Thermal conductivity analysis of Al_2O_3/water-ethylene glycol nanofluid by using factorial design of experiments in a natural convection heat transfer apparatus

Periasamy Manikandan Srinivasan, Nesakumar Dharmakkan, Maha Devaa Sri Vishnu, Hari Prasath and Ramaraj Gogul

Department of Chemical Engineering, Kongu Engineering College, Erode-638060, Tamil Nadu, India

Abstract

Thermal conductivity of a heat transfer fluid plays a significant role in improving the heat transfer performance of a heat exchanger. In this work, experiments were performed in a natural convection heat transfer apparatus by mixing homogenized Al_2O_3 nanoparticles in a base fluid of water-ethylene glycol mixtures. The effects of heat input, nanoparticle volume content in the base fluid, and ethylene-glycol volume content in the base fluid on thermal conductivity of the nanofluid were analyzed. Based on results obtained by MINITAB® design software (factorial design matrix), 16 experimental runs were performed with the lower and higher levels of input factors. The levels for heat input were 10 and 100 W; for nanoparticle volume content in the base fluid 0.1 and 1 vol.% and for the base fluid composition 30 and 50 vol.% of ethylene glycol in water. From the obtained experimental results, a Pareto chart, normal probability plot, contour plot and surface plot were drawn. Based on the results, a new correlation was proposed, and predictions were compared with the experimental results. From the study, the maximum thermal conductivity value 0.49 W m^{-1} K^{-1} was observed at a nanoparticle volume content in the base fluid of 1.0 vol.%, ethylene glycol volume content in the base fluid of 30 vol.% and heat input of 100 W.

Keywords: heat exchanger; base fluid; Minitab; nanoparticle; contour and surface plots.

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1. INTRODUCTION

Transfer of heat to and from the process fluid is an essential part of most chemical processes [1]. The initial idea on using solid nanosized particle suspensions in a liquid fluid for enhancing the thermo-physical properties of conventional heat transfer fluid was coined by Choi *et al.* [2]. They proposed both metals and metal oxides nano-suspensions in their invention. This idea gives a pathway to engineers to explore nanofluid applications in heat transfer processes. It was shown in the literature [3,4] that Al_2O_3 nanoparticle addition provides suitable thermal conductivity enhancement of a base fluid (water- ethylene glycol mixture) at minimal amounts of the nanoparticle additive. In another experimental work [5] with synthesized Al_2O_3 nanoparticles it was concluded that the nanoparticle material properties, nanoparticle volume content in the base fluid, bulk temperature, and nanoparticle size, all played a significant role in the improvement in thermal conductivity of base fluids. Also, in the experimental study in a horizontal tube with alumina nanofluid [6] it was reported that the Nusselt number of the nanofluid under turbulent flow increased with the nanoparticle concentration as well as the Reynolds number. Addition of nanoparticles was shown to enhance the overall heat transfer (*e.g*. addition of Al_2O_3 nanoparticles (0.01 vol.%) to therminol 55 [7], addition of copper nanoparticles (0.1 wt. %) to water [8] as well as the thermal conductivity of the base fluid (*e.g.* addition of graphene nanoparticles [9], TiO_2 and ZnO nanoparticles [10-12], Al_2O_3, ZnO, and TiO_2 nanoparticles in ethylene glycol-water mixtures as well as addition of Al_2O_3,CuO to water [13,14]). Furthermore, it was reported that in order to increase the thermal conductivity

Corresponding authors: Periasamy Manikandan Srinivasan, Department of Chemical Engineering, Kongu Engineering College, Erode-638060, Tamil Nadu, India; Tel: 91–4294–226429

E-mail: sriperiasamy@gmail.com

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particle size should be smaller [15]. Also, the overall heat transfer coefficient in a plate heat exchanger improved up to 30% at 6 vol.% Al_2O_3 nanofluid [16]. Thermal conductivity was enhanced by addition of copper oxide nanoparticles to water and ethylene glycol base fluids as compared to addition of microparticles [17], which was attributed to the smaller particle size and uniform dispersion of nanoparticles in the base liquid.

Higher nanoparticle concentrations were reported to increase the heat transfer coefficient [18,19] as well as the thermal conductivity [20] but decreases the specific heat capacity [21]. On the contrary, in the study by Pandey *et al.* [22] of Al_2O_3/water nanofluid in a plate heat exchanger, it was found that the heat transfer behaviour improved with a decrease in the nanoparticle concentration. Heat transfer in experimental Al_2O_3 nanoparticle-water systems was also studied regarding determination of the Nusselt number [23,24]. The base fluid also has an influence on the overall heat properties of a nanofluid [25]. Hence, it was shown that the heat transfer enhancement was higher for Al_2O_3/ethylene glycol nanofluid compared with Al_2O_3/water nanofluid [26]. Factorial design is a useful tool for studying the effects of several individual independent variables simultaneously and it was used to analyse a TiO_2-ZnO hybrid nanofluid and the effects of nanoparticle content, operating temperature, and channel height on heat transfer performance in a micro channel heat exchanger [27]. All the investigated input factors were found to significantly affect the thermo-physical properties of the prepared nanofluid. The summary of literature review is presented in Table. 1

