IJE TRANSACTIONS B: Application Vol. 26, No. 8, (August 2013) 837-844

International Journal of Engineering

Journal Homepage: www.ije.ir

Factor Effect Estimation in the Convective Heat Transfer Coefficient Enhancement of Al_2O_3/EG Nanofluid in a Double-pipe Heat Exchanger

A. H. Zamzamian *[a], M. Tajik Jamal-Abadi [b]

[a] *Department of Energy, Materials and Energy Research Center(MERC)Postal Code 1787-316, Karaj, Iran*
[b] *Department of Renewable Energy, Materials and Energy Research Center, P.O.B. 316-31787, Karaj, Iran*

PAPER INFO

Paper history:
Received 13 June 2012
Received in revised form 28 January 2013
Accepted 28 February 2013

Keywords:
Nanofluid
Heat Conduction
Heat Transfer
Alumina
Nanostructure
Fluid Mechanics

ABSTRACT

The forced convective heat transfer (CHT) coefficient of a particular nanofluid, Al_2O_3 nanoparticles-ethylene glycol (EG) mixture, was investigated experimentally in a double-pipe heat exchanger. Nusselt number of the nanofluid for different nanoparticle concentrations as well as various operating temperatures was found to increase up to 23.7% using 1.0% wt of nanoparticles. The significance and novelty of this work is that 2^2-screening design was used to investigate the effect of factors and the results emphasized that increasing nanoparticle concentration had considerable effect on the enhancement of CHT coefficient of nanofluid. The comparison of experimental results and semi-empirical correlation results showed considerable deviations for high operating temperatures and nanoparticle concentrations.

doi: *10.5829/idosi.ije.2013.26.08b.05*

1. INTRODUCTION

Nanofluids are composed of nanometer-sized particles as nanostructure in a base fluid which enrich the heat transfer characteristics of the original fluid. A vast number of nanofluids with various nanoparticles such as Cu, TiO_2, Al_2O_3, SiO_2, CuO, Ag and Au have nanostructure and in several base fluids like water, ethylene glycol, engine oil and epoxy have been prepared [1-5].

Improving the thermal properties of base fluid qualify them to miniaturize heat transfer equipments. For example, designing smaller and lighter heat exchangers provides thermal industries with more energy efficient and cleaner systems. Nanofluids can play important roles in industrial sectors including chemical production, power generations, air conditioning, transportation, and microelectronics [6]. They can also take part in high heat flux applications such as superconducting magnets, super fast computing and high power microwave tubes due to their large thermal conductivity. Most of the recent studies on nanofluids have focused on thermal conductivity and few on their convective heat transfer.

In this study, the impact of concentration of Al_2O_3 nanoparticles and the operating temperature on the advance of convective heat transfer coefficient of the Al_2O_3/EG nanofluid was researched in a counter-current laminar flow in a double-pipe heat exchanger. The Nusselt number was calculated for the system and the results were juxtaposed with the theoretical obtained data.

2. DESCRIPTION OF EXPERIMENT

2. 1. Nanofluids Preparation The Al_2O_3 nanoparticles with a mean diameter of 50 nm (purchased from Nanostructured & Amorphous Materials Inc.) were used as the source material and Ethylene Glycol (EG) was chosen as the base fluid. The EG-based alumina nanofluid was synthesized by a two-step method [7]. To avoid the agglomeration of nanoparticles, the electrostatic stabilization method was adopted [8]. For this purpose, ultra-sonication of Al_2O_3

* Corresponding Author Email: azamzamian@merc.ac.ir (A. H. Zamzamian)

nanoparticles under dry condition was accomplished for 2 h and then nanoparticles were added.

In order to obtain homogeneous suspension, the dispersion solution was ultrasonically vibrated continuously for 2 h with simultaneous magnetic homogenizing. Since the alumina nanoparticles could be stably suspended in EG at least for a week, the mentioned treatment was chosen in the preparation process. Finally Alumina nanofluids with three different mass fractions of 0.1, 0.5 and 1.0% were prepared for this experiment.

