SSRG International Journal of Mechanical Engineering Volume 6 Issue 7, 8-13, July 2019
ISSN: 2348 – 8360/doi: 10.14445/23488360/IJME-V6I7P102

Experimental Study of A 6063 Aluminium Alloy Two-Phase Closed Thermosyphon Charged with Tio_2 Nanofluid

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Abstract

This study reports the influence of TiO_2 nanofluid on the thermal performance of a 6063 Aluminium Alloy(A.A.) Two-Phase Closed Thermosyphon(TPCT) for various heat inputs, inclination angles and flow rates. The present study aims at experimentally demonstrating the improved performance of a 6063 AA TPCT while using a TiO_2 nanofluid. A straight 6063 AA TPCT with an inner diameter of 9mm, the wall thickness of 1 mm and the length of 750mm was used in the experimental setup. The model has been generated to validate the performance of 6063 AA TPCT by Response Surface Methodology (R.S. M).

Keywords : *6063AATPCT, BBD, RSM,TiO_2 nanofluid*

I. INTRODUCTION

Thermosyphons are known for its high performance when applied to ground thermal engineering applications and for solar energy systems in particular. The outstanding heat transfer capabilities render Heat Pipes (H.P.s) as the most prominent device when it comes to cost-effective thermal control solutions. Two-phase closed thermosyphon (TPCT) is an exceptional Heat Pipe where the flow of the condensate into the condenser section is by gravity without capillary structure. They find their application in processes involving wider thermal and temperature ranges than H.P.s with the wick. This is because flow by gravity and hence offer least flow resistance. This also removes the low boiling limit as in the case with H.P.s with the wick. Thermosyphon is found to operate even against gravity without compromising the performance concerning the classical capillary loops [1]. Drying out combined with flooding and entrainment limits are causes for concern in TPCTs, which will affect the transfer of thermal energy [2].

Trijo tharayil et al. [3].studied and compared thermal performance and entropy generation in a miniature loop heat pipe. Water and Graphene water nanofluids in two different concentrations are used as the working fluids. The use of nanofluid is found to diminish the entropy generation and increases MLHP efficiency. Renjith Singh et al. [4] used acetone as working fluid to investigate the thermal performance of a flat thermosyphon. Experiments are conducted in anodised and non anodises flat thermosyphon by varying the inclination angle (0,45,90) and fill ratios (40%,60% and 100%). Anodised thermosyphon is found to perform better with a maximum enhancement of 27%. The thermal performance of TPCT was studied by Kamyar et al. [5] by using different working fluids such as water and water bases of Al_2O_3 & $TiSiO_4$ nanofluids. The application of AL_2O_3 and $TiSiO_4$ nanofluids reduced the thermal resistance by 65% and 57% respectively. Zhang et al. [6] used the micro-grooved thermosyphon to study the effect of enhanced surface area. The results suggested that the performance of TPCT is affected by the geometry, the inclination angle, the vapour temperature and the pressure of the working fluid and significantly by the filling ratio. The thermal performance and the limitation of the TPCT operation have been extensively studied by past investigations [14]. Many attempts have been made to enhance the circulation of the working fluid in TPCTs. Centrifugal force [8], electrokinetic force [9] or vibration force [10] were used for increasing the circulation. Similarly, studies were carried out to explore the effect of surface modifications [11] and the use of nanofluids [12-14] to enhance the TPCT performance. K.S. Ong et al. concluded that the high thermal resistance while using R410A filled thermosyphon lowered the thermal performance [15].

The review of the literature provided the inspiration to employ the 6063 AA TPCT with TiO_2 nanofluid for the present study.

II. MATERIALS AND METHODS

To narrow down on the choice of material to be used in this study, the chemical composition test is performed, and it is presented in Table 1. From the chemical composition, it is identified that the selected container material is alloyed with magnesium and silicon in a high quantity by weight percentage (wt%). Therefore the grade of the material chosen for the study is 6063 aluminium alloy. Some of the important properties used for the study are listed in Table 2.

