International Journal of Engineering

Journal Homepage: www.ije.ir

Performance Investigation of 405 Stainless Steel Thermosyphon using Cerium (IV) Oxide Nano Fluid

N. Alagappan*, N. Karunakaran

Department of Mechanical Engineering, Annamalai University, Annamalainagar, Tamil Nadu, India

PAPER INFO

Paper history:
Received 31 August 2016
Received in revised form 22 November 2017
Accepted 11 February 2017

Keywords:
405 Stainless Steel Two-Phase Closed Thermosyphon
CeO_2 Nanofluid
Box – Behnken Design
Response Surface Methodology

ABSTRACT

A thermosyphon is an efficient heat transfer device, which transports heat using gravity for the evaporation and condensation of the working fluid. In the present study the Box-Benhnken (BBD) design approach was chosen for the Two-Phase Closed Thermosyphon (TPCT) with CeO_2 nanofluid using 0.1% volume of Nanofluid with surfactant of ethylene glycol. The experiment resulted in identifying the optimised set of parameters for 405SS TPCT, to achieve lower thermal resistance and better heat transfer. This work gains significance in the sense that with the number of experiments, reliable model has been generated validated and further, the process has been optimised with one objective which is thermal resistance. To obtain the optimum condition, the response surface methodology (RSM) through Box – Behnken (BBD) was applied.

***doi**: 10.5829/idosi.ije.2017.30.04a.16*

NOMENCLATURE

405SS	405 Stainless Steel Alloy
TPCT	Two Phase Closed Thermosyphon
CeO_2	Cerium (IV) Oxide
BBD	Box-Behnken Design
RSM	Response Surface Methodology
R_{th}	Thermal Resistance, $^oC/W$
Q_{in}	Heat input, Watts
DOE	Design of Experiments

1. INTRODUCTION

The two-phase closed thermosyphon is thermodynamically similar to wicked heat pipe, but relies on gravity to ensure liquid return from the condenser to the evaporator. Basically, a thermosyphon consists of an evaporator, an adiabatic zone and a condenser. In the lower part of the thermosyphon, the working fluid is evaporated and natural convection is utilised to carry the vapour to the condenser region. Here cooling forces the vapour to condense on the inner wall of the thermosyphon. Eventually, the down flowing condensate joins the liquid part of the working fluid again. Text books by Reay and Kew [1] and Faghri [2] discuss the design, operation principle and thermal performance of TPCT.

In many cases water is used as the working fluid in thermosyphons and heat pipes due to its high 'figure of merit' such as high latent heat, low cost and requiring a relatively low inventory water is compatible with all container materials of thermosyphon. The most popular

*Corresponding Author's Email: algatesmech06@gmail.com (N. Alagappan)

material being copper [3] noticeably, and steel with water as the working fluid shows that the fluid-wall combination has demonstrated a significant life [4].

The use of inhibitors-coated steel tested for up to 35000 hours has been reported from Ukraine [5].