2. 2. Experimental Apparatus The experimental apparatus manipulated in this work is a double-pipe heat exchanger composed of a reservoir tank with a heater equipped with thermostat to adjust the temperature, a centrifugal pump, a closed loop for hot fluid (tube side), an open loop for cold fluid (shell side) feeding with urban water supply and two flow meter for either cold and hot streams. Four thermocouples (k-type with ±0.1°C accuracy) were mounted on the heat exchanger section to measure the temperatures of both fluid streams. Two thermocouples were placed at the inlet and outlet of tube side, and the other two thermocouples were located at the inlet and outlet of shell side. The inner tube of double-pipe heat exchanger was fabricated by copper with an inner diameter of 15 mm and 0.7 mm in thickness. The shell side diameter was 50.8 mm with total length of 1.5 m and it was insulated to reduce heat loss. Figure 1 shows the flow loop of constructed system.

The nanofluid was run into the reservoir tank, and then the tank was heated. Using the thermostat, the temperatures were set on 45, 60 and 75 °C. When the centrifugal pump is switched on, the hot nanofluid flowed into the inner tube and swapped heat with cold water in shell side which was passing over the inner pipe in counter current case. After reaching the equilibrium the inlet and outlet temperatures were reported. The experiments were repeated for all the samples and also for the pure EG itself.

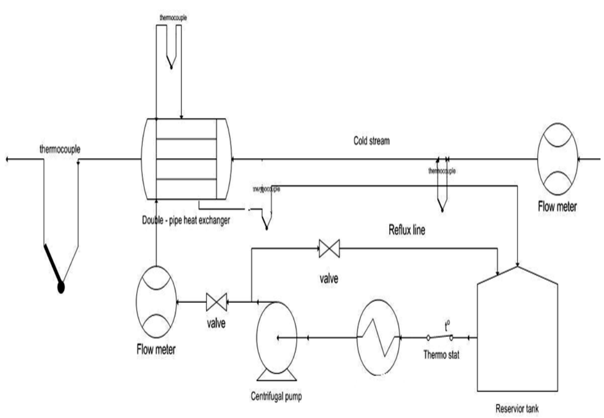


Figure 1. Experimental set up

3. CALCULATIONS PROCEDURE

3. 1. Experimental Heat Transfer Coefficient The shell side heat transfer coefficient, h_o, was calculated from *Monrad* and *Pelton's* equation for turbulent flow using experimental results as follows [9]:

$$Nu_o = \frac{h_o D_H}{k_w} = 0.02\, Re_o^{0.8}\, Pr_o^{\frac{1}{3}} \left(\frac{r_{out}}{r_{in}}\right)^{0.53} \tag{1}$$

The following well-known equations were used for calculating the tube side convective heat transfer coefficient, h_i, using experimental results:

$$U_o = \frac{q_c}{A_{out}\Delta T_{lm}} \tag{2}$$

$$U_o = \frac{1}{\frac{A_{out}}{A_{in}}\frac{1}{h_i} + \frac{A_{out}\, ln(r_{out}/r_{in})}{2\pi L k_{wall}} + \frac{1}{h_o}} \tag{3}$$

where the amount of heat transfer rate, q_c, is as follows:

$$q_c = (\rho c_p)_c\, Q_c (T_{c,outlet} - T_{c,inlet}) \tag{4}$$

3. 2. Theoretical Heat Transfer Coefficient The theoretical heat transfer coefficient of nanofluids ,h_i , in a tube for laminar flow could be estimated by *Li* and *Xuan's* equation [10]:

$$Nu_i = \frac{h_i d_i}{k_{nf}} = 0.4328(1.0 + 11.285\phi^{0.754} Pe_p^{0.218}) \mathrm{Re}_{nf}^{0.333} \mathrm{Pr}_{nf}^{0.4} \tag{5}$$

The effective thermal conductivity, k_{eff}, of macroscopic solid-liquid mixtures estimated from *Hamilton* and *Crosser's* equation is as follows [11]:

$$\frac{k_{eff}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)\phi(k_f - k_p)}{k_p + (n-1)k_f + \phi(k_f - k_p)} \tag{6}$$

where

$$n = \frac{3}{\psi},\quad \psi = \frac{\text{area of nanoparticle volume equivalent sphere}}{\text{area of nanoparticle}}$$