Table. 1 Chemical composition (wt%) of Aluminium (6063 AA) as container metal

Mg	Si	Fe	Cu	Mn	Zn	Cr	Al
0.7	0.532	0.35	0.1	0.7	0.02	0.1	Remainder

Table.2 Key properties of 6063 AA

Density	2.7 g/cm^3
Thermal conductivity K	200 W/mK
Thermal expansion coefficient	23 µm/m˚C

III. EXPERIMENTAL SETUP

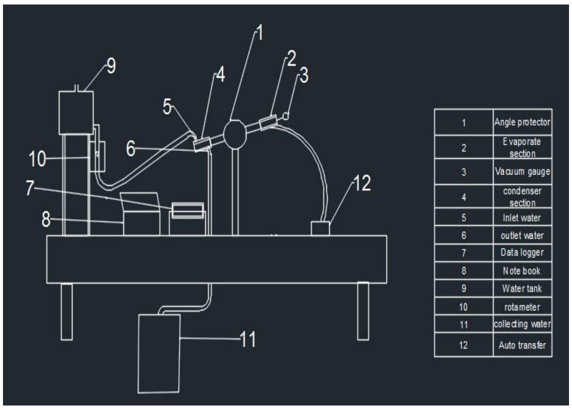

Fig 1. The layout of the experimental setup

An experimental setup was built to carry out the thermal performance analysis of Two-Phase Closed Thermosyphon (TPCT) with three different container materials and three different working fluids. The schematic layout of the experimental setup is shown in Fig 1. The setup consists of the following equipment and facilities.

6063AA TPCTs are used for this experimental study. The inclinometer (Bevel Protector) provision is made on the test rig to rotate the TPCT through 0˚ - 180˚ angle.

The electrical heater of 200 watts capacity is wrapped around the evaporator section for supplying heat input. A three-phase variac is used to regulate the power supply according to the need. The capacity of the variac, which is used for this experiment is 1800 watts, 230 Volts and 20 amps. A wattmeter is used to determine the power supply in watts to the load provided in the heater of the evaporator section through the three-phase variac, and its range is around 0-250 watts and 230 Volts. The digital display in the wattmeter shows the value of the load. The K-type thermocouples are soldered along the length of the TPCT at eight locations. All the eight K-type thermocouples are connected to the data logger system for the better results in temperature measurement. The efficient way to measure the power output of TPCT is by using the condenser jacket through which water is passed. In this experiment, for the 6063AA TPCT, a 6063 AA jacket with an outer diameter of 30 mm, and length of 250 mm, having the inlet and outlet connections located diagonally across each other to induce swirl flow is designed. Similarly, for 6063 Al Alloy TPCT, the jacket is also made with the same material, and the flow rate of the coolant water from the water tank is controlled by rotometer.

The evaporator section of the TPCT is connected with a heat source of plate type heater with a maximum power output of 200W at 220V, and the condenser section is cooled by tap water. The mass flow rate of the condenser section is controlled by rotometer. The adiabatic section is insulated by glass wool to avoid heat energy interaction with the ambience. Before charging the working fluid, the TPCT enclosure is evacuated and maintained at a vacuum of 99kPa to 100kPa. Then the required amount of the working fluid is charged.

The container material was tested with TiO2 at a filling ratio of 50 per cent. Eight thermocouples of K-type measure the wall temperature on the TPCT container materials. Two thermocouples were mounted on the evaporator section, two on the adiabatic section and four on the condenser section. The location of thermocouples is shown in Fig 4.2. All the thermocouples (K-Type) are connected and monitored using the 8-channel data logger system. The flat plate type heater of the evaporator section is connected to the three-phase variac of 20 amps. The heat input is varied by using a variac. The heating power input can be observed from watt mater.

A. Nano Fluids

The important part of this experiment is the preparation of nanofluids. Nanofluids are the metal or metal oxide nanoparticles being suspended in the base fluid such as water, oil, R134, R410, acetone or ethylene glycol. The thermal conductivity of the nanofluid is the basis of the selection of various nanoparticles.