Choi and Eastman [6] were the first to investigate the enhanced the thermal conductivity of nanofluids and opened the gate for numerous studies analyzing this specific class of fluids. At present, various types of nanoparticles such as metallic and ceramicones have been used in nanofluid preparation [7]. Namburu et al. and Praveen et al. demonstrated the Newtonian behaviour of nanofluids is independent of the nanoparticle material and is a function of temperature, and the viscosity decreases exponentially with temperature. They disclose the Newtonian behaviour of ethylene glycol based CuO nanofluids and Non-Newtonian behaviour of ethylene glycol based SiO nanofluids at low temperature and Newtonian behaviour at higher temperature [8, 9]. Fe_3O_4 –water nanofluids viscosity was studied by Sundar et al. with volume concentration range of 0.01–2.0% and the temperature range of 20–60°C. They observed that the viscosity of the nanofluid increased with an increase in the particle volume concentration, and at same volume concentration and temperature, the viscosity enhancement was greater compared to that of thermal conductivity enhancement [10]. Huminic and Huminic [11] investigated the effect of nanofluids on heat transfer characteristics of two-phase closed thermosyphon (TPCT) with different volume concentrations of iron oxide nanofluids. Then, no particles were found to have a significant effect on the enhancement of heat transfer characteristics of TPCT. Alizadet et al. [12] investigated thermal performance of flat shaped heat pipes using nanofluids of CuO, Al_2O_3 and TiO_2. They found an enhancement in thermal performance of the heat pipe for nanofluid with high volume concentrations. The Cerium oxide- water nanofluid in a corrugated plate heat exchanger enhances the heat transfer to about 39% for the optimum particle loading of 0.75%. The pressure drop for this optimum concentration is negligible [13]. Vermahmoudi et al. [14] presented the overall heat transfer coefficient of water based iron oxide nanofluid in a compact air-cooled heat exchanger under laminar flow conditions. The different volume concentrations (0.15–0.65%) Fe_2O_3–water nano-fluid was prepared and stabilized using 0.8% by weight of polyethylene glycol and the pH was maintained as 11.1. A maximum of 13% and 11.5% enhancement in overall heat transfer coefficient and heat transfer rate for 0.65% particle loading in the base fluid is observed. Alagappan et al studied the thermal performance of circular finned thermosyphon using nanofluid with alcohol and analysed and compared it with alcohol and base fluid DI water. Their results demonstrated that TiO_2 nanofluid with 0.2 ml of ethylene glycol improves the performance through reduction of thermal resistance by 85.86% [15]. Ajay et al. evaluated the performance of solar collector using Al_2O_3-$C_2H_6O_2$-H_2O nanofluid as a working fluid through both experimental and CFD analysis. From both experimental and CFD analysis, an improvement in overall efficiency of solar collector is reported when nanofluid is used as compared to water-ethylene glycol mixture. Also, with increasing volume flow rate of working fluid, corresponding improvement in the overall efficiency of solar collector takes place. Close agreement is also observed between experimental and CFD result [16]. Jamshidi et al. studied the effect of adding SiO_2 nanoparticles on the viscosity of base fluid which was investigated experimentally. The Base fluids are chosen among common heat transfer fluids such as ethylene glycol, transformer oil and water. In addition, different volume percentages of ethylene glycol in water are used as ethylene glycol-water solution. It is shown that the viscosity of solution is enhanced by adding nanoparticles. From their study it was revealed that there are very little differences between the viscosity of nanofluid in a specific temperature atmospheric cooling and heating cycles [17].Text book by M. Cavazzuti, [18] optimization methods: from theory to design, discuss the DOE (or) experimental design. DOE is the name given to the techniques used for guiding the choice of the experiments to be performed in an efficient way. Manohar et al discussed the use of Box Behnken design approach to plan the experiments for turning Inconel 718 alloy with an overall objective of optimizing the process to yield higher metal removal, better surface quality and lower cutting forces. Their work resulted in identifying the optimized set of turning parameters for Inconel 718 material using coated carbide tools to achieve better surface roughness and higher material removal [19].

The current experimental study resulted in identifying the optimised set of process parameters for 405 SS TPCT using 80mg/lit CeO_2 nanofluid by RSM using design expert software 7.0.

2. PREPARATION OF NANOFLUIDS

The CeO_2 nanoparticles (15-30 nm) were well dispersed into DI water at a concentration of 80 mg/lit. Then, the well dispersed sample was transferred into ultrasonic bath and sonicated continuously for 10 hours with surfactant of ethylene glycol of 0.1% of volume of nanofluid. The fluid was stable up to 50 days at atmospheric condition; beyond 50 days cluster size increased and agglomerated.

Figure 1 shows the TEM image of CeO_2 DI water-based nanofluids. The morphology of nanoparticles is perfect cubic crystalline structure. There is no agglomeration and clustering inside the base fluids and also seen that nanoparticles are well dispersed within base fluid.

Figure 2 represents the EDS pattern which implies the composition of selected nanoparticle CeO_2. The major portion of the nanoparticle is composed of Ce (Cerium) and O_2 (Oxygen). The EDS can help the researchers to verify the quality of nanoparticles used in their research.

3. EXPERIMENTAL SETUP

The experimentation was performed on 405 SS alloy made TPCT by RSM using design of expert software. The TPCT is made of 405 stainless steel alloy tube with outer diameter of 12 mm, 2 mm thickness and 750 mm in length. The evaporator, the adiabatic and the condenser section are uniformly 250 mm length. The grade of the selected TPCT container material was identified by conducting the chemical composition test, the results of which is shown in Table 1.

BBD method is employed with three input parameters namely heat input (A), angle of inclination (B) and flow rate (C) over the output response of thermal resistance.