Table 1 Summary of selected literature review

Ref.	Nanofluid, base fluid and concentration	Equipment used	Results of the study
[3]	Al_2O_3, CuO/water, EG* and 1-5 vol.% of CuO and Al_2O_3 in water.	Heat exchanger	Thermal conductivity ratios increase almost linearly with the content tested up to 0.05 vol.%, but at different rates of increase for each system
[4]	Al_2O_3, ZnO, TiO_2, CuO, Fe_2O_3, and CeO_2/EG and 0.5, 1.5, 3.0 and 4.0 vol.% of nanoparticles in the base fluid	Steady state parallel plate	The highest thermal conductivity enhancement at 4 % volume content
[27]	Copper-water, 0.1 wt.% of copper nanoparticle in water	Micro heat exchanger	42.1 % enhancement in the heat transfer coefficient
[5]	CuO/water, Al_2O_3/water and 2–10 vol.% of Al_2O_3 in water	Heat exchanger	A linear regression equation was proposed for estimation of the thermal conductivity ratio based on temperature and volume content
[6]	Al_2O_3/water	Horizontal tube	Nusselt number of the nanofluid under turbulent flow increased with nanoparticle concentration
[7]	Al_2O_3-Therminaol 55, 0.01 vol.% of Al_2O_3 in the base fluid.	Reactor	Heat transfer rate from the main vessel to the safety vessel was increased significantly by the addition of nanoparticles
[9-11]	graphene, TiO_2 and ZnO / EG-water	Plate heat exchanger	Thermal conductivity and heat transfer coefficient were directly enhanced with addition of the prepared nanoparticles
[13]	Al_2O_3 (particle size 36 and 47 nm)	Plate heat exchanger	Linear equations were proposed to determine the heat transfer coefficient
[16]	Al_2O_3/water 6 vol.% of Al_2O_3 in water	Plate heat exchanger	Overall heat transfer coefficient improved up to 30%
[14]	Copper/water	Moving wedge	Observed an improvement in thermal radiation
[18]	Al_2O_3/water	Heat exchanger	Increase in Reynolds number and nanoparticle concentration, led to increase in the heat transfer coefficient particularly at the entrance region
[23]	Al_2O_3/water	Natural convection heat transfer apparatus	Correlation was provided in order to determine the Nusselt number

Ref.	Nanofluid, base fluid and concentration	Equipment used	Results of the study
[19]	γ- Al_2O_3 in water	Corrugated cavity	Heat transfer coefficient enhanced significantly with the nanoparticle addition
[25]	SnO_2, Al_2O_3, Cu2O, ZnO, TiO_2, SiO_2, CuO, Cu, Fe_2O_3, SiC, and MWCNT**	Solar stills	Observed significant improvement in heat transfer performance of solar stills
[26]	Al_2O_3- water, Al_2O_3 EG	Inside circular tubes	Heat transfer enhancement was higher for Al_2O_3/EG nanofluid compared to Al_2O_3/water nanofluid
[22]	Al_2O_3/water	Corrugated plate heat exchanger	Heat transfer behaviour improved with a decrease in the nanoparticle concentration
[24]	Al_2O_3/water	U-tube heat exchanger	Maximum increment in the Nusselt number occurs at the maximal Reynolds number and nanoparticle volume content
[13]	Al_2O_3/water	Plate heat exchanger	At a constant Reynolds number, the heat transfer was better than that of the base fluid due to the increase in the thermal conductivity
[20]	Al_2O_3, CuO, SiO_2, ZnO/PG***, water and 6 vol.% of nanoparticle in water	Heat exchanger	Thermal conductivity of nanofluids mainly depended on the particle size, nanoparticle volume content, temperature, and properties of particles and the base fluid
[27]	TiO_2-ZnO hybrid nanofluid water	Micro channel heat exchanger	All input factors significantly affected the thermo- physical properties of the prepared nanofluid

*EG – ethylene glycol; **MWCNT – Multi Walled Carbon NanoTube; ***PG – Propylene Glycol

From the introduction of the concept "nanofluid", many research studies explored the unique properties and capabilities exhibited by these new engineered fluids. Literature search shows that many studies concentrated on size reduction of heat exchangers and utilization of lower volumes of heat transfer fluids based on beneficial heat transfer properties of these energy efficient fluids. Although nanofluids exhibit many advantages, there are certain weaknesses found in applications. Some of the common problems associated with the application of nanofluids in heat exchangers in real time situations are fouling and surface erosion. The other weaknesses are high costs of energy and materials. From the literature review, it was noted that miniature heat exchangers are more efficient with better performance of nanofluids.