B. Preparation of nanofluids

In the present work, a two-step method was employed to prepare the nanofluids. TiO_2 nanoparticles (15nm), purchased from the USA, is well dispersed into DI water at a concentration of 60 mg/lit. The well-dispersed sample is subjected to the sonication process in bath type ultrasonic homogeniser (Olee Pvt Ltd, 42K_{HZ}) up to 10 hours.

C. Test Procedure

Design of Experiments (DOE) is an efficient procedure for planning experiments so that the data obtained can be analysed easily. To optimise the input parameters for the desired performance, the RSM is employed for the Design of Experiments.

Box – Behnken Design is used with three varying input parameters were used, namely heat input (A), angle of inclination (B) and flow rate of water in the condenser section (C) to obtain the output responses of thermal resistance (R_{th}), and overall heat transfer coefficient ($U_{overall}$).

Table. 3 shows the process parameters and their levels. Table. 4 shows the design of the matrix.

Table. 3 Process parameters and their levels

Parameters	Level		
	-1	0	1
Heat Input, W	90	120	150
The angle of inclination, °	30	60	90
Flow Rate, ml/min	100	150	200

Table. 4 Design of Matrix

Std	Run	Factor 1 A: Heat Input	Factor 2 B: Angle of Inclination	Factor 3 C: Flow Rate
2	1	120	60	150
1	2	120	30	200
7	3	150	60	100
5	4	90	60	100
16	5	90	60	200
9	6	90	90	150
10	7	120	60	150
4	8	150	90	150
14	9	90	30	150
13	10	120	60	150
8	11	120	90	100
11	12	120	90	200
12	13	120	30	150
17	14	120	60	150
3	15	120	60	150
15	16	150	60	200
6	17	120	30	100

The BBD resulted in 17 runs of simulation arranged by three factors, as listed in Table 4. The 17 runs were conducted as per the resulting design matrix by varying, the mass flow rate of pure water flowing through the condenser section using rotometer, the inclination angle of TCPT and heat input. Approximately it took 20 minutes for TiO_2 nanofluid to attain the steady-state. The temperature at each trial is recorded after the attainment of the steady-state condition using data logger system.

D. Data reduction

Data reduction is the transformation of numerical or alphabetical digital information derived empirically or experimentally into a corrected, ordered, and simplified form. The basic concept is the reduction of multitudinous amounts of data down to the meaningful parts.

When information is derived from instrument readings, there may also be a transformation from analogue to digital form. When the data are already in digital form, the 'reduction' of the data typically involves some editing, scaling, coding, sorting, collating, and producing tabular summaries. When the observations are discrete, but the underlying phenomenon is continuous, then smoothing and interpolation are often needed. Often the data reduction is undertaken in the presence of reading or measurement errors.

Thermal resistance is defined as the ratio of the temperature gradient between the evaporator and condenser sections.

The thermal resistance of the thermosyphon (R_{th}) is evaluated by

$$R_{th} = \left(T_{eavg} - T_{cavg}\right) / Q_{input}$$

Where T_{eavg} and T_{cavg} are the arithmetic average of temperatures of the evaporator and the condenser sections respectively. The heating power input Q can be observed from wattmeter.

Overall, the heat transfer coefficient is defined as the convective heat transfer between a fluid and a solid.

Overall heat transfer coefficient of the thermosyphon ($U_{overall}$) is evaluated by

$$U_{overall} = \frac{Q_{in}}{\pi DL\,(\bar{T}_e - \bar{T}_c)}$$

Where D and L are the diameters and the total length of the TPCT.

$\bar{T}_e$ *and* $\bar{T}_c$ Are introduced as the average temperature of the evaporator and condenser sections, respectively.