Table 2 shows the process parameters and their levels. The importance of the work has been to highlight the thermal resistance on 405 SS alloy made TPCT under various heat input, angle of inclination and flow rates. Table 3 shows the design of matrix. The schematic diagram of the experimental setup is shown in Figure 3.

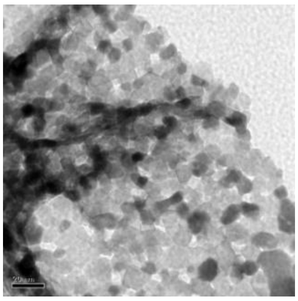

Figure 1. TEM image of CeO_2

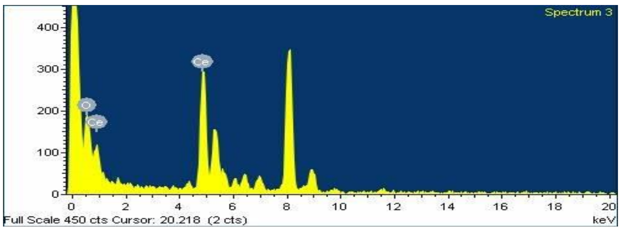

Figure 2. EDS pattern of CeO_2

TABLE 1. Chemical composition (wt%) of Steel (405) as container metal

Cr	Mn	C	P	S	Al	Fe
14.5	1	0.83	0.04	0.30	0.1	Remainder

TABLE 2. Process parameter and their levels

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

TABLE 3. Design of matrix

Std	RUN	Factor 1	Factor 2	Factor 3	Respons Rth
8	1	120	60	150	0.24
16	2	120	30	200	0.2025
10	3	150	60	100	0.2
1	4	90	60	100	0.3372
12	5	90	60	200	0.28
9	6	90	90	150	0.3333
3	7	120	60	150	0.2365
2	8	150	90	150	0.2072
5	9	90	30	150	0.2777
6	10	120	60	150	0.222
15	11	120	90	100	0.2645
14	12	120	90	200	0.24
13	13	120	30	150	0.2008
7	14	120	60	150	0.2485
4	15	120	60	150	0.2227
17	16	150	60	200	0.2033
11	17	120	30	100	0.2221

The plate type heater was used in the evaporator section with a maximum power output of 200 W at 220 V and the condenser section was cooled by pure water with the mass flow rate of 100 ml/min to 200 ml/min. The adiabatic section was insulated by glass wool to avoid no heat energy intersection to take place with the ambient. The TPCT was charged with CeO_2 nanofluid at 50% of fill ratio. The wall temperature on the TPCT was measured by eight thermocouples of K-type. The uncertainty in temperature measurement was ± 0.1°C. Two thermocouples were mounted on the evaporator section, two on the adiabatic section and four on the condenser section. All thermocouples (K-type) were connected and monitored using 8-channel data acquisition system. The flat-plate type heater of the evaporator section was connected to the variac. The heat input was varied by using variac which ranges between 90W-150W.

3. 1. Test Procedure DOE is an efficient procedure for planning experiments so that the data obtained can be analyzed. The experimental task starts with selecting the input variables and the response (output) that is to be measured. 17 runs of simulation are arranged by three factors (BBD) as listed for 405 SS thermosyphon. First, the mass flow rate of pure water flowing through the condenser section was set using rotameter. The inclination angle of TPCT was defined as the angle between the horizontal axis and the surface of the TPCT. The power supply was turned on and the heat input incremented with the help of variac. Approximately 405 SS TPCT attain steady state 30 minute in each of the 17 trials. The temperature at each trial was recorded after the attainment of steady state condition using data acquisition system [USB-Countron].

3. 2. Data Reduction The thermal resistance of the thermosyphon (R_{th}), is evaluated by:

$$R_{th} = \frac{T_{eavg} - T_{cavg}}{Q_{input}} \quad (1)$$

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

4. RESULT AND DISCUSSION

A regression analysis is carried out to develop a best fit model to the experimental data, which are used to generate response surface plots. The lack of fit (Figure 4) measures the success of the model to represent the data in the experimental domain at points which are not included in the regression. The non-significant values of lack of fit (>0.005) reveals that the quadratic model is statistically not significant for the 405 SS TPCT with CeO_2 nanofluid.

The ANOVA (Table 3) shows that the F-value for 405 SS TPCT is 36.84. The values of prob > F and less than 0.0500 indicates that the model terms are significant @ 5% level. In this model, the significant terms are A, B, C, AC and A^2 at 1% level and the values greater than 0.1 they are not significant (AB, BC, B^2 and C^2) at 1% and 5% level, respectively.

