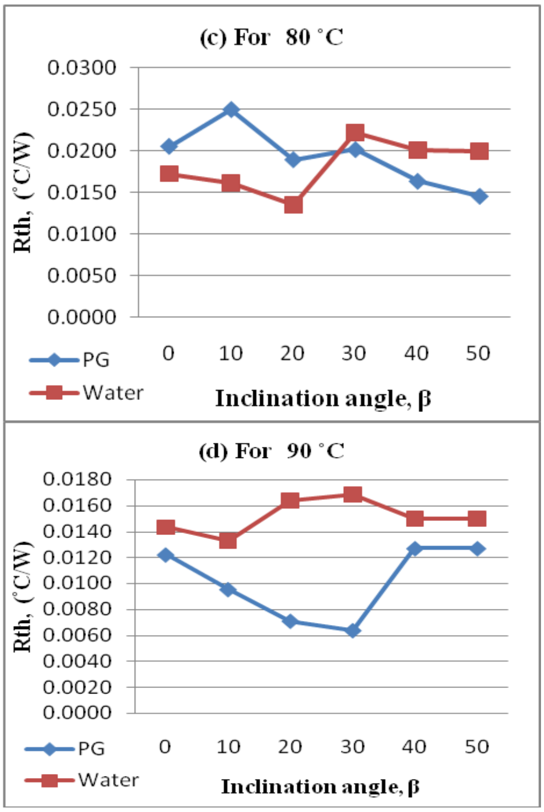
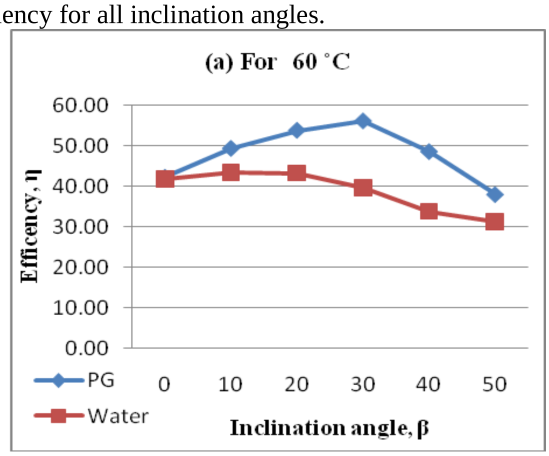


Fig. 6. (a–d) Thermal resistance (R) (˚C/W) for different inclination angles (β) at various heat inputs

When the pipe is vertical the effect of non condensable gases is maximum for the heat input of 70°C, but for all other heat inputs this effect is not observed. For maximum inclination of 50° for all heat inputs the thermal resistance is found to be decreased compared to 0° inclination.

E. Effect of the inclination angle on Efficiency

From the above plots we can observe the efficiency of PG pipe is slightly higher than the DI water pipe over all inclination angles. When the pipe is vertical then for all the heat inputs the PG pipe and DI water pipe is having the almost same efficiency. But with the increase in the inclination angle the efficiency starts varying. For 60°C heat input we can clearly witness the improvement in the efficiency for all inclination angles.



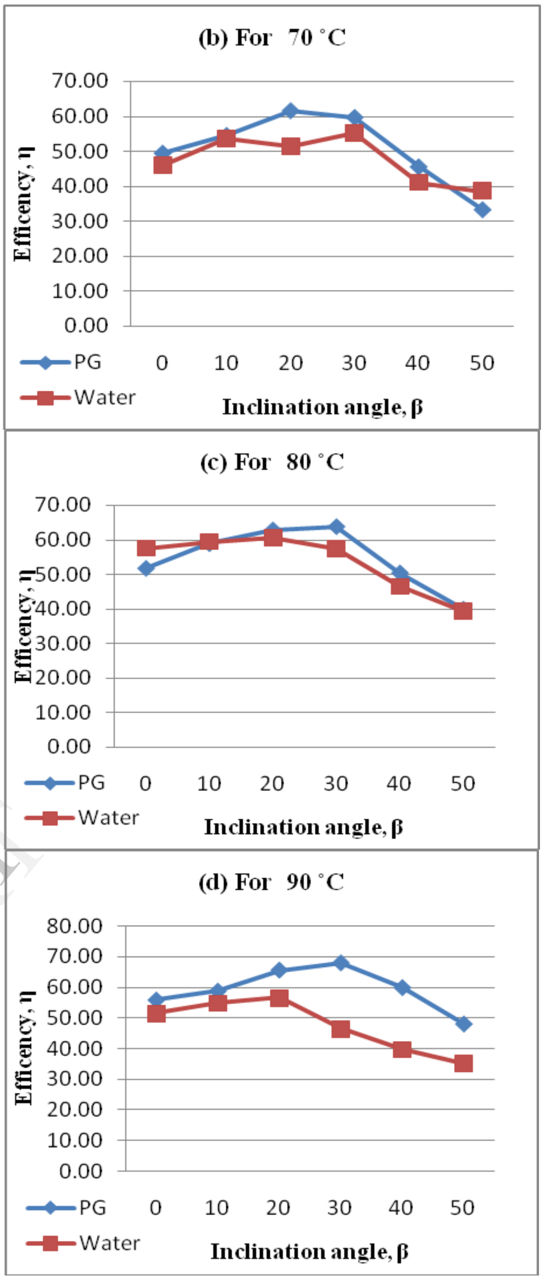


Fig. 7. (a–d) Efficiency (η) of TPCT for different inclination angles (β) at various heat inputs

For 70°C & 80°C heat input both pipes behave almost similarly over all inclination ranges. For PG pipe we can observe the 20° to 30° inclination angle as the optimum angle of heat transfer with the maximum efficiency of 67% and that of for DI water pipe it is 10° to 20°.

VI. CONCLUSION

Based on the experimental investigations presented in this paper the following conclusions can be drawn: The performance of PG TPCT is affected by heat input and inclination angle. For higher heat input the PG TPCT found to be work better than the DI water TPCT. Heat transfer rate is found to be improved for PG TPCT at 90°C over all inclination angles. The heat transfer coefficient of condenser of PG is higher than that of DI Water for 90°C heat input.

The thermal resistance of PG is less than the DI water TPCT. The PG pipe is having optimum inclination angle of 20° to 30° and that of DI water pipe is 10° to 20°. The PG shows better thermal performance at higher heat input of 90 °C. The experimental readings show good agreement with statistical techniques.

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