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Research Article

Reducing Heat Loss in the Adiabatic Section of a Two-Phase Closed Thermosyphon (TPCT) Using Acrylic Tube

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Abstract

This study aims to present a method of reducing heat loss in a two-phase closed thermosyphon (TPCT) by replacing copper tubing with acrylic in the adiabatic section. The designs used included total lengths of (L_T) 150, 300 and 450 mm. The evaporator section (L_E), Adiabatic section (L_A) and Condenser section (L_C) lengths were all alike at 50, 100 and 150 mm. The copper and acrylic tubes were of 15 mm external diameter and 12 mm internally. The temperatures applied at the evaporator section (T_E) were 60ºC and 80ºC. The angles of inclination were 0º, 20º, 40º, 60º, 80º and 90º, and air velocity at the condenser section was 1 m/s. The working fluid used was plain water with a filling ratio of 50% of the evaporator section volume. The experiment showed that as T_E increased so did heat flux, however shorter L_{Ts} resulted in lower heat flux, and the maximum heat flux achieved was 5 kW/m^2 at T_E 80ºC, L_E 150 mm, with an angle of inclination at 80º to 90º using acrylic tube in the adiabatic section. When acrylic tube was installed instead of copper tube at L_A the resulting thermal resistance (R_{tube}) Cº/W decreased and heat flux increased. The maximum R_{tube} result was recorded at around 2.78Cº/W with the acrylic tube of L_E 150 mm. with a T_E of 80ºC.

Keywords: Reducing, TPCT and thermal resistance

1 Introduction

A two-phase closed thermosyphon or TPCT is a simple, yet highly effective, wickless heat transfer device, which has been used in many different applications [1]. A TPCT needs no wick structure to return the condensate from the condenser to the evaporator as it utilizes gravity [2]. Normally a TPCT is made from metal clusters, cylindrical geometry and a single tube. The thermosyphon consists of three sections, as shown in Figure 1. The evaporator section has heat input, creating a phase change from fluid to vapor which then moves through the adiabatic section, which in theory neither generates nor loses heat as it's only function is to transfer the vapor. The condenser section releases the heat cause the working fluid to change phase back to liquid from vapor, and return to the evaporator through gravitational force. The history of TPCT's began with A.M. Perkins who, through his work on boilers and heat distribution systems, developed a two-phase flow device or Perkins tube in 1827 [3]. Subsequently, TPCT's continued to develop as part

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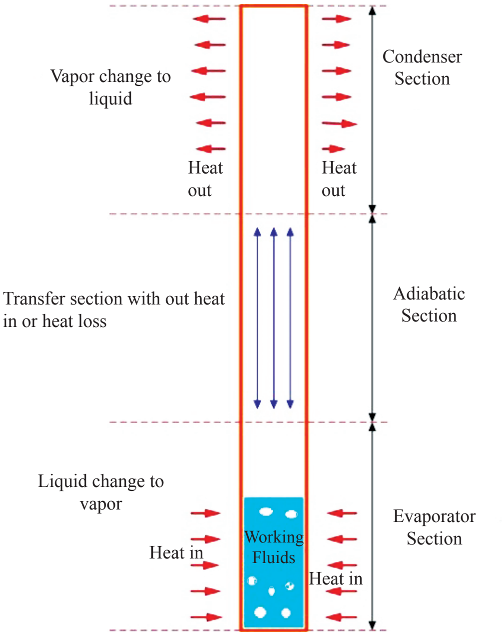

Figure 1: Thermosyphon (TPCT).

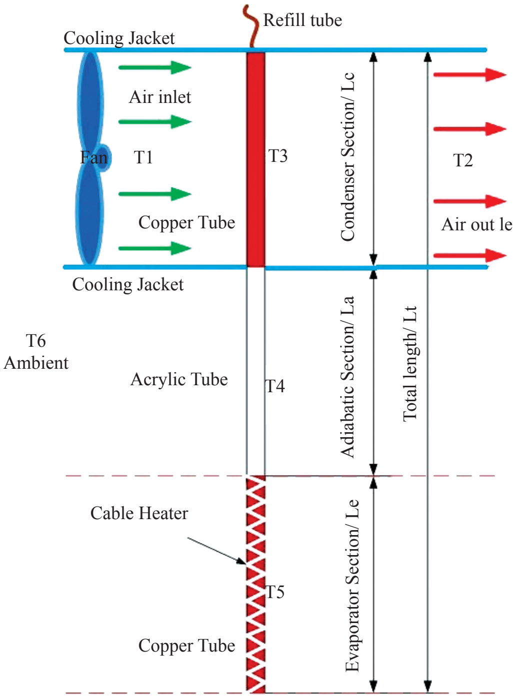

Figure 2: A schematic diagram.