Final equations in terms of coded factors are as follows:

RTH = + 0.89005-8.18794E-003 * HEAT INPUT + 2.37662 E-003 * ANGLE - 1.73517E-03 * FLOW RATE -7.80922 E-006* HEAT INPUT * ANGLE + 1.00833 E-005 * HEATINPUT * FLOW RATE - 8.16667 E-007 * ANGLE * FLOW RATE + 2.21627 E-005 * HEAT INPUT^2- 5.08366 E-006 *ANGLE^2 + 1.09725 E-006 * FLOW RATE^2

4. 1. Effect of Heat Input and Angle of Inclination on Thermal Resistance (RTH) Figure 5 shows the wire mesh plot, from which the interactive effect of the heat input and inclination angle of TPCT on thermal resistance is observed.

The increase in heat input significantly decreases the thermal resistance at the minimum inclination angle of TPCT. The thermal resistance is initially low and thereafter increases with the increase of the inclination angle of TPCT. The combinational effect of these two factors is found to be same as the individual effect of heat input.

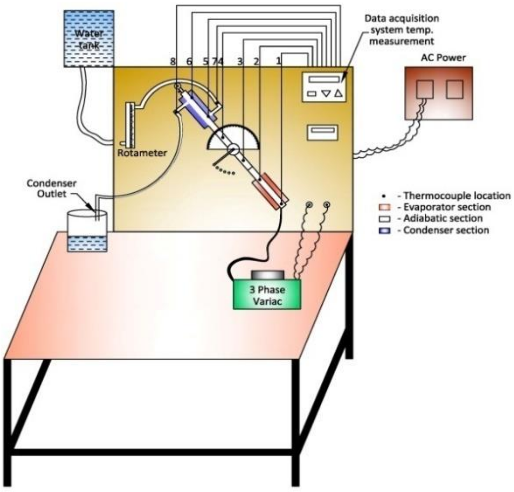

Figure 3. The Schematic diagram of experimental setup

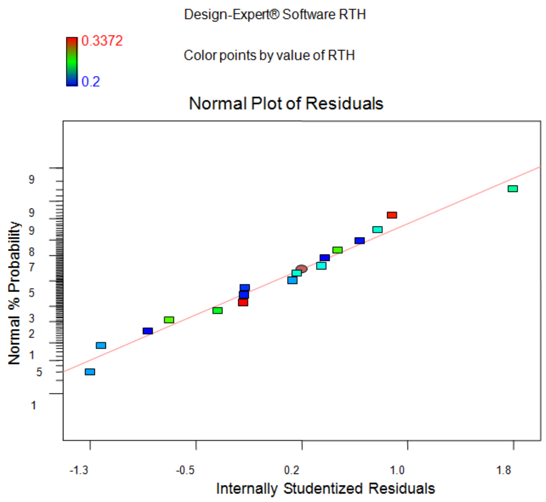

Figure 4. Normal plot of residual o thermal resistance

TABLE 3. ANOVA Table for 405 SS TPCT

Response RTH

ANOVA for response surface quadratic model

Analysis of variance table [partial sum of squares Type III]

Source	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Model	0.028957	0.003217	36.84032	< 0.0001	significant
A-Heat input	0.016857	0.016857	193.0194	< 0.0001	
B-Angle	0.003024	0.003024	34.62862	0.0006	
C-Flow rate	0.001201	0.001201	13.74603	0.0076	
AB	0.000107	0.000107	1.226275	0.3047	
AC	0.000915	0.000915	10.4777	0.0143	
BC	6E-06	6E-06	0.06873	0.8007	
A^2	0.001327	0.001327	15.19021	0.0059	
B^2	8.14E-05	8.14E-05	0.931682	0.3666	
C^2	2.84E-05	2.84E-05	0.325108	0.5864	
Residual	0.000611	8.73E-05			
Lack of Fit	8.72E-05	2.91E-05	0.221729	0.8769	not significant
Pure Error	0.000524	0.000131			
Cor Total	0.029568				
Std. Dev.	0.009345	R-Squared	0.979324		
Mean	0.243429	Adj R-Squared	0.952741		
C.V. %	3.839011	Pred R-Squared	0.883531		
PRESS	0.0034444	Adeq Precision	19.49726		