Several studies in literature were conducted to determine the effects of nanoparticle addition on thermal conductivity and heat transfer enhancement of the base fluid in different heat exchanger geometries. However, application of full factorial designs to analyze the influence of various input factors on the thermal conductivity is not often found in literature. In the present work, an experimental study was performed in a natural convection heat transfer apparatus with Al_2O_3/water-ethylene glycol mixture. The effects of input factors such as heat input (Q), nanoparticle volume content, and base fluid composition on the thermal conductivity as the output response were analyzed by using a Pareto chart, normal probability plot, contour plot and a surface plot. The optimized results obtained from the developed model are validated with the experimental results.

2. EXPERIMENTAL

2. 1. Nanofluid and base fluid preparation

Al_2O_3/water-ethylene glycol nanofluid used in the present study was prepared by using a two step method. Distilled water was used while EG was of technical grade and purchased from Global Scientific Company (India) and the Al_2O_3 nanoparticles (80 nm in size, 99 % purity) purchased from Sigma Aldrich (India) were suspended in two EG-water mixtures with different volumetric ratios of EG : water *i.e*. 30 : 70 and 50 : 50 %. The nanoparticles were added to the base fluid (water-EG) mixture to yield two volume content (ϕ = 0.1 and 1 vol.%) that are calculated by the equation (1):

$$\varphi = \frac{(m/\rho)_{Al_2O_3}}{(m/\rho)_{Al_2O_3} + (m/\rho)_{W:EG}} \tag{1}$$

where $(m/\rho)_{Al_2O_3}$ represents the nanoparticle volume (*i.e*. ratio of the nanoparticle mass and density (3500 kg m^{-3}, [23]) while $(m/\rho)_{W:EG}$ represents the base fluid volume (calculated as the ratio of the water-EG mixture mass and density where density was determined using specific gravity bottle.

In order to prepare a stable nanofluid, in the second step a high-pressure homogenizer (VS-500 Ltrs, Vino Technical Services, India) was used in our study for 180 min.

This prepared nanofluid was found to be stable in the operating temperature range (45 to 60 °C), evident from visual observation in the range of concentrations, as particle settling was not observed. It was also noted that the particles were homogeneously dispersed throughout the base fluid in an acceptable manner and ensured a good nanofluid suspension because of the use of the high-pressure homogenizer.

2. 2. Experimental procedure

The mechanism involved in natural convection heat transfer is the motion of fluid caused only due to a density difference resulting from temperature gradients without the use of external agents. The experimental set up of natural convection heat transfer apparatus is shown in Figure 1. The experimental setup consisted of a vertical stainless-steel tube of diameter (*d*) 45 mm and length (*L*) 500 mm with an electrical heater coil along the axis of the tube enclosed in a duct. Temperature was measured along the length of the plate by thermocouples embedded beneath the heated surface. Control panel instrumentation consisted of a multi channel digital display with a temperature indicator displaying surface temperatures T_1 to T_7 and ambient temperature T_8 and a digital ammeter and voltmeter (Legion, India). Heat input is provided by an electrical heating element. For measuring the surface temperature along the tube, thermocouples were inserted at different heights. In order to minimize radiation loss, the tube surface was polished. Temperature and voltage measurements associated with the electrical voltage and current supplied for heating were recorded. By increasing the power level, the system was allowed to stabilize, and temperature was recorded. The experiment was performed at various combinations of input parameters determined by the MINITAB factorial design of experiments. Thermal conductivity of the nanofluid was measured with the use of a thermal conductivity meter (Scientico, India).

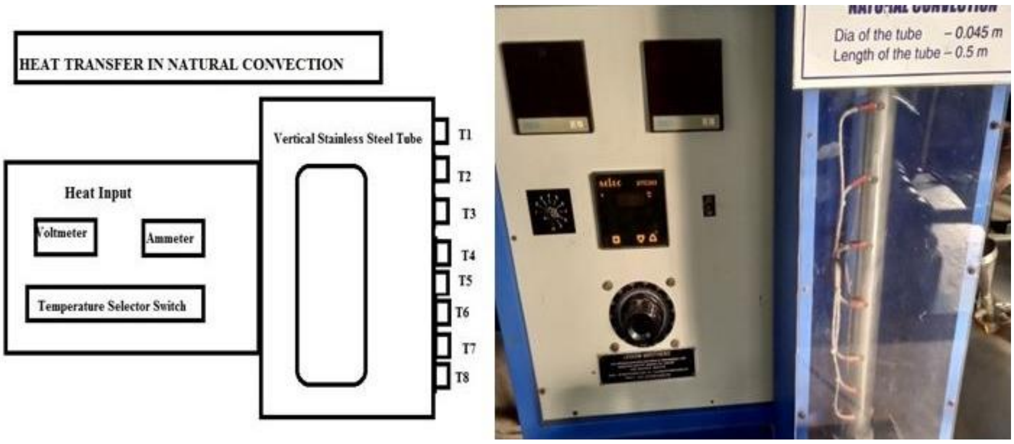


Figure 1. Experimental natural convection heat transfer apparatus

2. 3. Factorial design and analysis

2. 3. 1. Input parameters and their levels

Each experimental operating condition is a “Run", the output response is an “Observation” and the entire set of runs is the "Design" [28,29]. Two-level full factorial design was employed with two replications, which provides 16 experimental combinations. The response factor “thermal conductivity” is measured at all combinations of the experimental factor levels as provided by the design software. Table 2 shows the design summary and factors and levels for the full factorial design applied in the present study.