of Materials science, with the working fluids evolving from water and alcohol, to refrigerants [4] and currently the incorporation of nanoparticles [5]. The theory of TPCT and previous studies on the adiabatic section without any heat input or output identified heat loss within the adiabatic section. These studies suggested that the heat loss in the adiabatic section was negligible. This assumption is not necessarily true as heat loss is constantly observed in the adiabatic section. Therefore there should be additional protections to prevent this heat loss, over and above the standard insulation. Insulating this section does reduce heat loss, however to eliminate heat loss in this method is costly. By constructing this section of the TPCT with a material of greater thermal protection, or thermal resistance (˚C/W), we can effectively reduce the loss of heat without the need for insulation. This research aims to study ways of reducing heat loss from the adiabatic section with an acrylic tube and using different properties of thermal conductivity (˚C/W). This article will confirm theories about heat loss of thermosyphons in the adiabatic section and present guidelines for thermosyphon development in the future. Such as the use of different materials in production of thermosyphons to reduce costs, prolong the product life cycle, increase heat transfer, and look to identify further applications for potential use.

2 Experimental Apparatus and Procedure

The experiment design adopted total lengths of (L_T) 150, 300 and 450 mm. The evaporator section (L_E), adiabatic section (L_A) and condenser sections (L_C) were each of equal lengths, of a third of L_T, i.e. 50, 100 and 150 mm. The diameters of the copper and acrylic tubes were 15 mm externally and 12 mm internally. The temperatures applied at the evaporator section were 60ºC and 80ºC. The angle of inclination was 0º, 20º, 40º, 60º, 80º and 90º The air velocity at the condenser section was 1 m/s with water as the working fluid at a filling ratio of 50% of the evaporator section volume.

The apparatus schematics are shown in Figure 2. The evaporator section of the TPCTs were made of copper and were covered with a cable heater. The adiabatic section of a set of the TPCTs was constructed from acrylic tube, to form a comparison between those and the TPCTs with copper tube running the entire length of the TPCT. This section was left uncovered to compare the resulting heat loss, which is the main purpose of this study. The condenser section includes a cooling jacket cover made from insulated metal sheet. The condenser section of the TCPTs were cooled with air flow controlled at 1 m/s. The temperature was measured with 6 type K thermocouples and data was logged for analysis.

The schematic diagram shown in Figure 2 diagram was designed to compare heat loss at the adiabatic section. Historically, research articles and theories in general suggest that heat is neither lost nor input at the adiabatic section, however the opposite was found to be true as heat loss was constantly observed, despite the presence of insulation. This study presents recommendations for reducing heat loss from the adiabatic section through the use of different materials, based on their thermal conductivity properties. This is explained by the mathematical models (1)–(9) and table 1.

3 Mathematical Model

Normally the amount of heat input at the evaporator section is equivalent to the amount of heat released at the condenser section with no consideration given to heat loss. Thus the performance of the TPCT in terms of temperature between the evaporator section (T_E) and the condenser section (T_C) can be described by the general heat flux equation [6].

$$Q = U_E A_E (T_E - T_C) \tag{1}$$

The condenser temperature (T_C) is calculated from the relationship between the air inlet (T_I) and air outlet (T_O) at the condenser section, as follows:

$$T_C = \frac{T_I - T_O}{2} \tag{2}$$

The heat released at the air outlet ;

$$Q = \overset{\circ}{m} C_P (T_O - T_I) \tag{3}$$

and presented in the form of heat flux (q) ;

$$q = \frac{Q}{A} \tag{4}$$

The heat loss from the adiabatic section is explained in Figure 3.