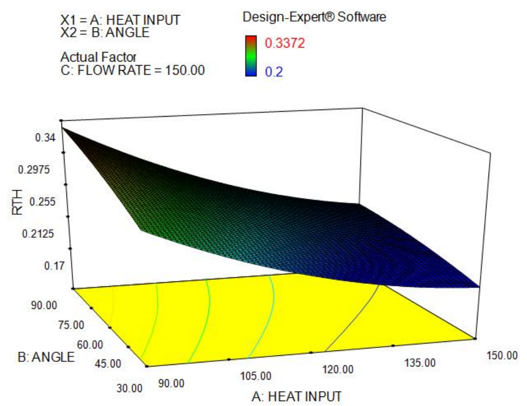

Figure 5. Effect of heat input and angle of inclination on thermal resistance (RTH)

This is due to the presence of CeO_2 nanoparticle in DI water which eventually achieves the minimal value of thermal resistance due to its thermal conductivity value which is estimated to be 0.718 W/mK. The existence of nanoparticles increases the surface area which paves the way for high heat absorption, which creates a pool boiling effect in the evaporator section.

4. 2. Effect of Heat Input and Flow Rate on Thermal Resistance (RTH) Figure 6 shows the wire mesh plot of the interactive effect of heat input and flow rate of 405 SS TPCT on thermal resistance. The increase in heat input decreases the thermal resistance when the flow rate of the water is at maximum in the condenser section. The thermal resistance initially increases with a minimum flow rate and then gradually decreases with the increase in flow rate. The combinational effect of heat input and flow rate is found to have a maximal decrease of thermal resistance as they both increase. However, the increase of heat capacity with the increase of flow rate leads to the decrease in the temperature difference in the inlet and outlet of the condenser section. Here, the thermal resistance is allied with heat input.

4. 3. Effect of Angle and Flow Rate on Thermal Resistance Figure 7 shows the interactive effect of the two factors: inclination angle and flow rate of 405 SS TPCT on thermal resistance. When the inclination angle of the SS TPCT is increased, the thermal resistance also increases to the maximum at the minimum flow rate.

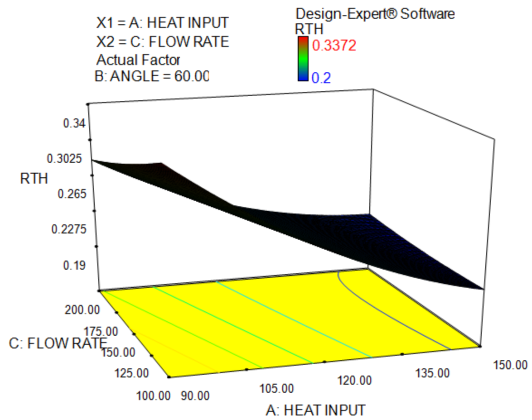

Figure 6. Effect of heat input and flow rate on thermal resistance (RTH)

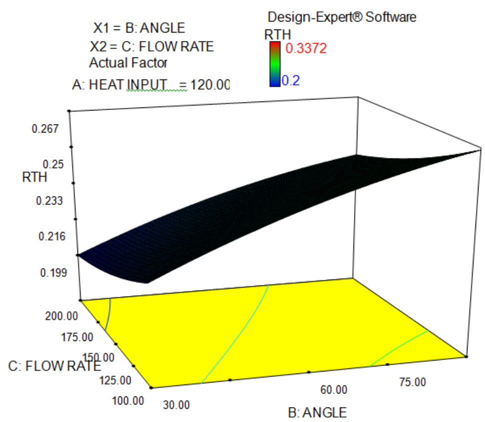

Figure 7. Effect of angle of inclination and flow rate on thermal resistance (RTH)

Noticeably, the combinational effect of inclination angle and flow rate show a slight decrease of thermal resistance compared to the individual effect of inclination angle. The flow rate is sufficient to form a liquid film in the condenser section which returns to the evaporator as a falling film which ultimately avoids the dry out in the evaporator.

CeO_2 nanofluid helps to reduce the thermal resistance at the minimum inclination angle, where in at a higher inclination angle, the vapour of the CeO_2 nanofluid started to condense before reaching the condenser section which resulted in maximum thermal resistance. Here, the thermal resistance is associated with the flow rate of water in the condenser section. Figure 8 shows the optimized value of input parameters and also the output response.

5. COMPARISON OF CeO_2 WITH OTHER NANOFLUIDS

When compared to the other nanofluids from the literature listed in Table 4, CeO_2 (15-30 nm) which is synthesized by two-step method used in this study, has a thermal enhancement of 17%.