IV. RESULT AND DISCUSSIONS

A. Effect of thermal resistance (Rth) on Various Input Parameters of 6063AA TPCT with TiO_2 Nanofluid:

Table 5. Anova table for thermal resistance (response 1)

Response 1

ANOVA for Response Surface Quadratic Model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob >F	
Model	0.002147	9	0.000239	6.882788	0.0093	Significant
A-Heat Input	0.0004	1	0.0004	11.55416	0.0115	
B-Angle	0.000284	1	0.000284	8.198696	0.0242	
C-Flow Rate	0.000677	1	0.000677	19.53813	0.0031	
AB	0.000282	1	0.000282	8.131554	0.0246	
AC	3.42E-05	1	3.42E-05	0.987482	0.3535	
BC	1.12E-05	1	1.12E-05	0.323822	0.5871	
A^2	6.26E-05	1	6.26E-05	1.8049	0.2210	
B^2	0.000205	1	0.000205	5.903847	0.0454	
C^2	4.34E-05	1	4.34E-05	1.253325	0.2999	
Residual	0.000243	7	3.47E-05			
Lack of Fit	0.000143	3	4.76E-05	1.90839	0.2696	Not Significant
Pure Error	9.98E-05	4	2.49E-05			
Cor Total	0.002389	16				
Std. Dev.	0.005887		R-Squared	0.90847		
Mean	0.127518		Adj R-Squared	0.8827		
CV %	4.616588		Pred R-Squared	0.863		
PRESS	0.004477		Adeq Precision	10.35		

From the ANOVA Table, a Model F-value of 6.88 implies the model is significant. This suggests that there is only a 0.93% chance that a "Model F-value" this large could occur due to noise.

Model terms with values of "Prob > F" less than 0.0500 indicate that those terms are significant. In this case, the linear effects of A, B & C, the interactive effects of A & B and the squared effects of B are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The contour plots for the output response to the changing input parameters are presented.

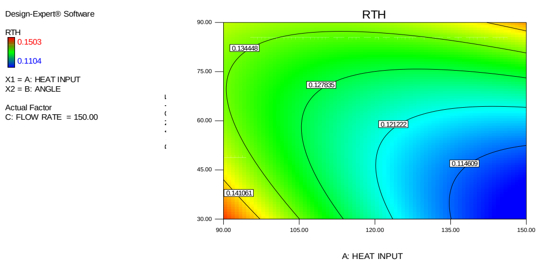

Fig 2: Countor plot for R_{th} concerning heat input and angle

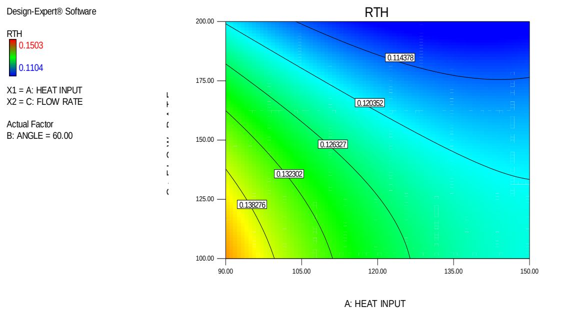

Fig 3: Countor plot for R_{th} concerning heat input and flow rate

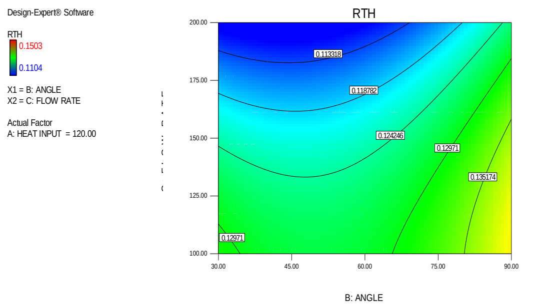

Fig 4: Countor plot for R_{th} concerning angle and flow rate

The response surface contour plot is depicted in Fig. 2 shows the interactive effect of the heat input and inclination angle of the 6063 AA TPCT filled with TiO_2 nanofluid on thermal resistance is observed. The increase in heat input slightly decreases the thermal resistance at the minimum inclination angle. A concurrent increase in the inclination angle increases the thermal resistance. The thermal resistance increases with the increase in both heat input and inclination angle. While observing from Fig.3, it is noted that there is a maximum decrease in the thermal resistance due to the interactive effect of heat input and flow rate of water in the condenser section. At a higher heat input, the flow rate has a much-pronounced influence in decreasing the thermal resistance than at higher flow rate compared to the heat input. From Fig. 4, it is found that the increase in the inclination increases the thermal resistance to the maximum at the minimum flow rate. Though the flow rate is increased from low to high, the thermal resistance remains constant.