Table 2. Design summary and factors and levels for the full factorial design

Factors		3	
Base design		3, 8	
Number of experimental runs		16	
Replicates		2	
Blocks		2	
		Level	
Input factors	Code	Low	High
Heat input, W	*A*	10	100
Nanoparticle content in the base fluid, vol.%	*B*	0.1	1.0
EG content in the base fluid, vol.%	*C*	30	50

Statistical analysis is used to investigate the significance of the input factors (*A*, *B*, *C*) and their interactions on the output response (thermal conductivity - K_{nf}).

3. RESULTS AND DISCUSSION

In order to measure nanoparticle size, size distribution and its morphology, Transmission Electron Microscopy (TEM) technique was used. Table 3 provides the experimental results of the full factorial design for 16 experiments with 3 input factors (*A*: heat input, *B*: nanoparticle volume content in the base fluid, *C*: EG volume content in the base fluid) and one output variable (thermal conductivity of the nanofluid) at the approximate temperature of 50 °C.

Table 3. Experimental results of the full factorial design

		Factorial input variable				
Standard order	Run order	*A* Q / W	*B* Nanoparticle content in the base fluid, vol. %	*C* EG content in the base fluid, vol.%	Response variable, K_{nf} / W m^{-1} K^{-1}	T_{avg} / °C
1	4	10	0.1	30	0.4850	49.2
2	1	100	0.1	30	0.4890	52.9
3	3	10	1.0	30	0.4750	49.4
4	5	100	1.0	30	0.4930	52.6
5	7	10	0.1	50	0.4390	51.2
6	6	100	0.1	50	0.4450	53.2
7	8	10	1.0	50	0.4660	51.4
8	2	100	1.0	50	0.4780	52.4
9	15	10	0.1	30	0.4860	51.6
10	14	100	0.1	30	0.4895	54.1
11	12	10	1.0	30	0.4760	49.5
12	9	100	1.0	30	0.4935	52.0
13	11	10	0.1	50	0.4395	49.7
14	10	100	0.1	50	0.4455	53.9
15	16	10	1.0	50	0.4670	49.6
16	13	100	1.0	50	0.4788	49.3

The measured thermal conductivity for 30 % EG : 70 % water is 0.45 W m^{-1} K^{-1} and for 50 % EG : 50 % water is 0.4295 W m^{-1} K^{-1}. The thermal conductivity obtained for the 0.1 vol.% of nanoparticle volume content in the base fluid, 10 W heat input and 30 % EG : 70 % water is 0.439 W m^{-1} K^{-1}, whereas the value is 0.493 W m^{-1} K^{-1} for 30 % EG and 70 % water with 1 vol.% of nanoparticle volume content in the base fluid and 100 W heat input. K_{nf} of pure water is 0.598 W m^{-1} K^{-1} and for Ethylene Glycol is 0.258 W m^{-1} K^{-1}. Hence it was noted from the study that 9.55 % improvement in the thermal conductivity of 30 % EG : 70 % water base fluid, by the addition of nanoparticle content of 1.0 vol.%. The observed thermal conductivities of Al_2O_3 nanofluids were analysed by using the factorial fit and ANOVA results for thermal conductivity values versus input variables *A*, *B*, and *C* as shown in Table 3. The ANOVA analysis is used to test the significance of main effects and interaction effects on the output response (thermal conductivity, K_{nf}).

A second order polynomial equation was derived from the observed data by MINITAB® statistical software (Minitab llc, US), by using a multiple regression analysis. The objective of the equation is to articulate the relationship between factors and the response. The second order polynomial equation in its coded form is:

$$K_{nf} = 0.00981A + 0.01356B - 0.02856C + 0.00494AB - 0.00094AC + 0.01656BC - 0.0021ABC \quad (2)$$

The maximum thermal conductivity of 0.493 W m^{-1} K^{-1} was observed at the operating conditions (30 % EG : 70 % water, 1 vol.% of nanoparticle volume content in the base fluid and 100 W heat input) and it is consistent with the thermal conductivity determined by the Eq.(2).