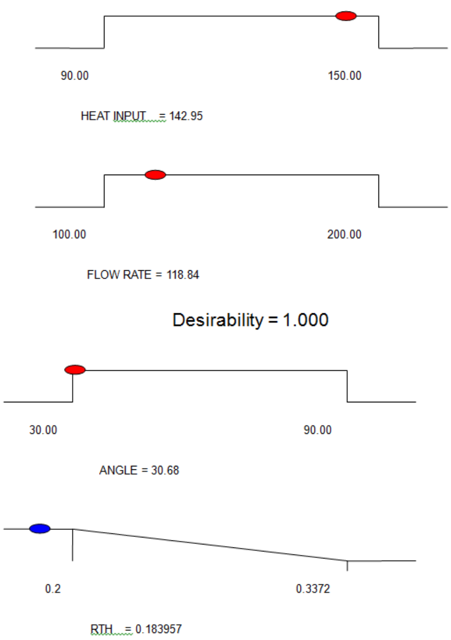

Figure 8. Optimized plot

TABLE 4. Thermal enhancement of different nanofluids

SL.NO	Nano particle	Synthesis process	Particle size (nm)	Heat transfer enhancement (%)	Ref.
1	AU/ETHANOL	two step	4	13	[20]
2	CUO/ H_2O	two step	33	11	[21]
3	SIC/ H_2O	two step	25	15.9	[22]

The main motive of selection of CeO_2 nanofluid is due to its thermo-physical properties at an affordable cost [13].

6. CONCLUSION

This experimental study aims at obtaining the thermal performance of the 405 SS TPCT carried out by BBD using RSM.

The BBD was successfully adopted and the experiments were designed choosing the input variables for the levels selected with minimum number of experiments; the Rth values were collected and the models were developed.

The response surface models are evolved for responses as the effect of each input parameter and its interaction with other parameters, depicting the trend of the response.

The set of optimised input parameters could be identified taking into consideration of heat input angle of inclination and flow rate (142.95 W, 30°68 & 118.84 ml/min).

The output response of Rth optimised value is 0.183957°C/W with reduced number of experimental runs, fairly convincing, logical and acceptable results have been obtained.

7. REFERENCES

1. Dunn, P.D. and Reay, D., "Heat pipes, Elsevier, (2012).
2. Faghri, A., "Heat pipe science and technology, Global Digital Press, (1995).
3. Cotter, T., *Theory of heat pipes*. 1965, DTIC Document.
4. Basiulis, A. and Prager, R., "Compatibility and reliability of heat pipe materials", in 10th Thermophysics Conference., (1975), 660-669.
5. Rassamakin, B., Gomelya, N., Khairnasov, N. and Rassamakina, N., "Choice of the effective inhibitors of corrosion and the results of the resources tests of steel and aluminum thermosyphon with water", in Proceedings of the Tenth International Heat Pipes Conference., (1997), 90-93.
6. Chol, S., "Enhancing thermal conductivity of fluids with nanoparticles", ***ASME-Publications-Fed***, Vol. 231, (1995), 99-106.
7. Buschmann, M.H., "Nanofluids in thermosyphons and heat pipes: Overview of recent experiments and modelling approaches", ***International Journal of Thermal Sciences***, Vol. 72, (2013), 1-17.
8. Namburu, P., Kulkarni, D., Dandekar, A. and Das, D., "Experimental investigation of viscosity and specific heat of silicon dioxide nanofluids", ***Micro & Nano Letters***, Vol. 2, No. 3, (2007), 67-71.
9. Namburu, P.K., Kulkarni, D.P., Misra, D. and Das, D.K., "Viscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture", ***Experimental Thermal and Fluid Science***, Vol. 32, No. 2, (2007), 397-402.

10. Sundar, L.S., Singh, M.K. and Sousa, A.C., "Thermal conductivity of ethylene glycol and water mixture based fe 3 o 4 nanofluid", ***International Communications in Heat and Mass Transfer***, Vol. 49, (2013), 17-24.

11. Huminic, G. and Huminic, A., "Heat transfer characteristics of a two-phase closed thermosyphons using nanofluids", ***Experimental Thermal and Fluid Science***, Vol. 35, No. 3, (2011), 550-557.