Well-known *Einstein's* equation for a viscous fluid has been extended by *Brinkman* to a more generalized formula as:

$$\mu_{eff} = \mu_f \frac{1}{(1-\phi)^{2.5}} \tag{7}$$

Kinematic viscosity and thermal diffusivity, also, will be calculated using:

$$\upsilon_{nf} = \frac{\mu_{nf}}{\rho_{nf}} \tag{8}$$

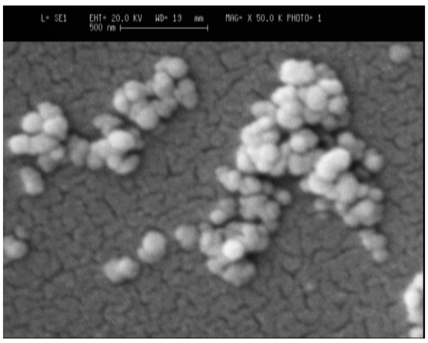
$$\alpha_{nf} = \frac{k_{nf}}{(\rho c_p)_{nf}} \tag{9}$$

where μ_{nf} and k_{nf} are the same as μ_{eff} and k_{eff} calculated from Equations (6) and (7), respectively. The Peclet number for nanoparticles is then:

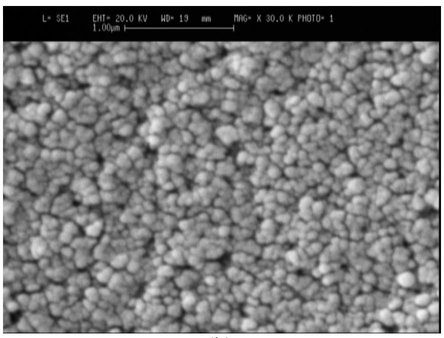
$$Pe_p = \frac{u_{m,nf}\, d_p}{\alpha_{nf}} \tag{10}$$

4. RESULTS AND DISCUSSION

4. 1. Nanofluids Stability In order to examine the stability of nanofluids, two samples with different procedures were prepared. First sample contained Al_2O_3 nanoparticles and EG which were mixed normally for a while. The second sample was provided by ultra-sonication and well mixing of the suspension by magnetic homogenizer. To determine the nanoparticles dispersion in samples, SEM images were taken 1 h after preparation (Figure 1). As can be seen from Figure 1, the nanoparticles in second sample are well-dispersed and there is no agglomeration. To estimate the stability and amount of precipitation of samples, they were observed attentively for several weeks of regular periods. The results have shown that only the second sample retained in a remarkably stable state condition with no visually noticeable sedimentation after 3 weeks.



(a)



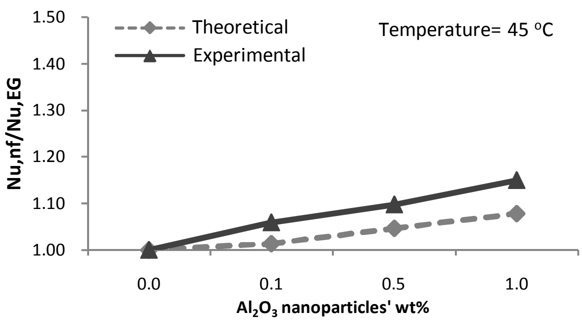
(b)

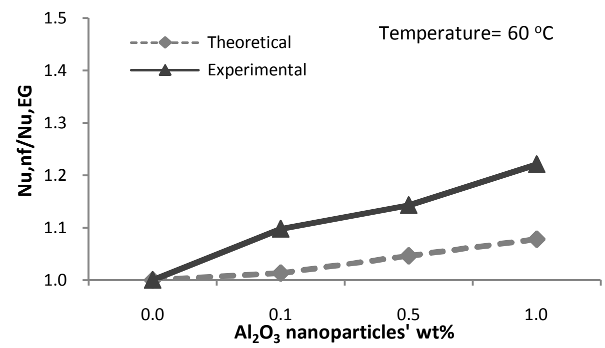
Figure 1. SEM images of the nanofluid prepared sample (a) before ultrasonic procedure and (b) after ultrasonic procedure

It can be inferred that ultrasonic procedure causes a reasonably good dispersion for alumina nanoparticles in EG.

4. 2. Enhancement of Convective Heat Transfer Coefficient The experimental and theoretical CHT coefficients for all samples with different Al_2O_3 nanoparticle concentrations at three operational temperatures were computed from Equations (1-5) based on volume flow rate and temperature measurements.