3. 1. Pareto chart for thermal conductivity of Al_2O_3/water-EG nanofluid

A Pareto chart is drawn for identifying the significant input factors and differentiating these factors from the insignificant ones in experiments performed. Figure. 2 shows the Pareto chart drawn for thermal conductivity as the output response for three input factors *A*, *B* and *C.* Pareto charts show the absolute values of the standardized effects. The standardized effects are t-statistics that test the null hypothesis that the effect is 0. If the error term has one or more degrees of freedom, the red line on the Pareto chart is drawn at *t*, where *t* is the $(1 - \alpha / 2)$ quantile of a *t*-distribution with degrees of freedom equal to the degrees of freedom for the error term. Minitab labels this graph Pareto Chart of the Standardized Effects. Minitab identifies important effects using Lenth's pseudo standard error (PSE). The red line of the Pareto chart is drawn at the margin of error (ME = *t* PSE). In Minitab Pareto chart, the factors crossing the margin of error (reference line) indicates significant factor. Hence it is revealed from the chart that the bars representing all the factors and their interactions cross the reference line (*i.e.*, 2.4) indicating these factors as significant with respect to thermal conductivity. These factors show statistical significance of the present model at the 0.05 level of significance.

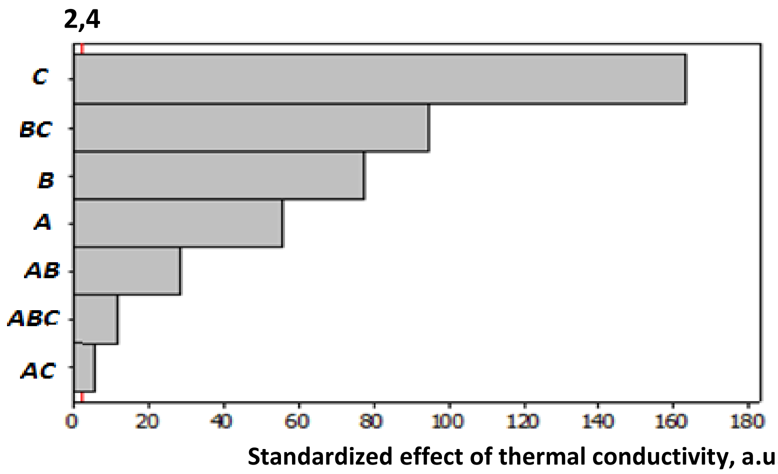


Figure 2. Pareto Chart for thermal conductivity of Al_2O_3/water-EG nanofluid at the significance level of 0.05

3. 2. Normal probability plot for thermal conductivity of Al_2O_3/water-EG nanofluid

A normal probability plot indicates the relationship among the input-output variables involved in an experiment. Figure 3 shows the normal probability plot of the standardized effects for the thermal conductivity as the response. In normal probability plot, the factors far from 0 (red line) are statistically significant. Positive effects increase the output response (thermal conductivity), whereas negative effects decrease the response when the settings change from the low-level value of the input factor to the high-level value.

Hence the factors *A*, *B*, *AB* and *BC* have a positive standardized effect and factor *C* has negative standardized effect on the response. According to the Figure 3, the factors *AC* and *ABC* are slightly significant.

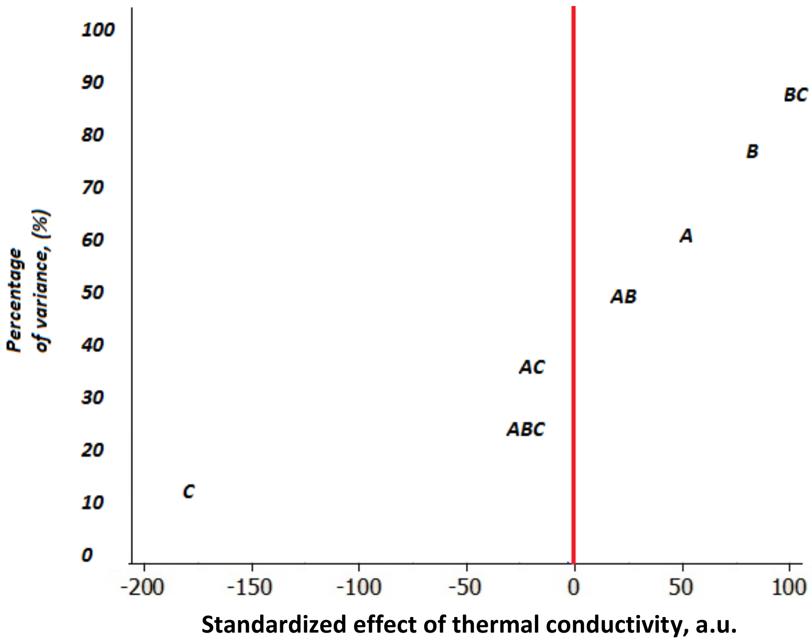


Figure 3. Normal probability plot of the standardized effect for thermal conductivity of Al_2O_3/water-EG nanofluid

3. 3. Main effect, interaction and cube plots for thermal conductivity of Al_2O_3/water-EG nanofluid

Main and interaction effects of various input factors are analysed by corresponding plots as shown in Figure 4.