12. Alizad, K., Vafai, K. and Shafahi, M., "Thermal performance and operational attributes of the startup characteristics of flat-shaped heat pipes using nanofluids", ***International Journal of Heat and Mass Transfer***, Vol. 55, No. 1, (2012), 140-155.

13. Tiwari, A.K., Ghosh, P. and Sarkar, J., "Performance comparison of the plate heat exchanger using different nanofluids", ***Experimental Thermal and Fluid Science***, Vol. 49, (2013), 141-151.

14. Vermahmoudi, Y., Peyghambarzadeh, S., Hashemabadi, S. and Naraki, M., "Experimental investigation on heat transfer performance of/water nanofluid in an air-finned heat exchanger", ***European Journal of Mechanics-B/Fluids***, Vol. 44, (2014), 32-41.

15. Alagappan, N. and Karunakaran, N., "Thermal characteristics of a circular finned thermosyphon using different working fluids", in Applied Mechanics and Materials, Trans Tech Publ. Vol. 575, (2014), 322-328.

16. Ajay, K. and Kundan, L., "Performance evaluation of nanofluid (al2o3/h2o-c2h6o2) based parabolic solar collector using both experimental and cfd techniques", ***International Journal of Engineering-Transactions A: Basics***, Vol. 29, No. 4, (2016), 572-580.

17. Jamshidi, N., Farhadi, M., Ganji, D. and Sedighi, K., "Experimental investigation on viscosity of nanofluids", ***International Journal of Engineering***, Vol. 25, No. 3, (2012), 201-209.

18. Cavazzuti, M., "Optimization methods: From theory to design scientific and technological aspects in mechanics, Springer Science & Business Media, (2012).

19. Manohar, M., Joseph, J., Selvaraj, T. and Sivakumar, D., "Application of box behnken design to optimize the parameters for turning inconel 718 using coated carbide tools", ***International Journal of Scientific & Engineering Research***, Vol. 4, No. 4, (2013), 620-644.

20. Putnam, S.A., Cahill, D.G., Braun, P.V., Ge, Z. and Shimmin, R.G., "Thermal conductivity of nanoparticle suspensions", ***Journal of Applied Physics***, Vol. 99, No. 8, (2006), 084308.

21. Zhang, X., Gu, H. and Fujii, M., "Experimental study on the effective thermal conductivity and thermal diffusivity of nanofluids", ***International Journal of Thermophysics***, Vol. 27, No. 2, (2006), 569-580.

22. Xie, H., Wang, J., Xi, T. and Liu, Y., "Study on the thermal conductivity of sic nanofluids", ***Journal of Chinese Ceramic Society***, Vol. 29, No. 4, (2001), 361-364.

Performance Investigation of 405 Stainless Steel Thermosyphon using Cerium (IV) Oxide Nano Fluid

N. Alagappan, N. Karunakaran

Department of Mechanical Engineering, Annamalai University, Annamalainagar, Tamil Nadu, India

PAPER INFO

Paper history:
Received 31 August 2016
Received in revised form 22 November 2017
Accepted 11 February 2017

Keywords:
405 Stainless Steel Two-phase Closed Thermosyphon
CeO_2 Nanofluid
Box – Behnken Design
Response Surface Methodology

چکیده

ترموسیفون یک دستگاه انتقال حرارت کاراست که کرما را با استفاده از گرانش برای تبخیر و تراکم سیال جابه‌جا می‌کند. در مطالعه حاضر روش طراحی جعبه–Benhnken (BBD) برای ترموسیفون بسته‌ی دو مرحله‌ای (tPCT) با استفاده از نانوسیال حاوی ۰,۱ درصد حجمی CeO2 و سورفاکتانت اتیلن گلیکول انتخاب شد. این آزمایش برای شناسایی مجموعه‌ای بهینه شده از پارامترها برای SS tPCT۴۰۵ به منظور رسیدن به مقاومت حرارتی پایین‌تر و انتقال حرارت بهتر است. این اهمیت دستاوردهای کار به این معناست که با تعدادی آزمایش، مدل قابل اعتماد شده‌ای تولید شده که دارای اعتبار بیشتر است. همچنین، فرایند با یک هدف، یعنی مقاومت حرارتی، بهینه شده است. برای به دست آوردن شرایط بهینه، روش سطح پاسخ (RSM) با بهره‌گیری از جعبه – بنکن (BBD) استفاده شده است.

***doi**: 10.5829/idosi.ije.2017.30.04a.16*