The results are available in Figure 2 as a nanofluid Nusselt number (Nu_{nf}) enhancement to the base fluid Nusselt number (Nu_{EG}) versus Al_2O_3 nanoparticle concentration at three operational temperatures. As shown in Figure 2, considerable improvement in heat transfer coefficient at all temperatures and for all alumina nanoparticle concentrations can be observed. High thermal conductivity of Al_2O_3, about 46 W/m.K at room temperature [12] with respect to EG, is the first and most important parameter which influences the enhancement of convective heat transfer coefficient. But it is not the only factor and other determinants like dispersion and chaotic movement of nanoparticles, Brownian motions, particles migration and nanofluid viscosity also can take part in improving the heat transfer coefficient [13]. Increasing the temperature and concentration may escalate the irregular movements of nanoparticles in the base fluid, thus may intensify the effect of thermophoresis forces on convective heat transfer coefficient of nanofluids.





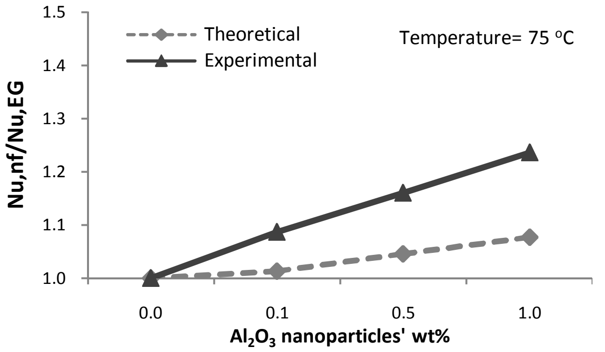


Figure 2. Experimental and theoretical Nu_{nf} enhancement to Nu_{EG} at (a) 45 °C, (b) 60 °C and (c) 75 °C

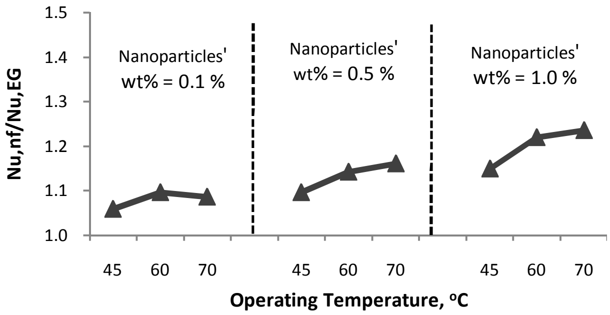


Figure 3. Effect of operating temperature on experimental Nu_{nf} enhancement

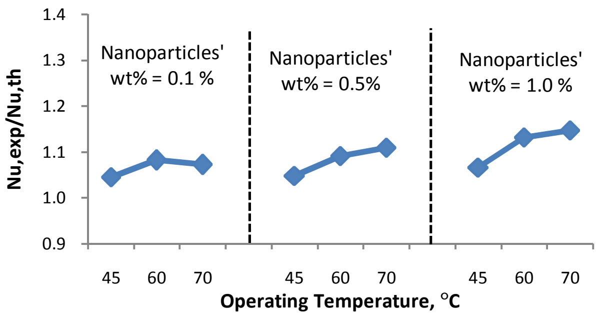


Figure 4. The comparison of experimental and theoretical enhancement of Nusselt numbers

Figure 2 also shows the effect of nanoparticle concentration on the heat transfer coefficient of nanofluids. It clearly expresses that CHT coefficient rises with increasing the concentration of nanoparticles in fluids at all operating temperatures.

Figure 3 shows the increase of CHT coefficient with raising the temperature which represents that it strongly depends on the operating temperature.

4. 3. Comparison Between the Theoretical and Experimental Results Figure 4 compares the enhancement of Nusselt numbers obtained from the theoretical and experimental results. There is a good agreement between theoretical and experimental results at low temperatures and low nanoparticle concentrations. But when the temperature rises, as shown in Figure 4, obvious difference between two groups of results is observed. This divergence reaches its maximum at 75 °C to 15% for both 1.0 wt% of nanoparticles.

4. 4. The 2^2 Screening Design The design of experiments on the basis of most important factors, each in two levels, is called screening design [14]. In this method, main controllable factors are considered those that exert most influence on the response, and to estimate the magnitude of factors effects and the interactions. For investigation of heat transfer process of alumina nanofluid, two factors each in two levels were considered; this design has four different combinations of factors or four experiments. The two main investigated factors were temperature (A) and nanoparticles weight fraction (B) which were considered in two levels; high (+) and low (-) as indicates in Table 1. Plus and minus signs for individual factors and their interactions are available in Table 2 [15]. The experiments were carried out in randomized order (as indicated in Table 3) using *Standard Random Numbers Table*. Table 4 represents the experimental design and responses (Nu_{nf} enhancement percent to the Nu_{EG}) for each treatment combination of heat transfer procedure.