The main effect is obtained when the mean response changes across the levels of an input factor. Interaction and cube plots are used to compare the relative strength of each effect across factors. Figure 4(a) shows the difference between the level means for the factors *A*, *B* and *C*. Based on the results it can be deduced that the order of significant factors are *B*, *C* and *A*. Figure 4(b) shows the interaction effects of Al_2O_3 nanoparticle addition on thermal conductivity of water-EG base fluids. It can be observed that factor B (nanoparticle volume content in the base fluid) shows a significant effect on thermal conductivity. A similar trend was observed in the cube plot for thermal conductivity of the nanofluid as shown in Figure 4(c). This positive effect is due to the fact that solids have higher thermal conductivities than liquids, hence the thermal conductivity of a base fluid increased significantly.

3. 5. Contour and surface plots for thermal conductivity of Al_2O_3/water-EG nanofluid

Figure 5 shows the two-dimensional contour plot with input variables heat input, nanoparticle volume content in the base fluid and base fluid composition. For drawing the contour plot, significant factors identified from ANOVA results were taken (*i.e.,* factors *B* and *A* are significant). Thermal conductivity (output response) varied between 0.476 and 0.492 kW m^{-1} K^{-1} based on variations of *B* (nanoparticle volume content in the base fluid) and *A* (heat input). With increasing the nanoparticle concentration and heat input, thermal conductivity also gradually increased.

Figure 6 provides the surface plot for thermal conductivity with respect to input factors *B* and *A*. A similar pattern as in the contour plot can be observed that is, thermal conductivity gradually increased with respect to both the nanoparticle volume content in the base fluid and heat input. The reason for the enhancement is due to the mixing of high conductive solid nanoparticles with the liquid.

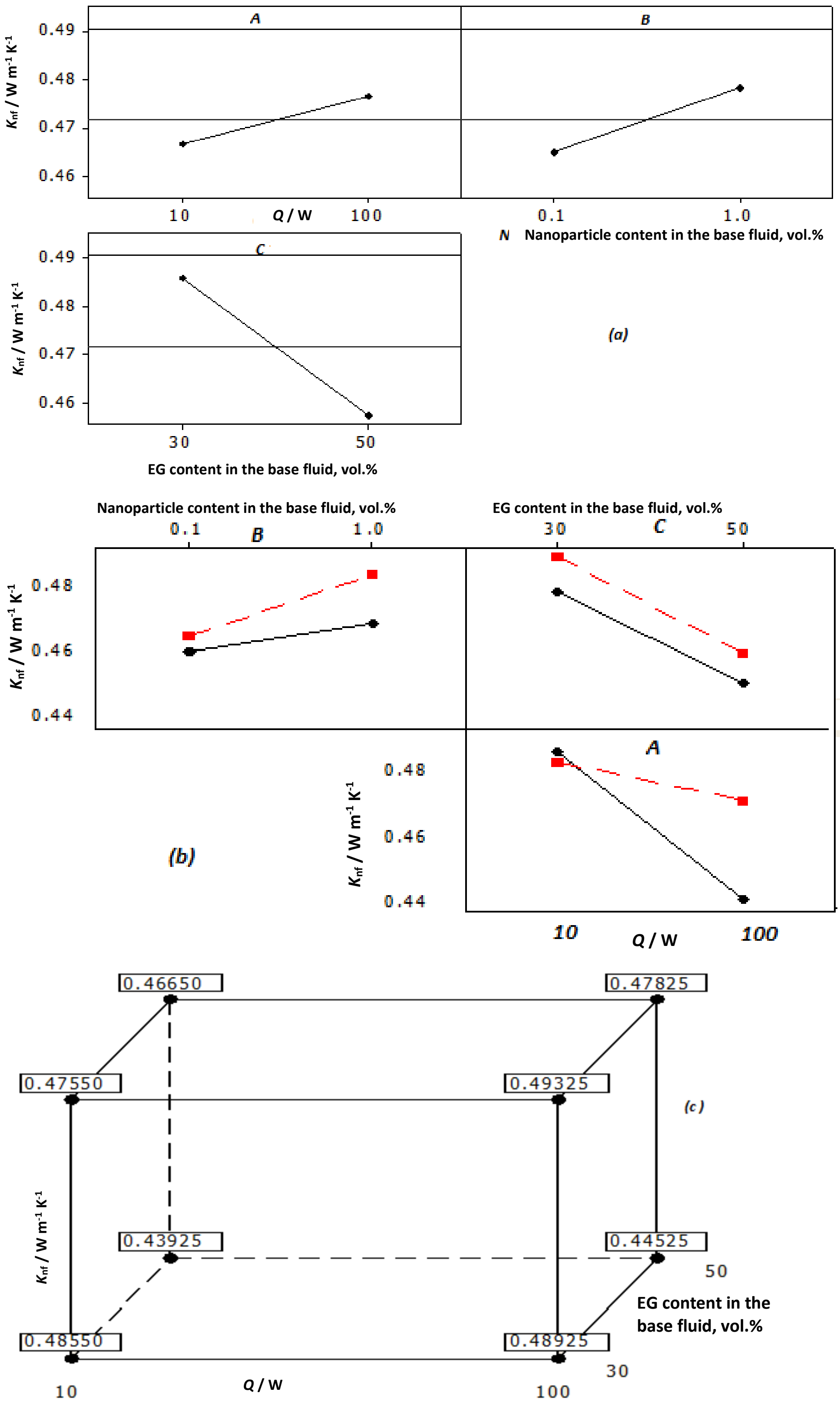
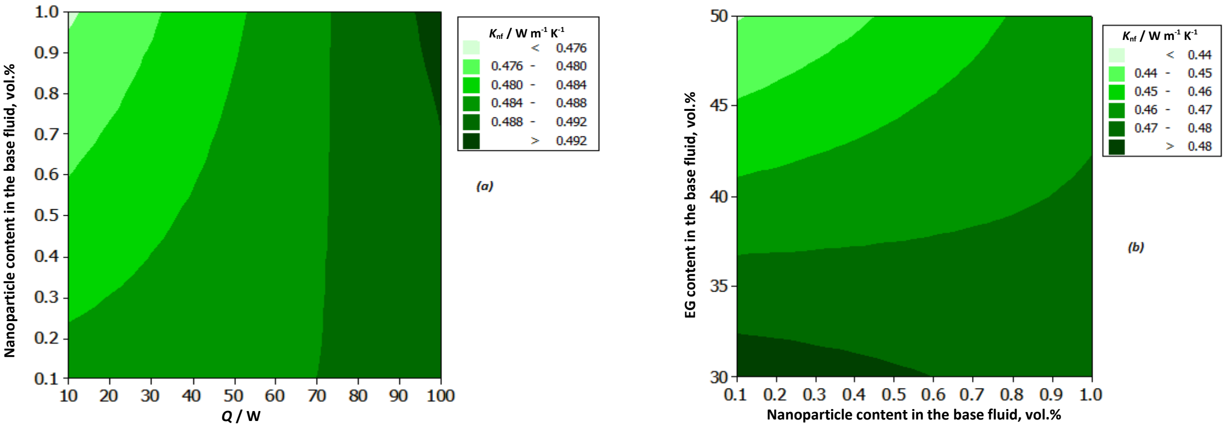