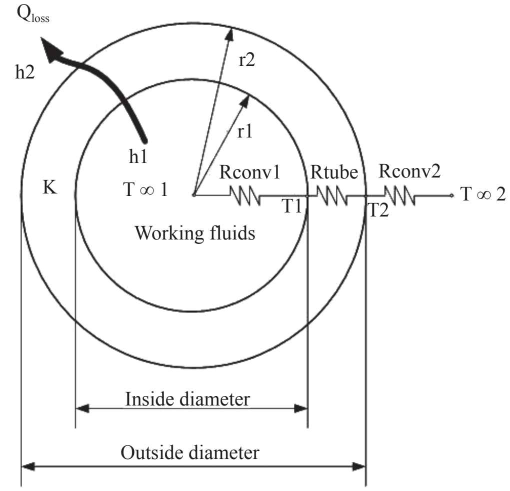

Figure 3: The thermal resistance network for an adiabatic section of TPCT.

Fourier's law of heat conduction for heat transfer through a cylindrical layer [6], is as follows:

$$Q_{Cond,cyl} = -kA\frac{dT}{dr} \tag{5}$$

where $A=2\pi r L_A$ with L_A referring to the adiabatic section length. This then suggests the following:

$$\int_{r=r_1}^{r_2} \frac{Q_{Cond,cyl}}{A} dr = -\int_{T=T_1}^{T_2} k dT \tag{6}$$

$$Q_{Cond,cyl} = \frac{T_1 - T_2}{\ln(r_2/r_1)} \tag{7}$$

Furthermore, as $Q_{Cond,cyl}$ = constant. The equation can be rearranged as follows;

$$Q_{Cond,cyl} = \frac{T_1 - T_2}{R_{tube}} \tag{8}$$

where;

$$R_{tube} = \frac{\ln(r_2/r_1)}{2\pi L_A K_A} \tag{9}$$

From Equation (9), the consideration of thermal conductivity of copper and acrylic at 25ºC, were 0.2 and 401 W/m·ºC respectively. This study investigated two materials used within the adiabatic section, copper tube D_O = 15 mm, D_I = 12.5 mm and acrylic tube

D_O = 15 mm, D_I= 12 mm. Thermal resistance was calculated using Equation (9) with copper and acrylic tube results shown in Table 1.

Table 1: Thermal resistance at 25ºC (R_{tube})

Adiabatic Section Length (mm)	Thermal Resistance at 25ºC°C/W	
	Copper Tube	Acrylic Tube
150 mm	0.0032	6.63
300 mm	0.0016	3.31
450 mm	0.001	2.21

From table 1 we can see the thermal resistance of the tube at the adiabatic section R_{tube}. For the purpose of the study this demonstrates that a lower R_{tube} means higher heat loss, and alternatively, a higher R_{tube} indicates lower heat loss. This suggests acrylic tubing can reduce heat loss from the adiabatic section of the TPCT and L_A directly affects heat loss from the adiabatic section of the TPCT. This paper presents the study results of the heat transfer in regards to this area.

4 Result and Discussions

All of the findings of the study are presented in order to confirm the concept of the study regarding the angle of inclination of the TPCT impacting on heat flux, as well as the comparison between an all copper TPCT, and one with the adiabatic section constructed from acrylic tube.

4.1 *Heat flux of TPCT (copper)*

Figure 4 shows the heat flux of the copper tube with a temperature at the evaporator section (T_E) of 60ºC and 80ºC for TPCTs of lengths 150, 300 and 450 mm. The experimental results for the trend of heat flux shows that as the temperature increases so does the heat flux, which corresponds with the study by Paramatthanuwat [7]. The results indicate that the TPCT total length (L_T) has a direct impact on heat flux, as the surface area of each of the three sections L_E, L_A, and L_C are increased proportionately, providing a greater potential for the identified heat loss from the adiabatic section. With regard to the angle of inclination, the results show that a greater vertical angle allows the working fluid to fall quicker, resulting in increased heat flux. The maximum heat flux observed in this study was 4.5 kW/m^2 at a temperature of 80ºC.