In all the above affects the thermal resistance value is mainly affected by the inclination angle of TPCT. This is because of the increase in the input increases the temperature in the evaporator section resulting in less vapour protection at a higher tilt angle. The thermal resistance was observed to be higher for the tilted pipe of inclination angle 60^{o} to 90^{o}. This is considered to be the poorest performance of 6063 AA TPCT filled with Tio2 nanofluid. Since the thermal expansion coefficients of the 6063 AA TPCT is high, during higher heat input and higher flow rate the thermal resistance turns out to be minimum due to the smooth process of the heat transport in the evaporator and condenser section.

B. Effect of Overall heat transfer co-efficient (Uoverall) on Various Input Parameters of 6063AA TPCT with Tio2 Nanofluid:

TABLE 5. Anova Table For Overall Heat Transfer Co-Efficient (Response 2)

Response 3 $U_{Overall}$						
ANOVA for Response Surface Quadratic Model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	132512	9	14723.55	53.2206	< 0.0001	Significant
A-Heat Input	25156.8	1	25156.8	90.93322	< 0.0001	
B-Angle	19773.25	1	19773.25	71.47352	< 0.0001	
C-Flow Rate	22041.6	1	22041.6	79.67284	< 0.0001	
AB	8717.554	1	8717.554	31.51097	0.0008	
AC	5559.939	1	5559.939	20.09728	0.0029	
BC	34.39822	1	34.39822	0.124338	0.7348	
A^2	6694.753	1	6694.753	24.19924	0.0017	
B^2	27739.59	1	27739.59	100.2691	< 0.0001	
C^2	1390.096	1	1390.096	5.024719	0.0599	
Residual	1936.56	7	276.6514			
Lack of Fit	1921.684	3	640.5615	172.2486	0.4001	Not significant
Pure Error	14.87528	4	3.71882			
Cor Total	134448.5	16				
Std. Dev.	16.63284		R-Squared	0.985596		
Mean	869.6976		Adj R-Squared	0.967077		
CV %	1.912485		Pred R-Squared	0.92 0788		
PRESS	53135.62		Adeq Precision	20.52401		

From the ANOVA Table, a Model F-value of 53.22 implies the model is significant. This suggests that there is only a 0.01% chance that a "Model F-value" this large could occur due to noise.

Model terms with values of "Prob > F" less than 0.0500 indicate that those terms are significant. In this case, the linear effects of A, B & C, the interactive effects of A – B and A-C and the squared effects of A and B are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The contour plots for the output response to the changing input parameters are presented.