TABLE 1. Data for 2^2 screening design

	Factors	
	Temperature °C, (A)	Alumina wt%, (B)
High level (+)	75	1.0
Low level (-)	45	0.1

TABLE 2. Standard plus and mines signs for the 2^2 screening design

Treatment combination	1	A^*	B^*	A^*B^*
(1)	+	-	-	+
a	+	+	-	-
b	+	-	+	-
ab	+	+	+	+

TABLE 3. Randomized order of experiments

Randomized run order	Treatment combination	A^*	B^*	A^*B^*
4	ab	+	+	+
2	a	+	-	-
1	(1)	-	-	-
3	b	-	+	+

TABLE 4. Experimental design and responses for alumina nanofluid heat transfer coefficient

Experiment No.	Treatment combination	A^*	B^*	A^*B^*	Response (R), %
1	(1)	-	-	+	5.9
2	a	+	-	-	8.7
3	b	-	+	-	15
4	ab	+	+	+	23.7

TABLE 5. Effect of factors due to 2^2 screening design

Factors and possible interactions	A	B	AB
Effects	5.75	12.05	2.95

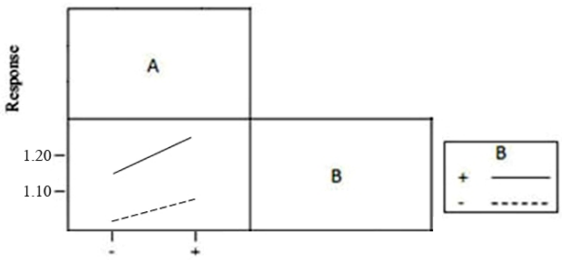


Figure 5. Factors interaction plots

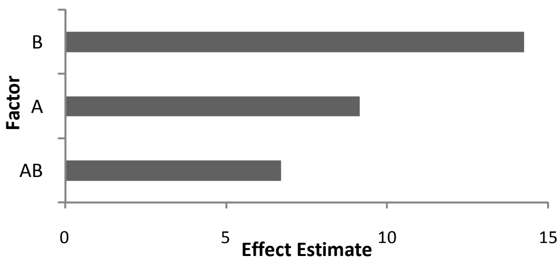


Figure 6. The Pareto chart of effects

The best condition for obtaining the highest heat transfer coefficient enhancement for nanofluid to the base fluid was found in the fourth row of Table 4. The MINITAB software was used to obtain the interaction plot of factors. As represented in Figure 5, factor A and B have no significant interactions because of the almost parallel lines estimated in the available plot.

The effects of individual factors and their interactions for the higher production yield of process can be calculated as the difference between responses of a factor at high (+1) and low (-1) levels according to the 2^2-screening design from the following formula [15]:

$$E_i = \frac{(\sum R_j)_{upper\ case}}{\frac{n}{2}} - \frac{(\sum R_j)_{lower\ case}}{\frac{n}{2}} \tag{11}$$

where E_i means the effect of factor i and n is the number of runs. So the factors' effect is calculated according to Tables 3 and 4 as follows:

$$E_A = \frac{R_2 + R_4}{2} - \frac{R_1 + R_3}{2} = 5.75$$

$$E_B = \frac{R_3 + R_4}{2} - \frac{R_1 + R_2}{2} = 12.05$$

$$E_{AB} = \frac{R_1 + R_4}{2} - \frac{R_2 + R_3}{2} = 2.95$$

The results are summarized in Table 5. Figure 6 is the Pareto chart representation of these effects.

The experimental model for 2^2-screening design can be obtained with following formula:

$$R = b_0 + \sum_{i=A}^{C} b_i X_i + \sum_{i=A}^{B} \sum_{j \neq i=B}^{C} b_{ij} X_i X_j \tag{12-a}$$

$$R = b_0 + b_a A^* + b_b B^* + b_{ab} A^* B^* \tag{12-b}$$

where R is the response, X's (A and B) are the signs of factors according to Table 2, and b_o, b_i *and* b_{ij} are the regression constants which are calculated as follows:

$$b_0 = \tfrac{1}{n} \sum R_i = 13.325$$

$$b_b = \tfrac{1}{n} \sum B_i^* R_i = 6.025$$

$$b_a = \tfrac{1}{n} \sum A_i^* R_i = 2.875$$

$$b_{ab} = \tfrac{1}{n} \sum A_i^* B_i^* R_i = 1.475$$

where n is the number of runs, in this case 4. The coded empirical model is then:

$$R = 13.325 + 2.875A^* + 6.025B^* + 1.475A^*B^* \tag{13}$$

To check the results of the experimental design we substitute the coded factor levels for the fourth run into the coded empirical model (Equation (13)). The result R=23.7 is in agreement with the experimental response. Figure 7 is a three-dimensional response surface plot of response (percent of heat transfer coefficient) versus main factors (A and B) based on the empirical model. It is clear in this figure that increscent in both operating temperature and alumina concentration, increases the enhancement of CHT coefficient of nanofluid. But the surface plot slope behavior which is to the right side of the chart emphasizes the higher effect of nanoparticles concentration in comparision to operating temperature. It is in agreement with the results of screening design (see Table 5).

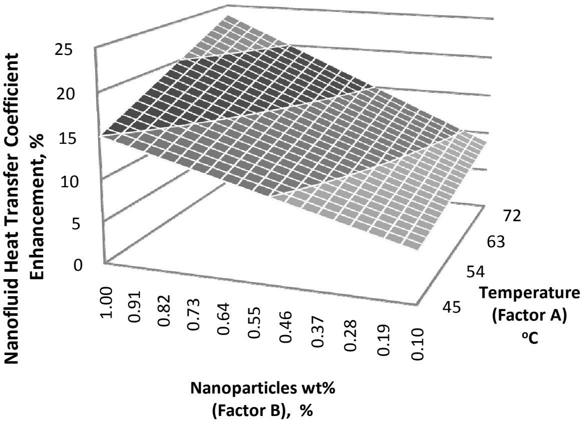


Figure 7. Response surface plot of nanofluid heat transfer coefficient enhancement

5. CONCLUSION

This paper presents a recent study on Al_2O_3/EG nanofluids which were stabilized with the use of ultrasonic procedure and their convective heat transfer coefficient were figured in a double-pipe heat exchanger in laminar flow. Critical enhancement of the *Nu* number in comparison to EG as a base fluid, up to 23.7% was achieved for 1.0% wt nanoparticle concentration.

The effect of temperature and concentration of nanoparticles on nanofluid *Nu* number were inquired. The convective heat transfer coefficient increases by increasing the temperature and nanoparticle concentration so the greatest *Nu* number was yielded at 75 °C and 1.0 wt% of alumina nanoparticles. In addition, the heat transfer coefficient of nanofluids was calculated from theoretical equations and compared with experimental results.

There is big deviation in theoretical and experimental results in high operating temperature and concentration of nanoparticles. It can be due to parameters neglected in theoretical equations. It may be concluded that these equations may not be used comprehensively for all types of nanofluids. For novelty in this work, the effect of alumina nanoparticle concentration in EG (base fluid) and the operating temperature, as main parameters, on the enhancement of heat transfer coefficient were investigated by 2^2-screening design and an experimental model was derived for these factors. As a result of this experimental design, it was found that the alumina nanoparticles' weight fraction was the most effective factor having significant effect on the enhancement of heat transfer coefficient of nanofluid.

6. ACKNOWLEDGEMENTS

The financial support of Material and Energy Research Center (MERC) of I. R. Iran is gratefully acknowledged.