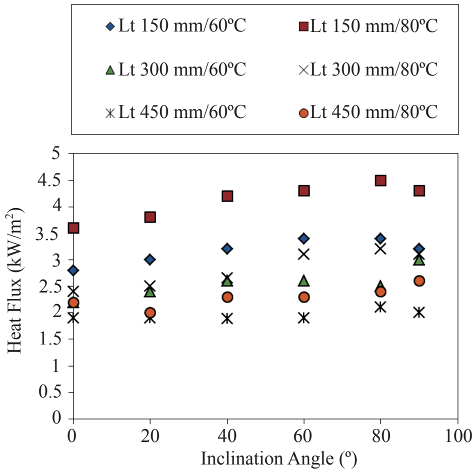

Figure 4: Heat flux of TPCT (copper).

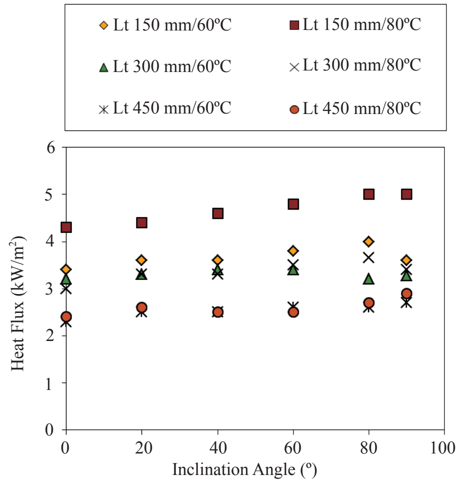

Figure 5: Heat flux of TPCT (Acrylic tube at adiabatic section).

4.2 *Heat flux of TPCT (Acrylic tube at adiabatic section)*

Figure 5 shows the corresponding heat flux of the TPCT when acrylic tube was used for the adiabatic section, with all other variables identical to the copper TPCT. The experiment also demonstrated that higher temperatures increase heat flux as heating at the evaporator section directly effects the temperature of the condenser section. Again the experiment showed that the greater angles of inclination provided greater heat flux. The maximum heat flux recorded was 4.8 kW/m^2 at an angle of inclination of 60º.

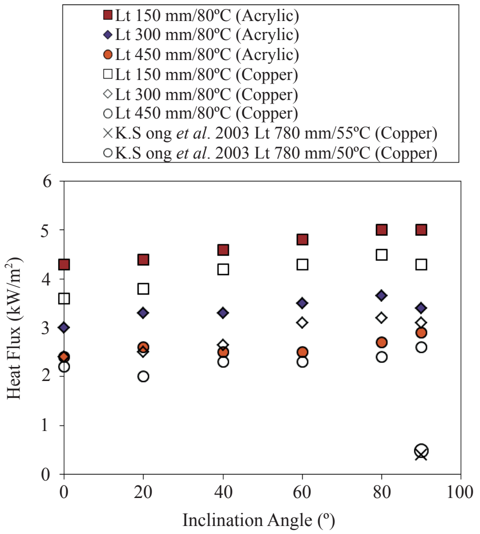

Figure 6: The comparisons of heat flux.

4.3 *Heat flux comparisons*

The aim of this study is to compare the heat flux results of TPCTs made from copper or acrylic tube. The general concept of a TPCT suggests the adiabatic section as part of the flow of working fluids neither receives nor releases heat, however in reality this section has demonstrated heat loss through heat convection and radiation from the surface area of TPCT within the adiabatic section. The experiment was done without insulation on the adiabatic section for comparison, the results of which are shown in Figure 5.

Figure 6 compares the heat flux between the TPCTs made with copper along the full length of the tube and those where the adiabatic section was made from acrylic tube. Overall, the experimental results showed that heat flux in the TPCTs made with all copper was lower than those where the adiabatic section was made from acrylic tube. This was due to heat loss from the adiabatic section being greater with copper tube than it was with acrylic tube.