Figure 4. Plots showing relationships between factors and the response (thermal conductivity of Al_2O_3/water-EG nanofluid): a - main effects plot; b - interaction plots; c - cube plot



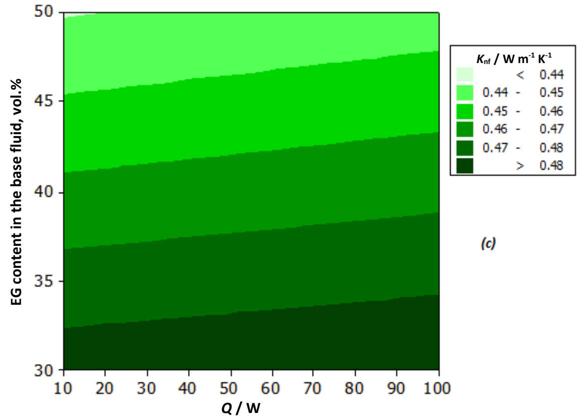
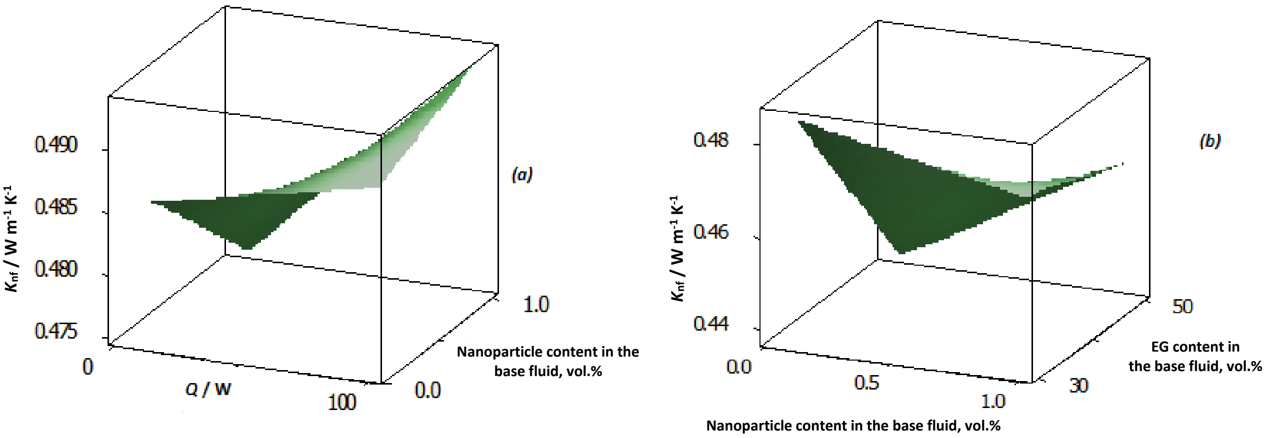