7. REFERENCES

1. Nagasaka, Y. and Nagashima, A., "Absolute measurement of the thermal conductivity of electrically conducting liquids by the transient hot-wire method", ***Journal of Physics E: Scientific Instruments***, Vol. 14, No. 12, (1981), 1435.
2. Wang, X., Xu, X. and S. Choi, S. U., "Thermal conductivity of nanoparticle-fluid mixture", ***Journal of Thermophysics and Heat Transfer***, Vol. 13, No. 4, (1999), 474-480.
3. Xie, H., Lee, H., Youn, W. and Choi, M., "Nanofluids containing multiwalled carbon nanotubes and their enhanced thermal conductivities", ***Journal of Applied Physics***, Vol. 94, No. 8, (2003), 4967-4971.
4. Zhu, H.-t., Lin, Y.-s. and Yin, Y.-s., "A novel one-step chemical method for preparation of copper nanofluids", ***Journal of Colloid and Interface Science***, Vol. 277, No. 1, (2004), 100-103.
5. Hong, T.-K., Yang, H.-S. and Choi, C., "Study of the enhanced thermal conductivity of fe nanofluids", ***Journal of Applied Physics***, Vol. 97, No. 6, (2005), 064311-064311-4.
6. Wen, D. and Ding, Y., "Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions", ***International Journal of Heat and Mass Transfer***, Vol. 47, No. 24, (2004), 5181-5188.
7. Li, C. H. and Peterson, G., "The effect of particle size on the effective thermal conductivity of Al_2O_3-water nanofluids", ***Journal of Applied Physics***, Vol. 101, No. 4, (2007), 044312-044312-5.
8. Li, X., Zhu, D., Wang, X., Wang, N., Gao, J., and Li, H., "Thermal conductivity enhancement dependent ph and chemical surfactant for Cu-H_2O nanofluids", ***Thermochimica Acta***, Vol. 469, No. 1, (2008), 98-103.
9. Choi, S., Zhang, Z. and Keblinski, P., Nanofluids, encyclopedia of nanoscience and nanotechnology, nAmerican Scientific Publisher, Vol. 5, (2004), 757-773
10. Li, Q. and Xuan, Y., "Convective heat transfer and flow characteristics of Cu-water nanofluid", ***Science in China Series E: Technolgical Science***, Vol. 45, No. 4, (2002), 408-416.
11. Hamilton, R. and Crosser, O., "Thermal conductivity of heterogeneous two-component systems", ***Industrial & Engineering Chemistry Fundamentals***, Vol. 1, No. 3, (1962), 187-191.
12. Yang, Y., Zhang, Z. G., Grulke, E. A., Anderson, W. B. and Wu, G., "Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow", ***International Journal of Heat and Mass Transfer***, Vol. 48, No. 6, (2005), 1107-1116.
13. Zeinali Heris, S., Etemad, S. G. and Nasr Esfahany, M., "Experimental investigation of oxide nanofluids laminar flow convective heat transfer", ***International Communications in Heat and Mass Transfer***, Vol. 33, No. 4, (2006), 529-535.
14. Kellner, R., Mermet, J.-M., Otto, M., Valcarcel, M. and Widmer, H., "Analytical chemistry: A modern approach to analytical science", Wiley-Vch Germany, (2004).
15. Douglas, C. M., "Design and analysis of experiments", ***Design and Analysis of Experiments***, (1997).

Factor Effect Estimation in the Convective Heat Transfer Coefficient Enhancement of Al_2O_3/EG Nanofluid in a Double-pipe Heat Exchanger

A. H. Zamzamian[a], M. Tajik Jamal-Abadi[b]

[a] *Department of Energy, Materials and Energy Research Center(MERC)Postal Code 1787-316, Karaj, Iran*
[b] *Department of Renewable Energy, Materials and Energy Research Center, P.O.B. 316-31787, Karaj, Iran*

PAPER INFO

Paper history:
Received 13 June 2012
Received in revised form 28 January 2013
Accepted 28 February 2013

Keywords:
Nanofluid
Heat Conduction
Heat Transfer
Alumina
Nanostructure
Fluid Mechanics

چکیده

در این مقاله ضریب انتقال حرارت به روش جابجائی(همرفت) در جریان اجباری یک نانوسیال خاص که حاوی نانوذرات Al_2O_3 همراه با سیال اتیلن گلیکول (EG)، بصورت تجربی در یک مبدل حرارتی دو لوله مورد بررسی قرار گرفت. عدد نوسلت نانوسیال در غلظت مختلف نانوذرات و همچنین درجه حرارت های عملکرد مختلف اندازه گیری شده است بطوری که در غلظت های حدود ۱۰ ٪ وزنی از نانوذرات مقادیر فوق(عدد ناسلت) تا ۲۳.۷٪ افزایش یافته است .اهمیت این کار و نوآوری آن به طراحی آزمایشات به روش عاملی ۲ مربوط می شود که به این منظور اثر عوامل مختلف و نتایج آنها مورد بررسی قرار گرفته است بطوری که افزایش غلظت نانوذرات اثر بیشتری در افزایش ضریب عملکرد نانوسیالات خواهد داشت .مقایسه نتایج تجربی و روابط نیمه تجربی انجام شده است و لذا نشان داده شده است که انحراف قابل توجهی در درجه حرارت های عملکرد یا عملیاتی بالا و غلظت های مختلف نانوذرات به عنوان غلظت نانوساختار مشاهده می شود.

doi: *10.5829/idosi.ije.2013.26.08b.05*