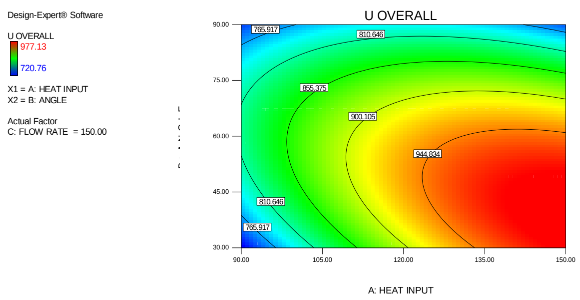

Fig 5: Countor plot for U $_{Overall}$ concerning heat input and angle

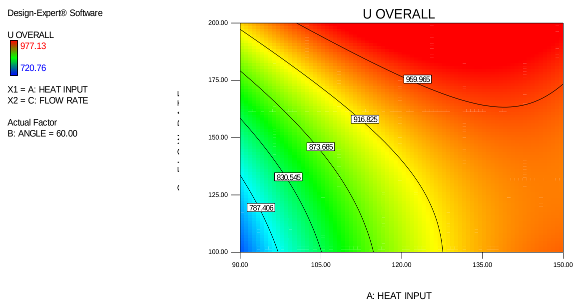

Fig 6: Countor plot for U $_{overall}$ concerning heat input and flow rate

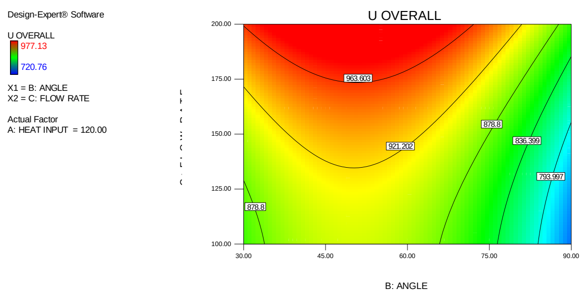

Fig 7: Countor plot for U $_{overall}$ concerning angle and flow rate

From Fig. 5, it is found that the variation of heat input increases the overall heat transfer coefficient ($U_{overall}$) at the minimum inclination angle. The increase in inclination angle slightly pushes the overall heat transfer coefficient to the maximum. Fig. 6 represents that the increase in heat input increases the $U_{overall}$ at the minimum flow rate. Though the increase in flow rate also increases the $U_{overall.}$ The combinatorial effect of heat input and the flow rate is found to have a maximum of $U_{overall}$ as they both increase. Fig. 7 shows that the increase in the inclination angle reduces the $U_{overall,}$ but the increase in flow rate does not impact the $U_{overall}$. For this gravity-assisted thermosyphon equipped with 50% filling ratio of TiO_2 nanofluid, the inclination angle can influence on the quantity of working fluid that is available in the evaporator section. As expected, when the inclination of the thermosyphon decreases, the amount of working fluid in the evaporator section decreases. In this case, the fouling resistance will be prompt while in due course layers of fouling will be formed on the wall of the evaporator. The overall heat transfer coefficient of the thermosyphon gradually decreases while a significant decrease of fouling resistance over the inclination angle. For higher heat input the rate of heat transfer enhancement dramatically increases, showing evidence that the dominant heat transfer mechanism has been changed to nuclear boiling inside the evaporator and the corresponding variation in the flow rate of the TPCT. The optimised value from the RSM model is shown in fig 8.

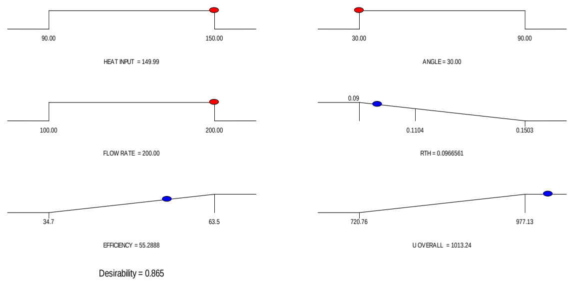

Fig.8 Optimised plot

CONCLUSIONS

The main parameters, concerning thermal resistance and overall heat transfer co-efficient and their impacts on the 6063 AA TPCT along with TiO2 nanofluid, were examined. The following are the reasons for the thermal enhancement of 6063 AA TPCT using TiO_2 nanofluid,

- ✓ The Rth is mainly affected by the inclination angle of 6063 AA TPCT.
- ✓ Since the thermal conductivity TiO_2 nanofluid is high, the Rth decreases with increase in heat input.
- ✓ Similarly, the Rth is at a maximum at the minimum flow rate and also at higher tilt angle shows the poorest performance of 6063 AA TPCT.
- ✓ The optimum value of Rth is 0.096 C/W obtained at 149.99 W,200 ml/min, and 30 deg.
- ✓ Increase in inclination angle pushes the overall heat transfer coefficient to the maximum.
- ✓ Inclination angle influences the quantity of working fluid that is available in the evaporator section. As expected, when the inclination of the thermosyphon decreases, the amount of working fluid in the evaporator section decreases. In this case, the fouling resistance will prompt while in due course layers of fouling will be formed on the wall of the evaporator. The overall heat transfer coefficient of the thermosyphon gradually decreases while a significant decrease of fouling resistance over the inclination angle.
- ✓ For higher heat input the rate of heat transfer enhancement dramatically increases, showing evidence that the dominant heat transfer mechanism has been changed to nuclear boiling inside the evaporator and the corresponding variation in the flow rate of the TPCT.
- ✓ The optimum value of U overall is 1013.24 W/m2C obtained at 149.99 W,200 ml/min, and 30 deg.

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