The experiments with T_E 80ºC show that longer L_T decreases heat flux as a result of heat being transferred a longer distance, while increasing the angle of inclination (vertically) provides better heat transfer due to the effects of gravity. The maximum heat flux of 5 kW/m² was achieved with an L_T of 150 mm, an angle of inclination of 90º with the TPCT made from acrylic tube in the adiabatic section. The minimum heat flux of 2 kW/m² was recorded with an L_T of 450 mm, angle of inclination of 20º where the TPCT was made entirely from copper tube. The experimental results are consistent with K.S Ong *et al*. 2003 [4] who tested with the conditions of L_T 780 mm T_E 50ºC and 55ºC presented in Figure 6.

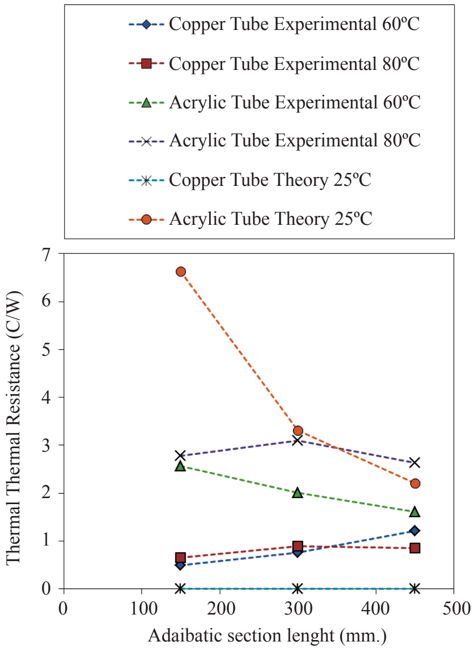

Figure 7: Thermal resistance of the adiabatic section.

4.4 *Thermal resistance (R_{tube}) of adiabatic section*

The thermal resistance, R_{tube} (Cº/W) was calculated using Equation (9), Figure 7 presents R_{tube} at the adiabatic section of the TPCTs. Comparing the effects of increases to both L_A and T_E on thermal resistance at L_A, the results demonstrate a direct increase to heat loss from L_A which is explained by the logic of thermal resistance R_{tube}.

The experiment demonstrated that greater T_E reduced R_{tube}, causing increased heat loss. The results of the TPCT made entirely of copper tube with L_A of 150 mm and T_E of 60º and C 80ºC, showed R_{tube} values of 0.5 and 0.65 Cº/W respectively. In contrast, when testing the L_A made from acrylic tube under the same conditions, the R_{tube} results produced were 2.57–2.78 Cº/W, suggesting a lower heat loss. The experiment results clearly show when an acrylic tube is installed instead of copper at L_A the R_{tube} increases, and therefore heat loss at L_A is decreased.

5 Conclusions

The final test results show that when the adiabatic section of a TPCT is made from acrylic tube it can reduce heat loss from that section and positively affect the heat flux of the overall TPCT. The experiment results can be summarized as follows:

- Increased T_E increases heat flux.
- Increased L_T decreases heat flux as a result of the heat needing to travel a longer distance.
- An adiabatic section made from copper results in lower R_{tube} as per eq.(8), lower $Q_{cond,cyl}$, and higher heat loss, whereas the opposite is true when acrylic tube replaces the copper in the adiabatic section, i.e. higher R_{tube}, higher $Q_{cond,cyl}$, and lower heat loss.
- Higher thermal resistance R_{tube} (C^o/W) of the TPCT resulted in a reduction of heat loss, and conversely lower R_{tube} resulted in increased heat loss. The results comply with the thermal resistance network and heat conduction in cylinder theory [6].

Nomenclature

A	Total heat transfer area (m^2)
D	Diameter (m)
D_O	Outside diameter (m)
D_I	Unside diameter (m)
C_P	Specific heat of the ambient air (kJ/kgºC)
$\mathring{m}$	Mass flow rate (kg/s)
Q	Heat transfer (W)
q	Heat flux (kW/m^2)
Z	Thermal resistance (ºC/W)
T	Temperature (ºC)
ΔT	Temperature difference (ºC)
c	Condenser
h	Evaporator
R	Thermal resistance (ºC/W)
K	Thermal conductivity (W/m·ºC)
L	Length (m)

Subscripts

in	Input
out	Output
T	Total
tube	Tube
cond	Conduction
cyl	Cylindrical
A	Adiabatic section
C	Condenser section
E	Evaporator section

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