Figure 5. Contour plots for thermal conductivity of Al_2O_3/water-EG nanofluid: (a) function of nanoparticle volume content in the base fluid and heat input; (b) function of nanoparticle volume content in the base fluid and EG content in the base fluid; (c) function of heat input and EG content in the base fluid



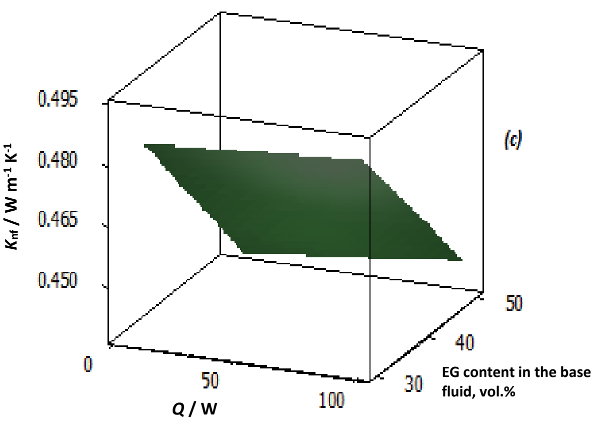


Figure 6. Surface plot for thermal conductivity of Al_2O_3/water-EG nanofluid: a - function of nanoparticle volume content in the base fluid and heat input; b - function of nanoparticle volume content in the base fluid and EG content in the base fluid; c - function of heat input and EG content in the base fluid

4. CONCLUSION

Variations of thermal conductivity of nanofluids based on a suspension of Al_2O_3 nanoparticles in mixtures of ethylene glycol and water as a base fluid were analyzed by the application of a full factorial design of experiments (2^3 full factorial design matrix), and the influences of heat input (*A*), nanoparticle volume content in the base fluid (*B*) and ethylene glycol volume content in the base fluid (*C*) were studied in a natural convection heat transfer apparatus. The obtained results were graphically presented and analysed by Pareto, normal probability, main effect, interaction, cube, contour, and surface plots. Based on the plots, all the investigated factors and their interactions are significant factors with respect to thermal conductivity enhancement. It may be concluded from the results of contour and surface plots that by increasing the nanoparticle concentration and heat input, the thermal conductivity increases gradually as also reported in literature [9,15,17]. A new correlation was proposed, and the predictions were compared with the results obtained from the experimental study showing that the thermal conductivity prediction was consistent with the experimental result. The maximal thermal conductivity value of 0.493 W m^{-1} K^{-1} was observed at the higher investigated nanoparticle volume content in the base fluid of 1.0 vol.%, lower EG content in the base fluid of 30 vol.% and the higher heat input of 100 W. Significance of this study lies in the possibility for scaling up the presented concept to utilize potential benefits of the investigated nanofluid in industries handling heat exchangers.

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SAŽETAK

Analiza toplotne provodljivosti nanofluida Al_2O_3/voda-etilen glikol korišćenjem faktorskog dizajna eksperimenata u aparatu za prenos toplote sa prirodnom konvekcijom

Periasamy Manikandan Srinivasan, Nesakumar Dharmakkan, Maha Devaa Sri Vishnu, Hari Prasath i Ramaraj Gogul

Department of Chemical Engineering, Kongu Engineering College, Erode-638060, Tamil Nadu, India

(Naučni rad)

Toplotna provodljivost fluida za prenos toplote ima značajnu ulogu u poboljšanju performansi razmenjivača toplote. U ovom radu eksperimenti su izvedeni u aparatu za prenos toplote sa prirodnom konvekcijom mešanjem homogenizovanih nanočestica Al_2O_3 u osnovnom fluidu koji predstavlja smešu voda-etilenglikol. Analizirani su efekti unosa toplote, zapreminskog sadržaja nanočestica u osnovnom fluidu i zapreminskog udela etilenglikola u osnovnom fluidu na toplotnu provodljivost nanofluida. Na osnovu rezultata dobijenih pomoću programskog paketa MINITAB® (matrica faktorskog dizajna), izvedeno je 16 eksperimentalnih ciklusa sa nižim I višim nivoima ulaznih faktora. Nivoi za unos toplote bili su 10 i 100 W; za zapreminski sadržaj nanočestica u osnovnom fluidu 0,1 i 1,0 vol.% i za sastav osnovnog fluida 30 i 50 vol.% etilenglikola u vodi. Iz dobijenih eksperimentalnih rezultata kostruisani su Pareto dijagram, dijagram normalne verovatnoće, konturni grafikon i površinski grafikon. Na osnovu rezultata predložena je nova korelacija, a predviđanja su upoređena sa eksperimentalnim rezultatima. Iz studije je uočena maksimalna vrednost toplotne provodljivosti od 0,49 W $m^{-1}K^{-1}$ pri zapreminskom sadržaju nanočestica u osnovnom fluidu i od 1,0 vol.%, zapreminskom udelu etilenglikola u osnovnom fluidu od 30 vol.% i unosu toplote od 100 W.

Ključne reči: izmenjivač toplote; osnovni fluid; MINITAB; nanočestica; konturni i površinski dijagrami