CI&CEQ
Chemical Industry & Chemical Engineering Quarterly

Available on line at
Association of the Chemical Engineers of Serbia *AChE*
www.ache.org.rs/CICEQ

Chem. Ind. Chem. Eng. Q. 27 (1) 15–20 (2021) CI&CEQ

SRINIVASAN PERIASAMY MANIKANDAN[1]
RAJOO BASKAR[2]

[1]Department of Chemical Engineering, Kongu Engineering College, Erode, India
[2]Department of Food Technology, Kongu Engineering College, Erode, India

SCIENTIFIC PAPER

UDC 536.2:546.56:544:66

EXPERIMENTAL HEAT TRANSFER STUDIES ON COPPER NANOFLUIDS IN A PLATE HEAT EXCHANGER

Article Highlights

- Copper/ethylene glycol/propylene glycol/water mixed nanofluids were prepared
- The heat transfer performance of the copper suspended base fluid was studied
- Obtained Nusselt number was compared with base fluids at different temperatures
- Effect of copper nanoparticle concentration on the heat transfer coefficient was also studied

Abstract

The objective of the present work is to study the influence of copper nanoparticle concentration on heat transfer performance of a mixed base fluid. In the present study, the performance of copper nanoparticles in ethylene glycol (eg) + propylene glycol (pg) + water (W) base fluid was analyzed in the chevron-type plate heat exchanger. The sol-gel method was used to prepare copper nanoparticles (100 nm), dispersed in two different mixed base fluids of volume fractions 5%EG + 5%PG + 90%W and 15%EG + 5%PG + 80%W. Experiments were performed by varying the nanoparticle concentration from 0.2 to 1.0 vol.%. Three different hot fluid inlet temperatures were used (55, 65 and 75 °C). It is revealed from the study that the rate of heat transfer increased significantly with the mixed base fluid. Result shows that at 75 °C, 9 and 14.9% enhancement in the Nusselt number is obtained for 5%EG + 5%PG + 90%W and 15%EG + 5%PG + 80%W base fluid, respectively, for the nanoparticle concentration of 1%.

Keywords: heat transfer, nanofluid, plate heat exchanger.

Improvement in the rate of heat transfer in industrial processes may save energy consumption and utilization significantly. From the energy point of view, it is important to reduce the energy consumption by modifying the production method or upgrading the equipment used for the above purpose. The development of miniaturized technology, mini- and micro-components, has been introduced as one of the heat transfer enhancement techniques. Shell and tube heat exchangers are used in many process industries. The plate heat exchanger is an alternative heat exchanger for shell and tube exchangers and is used even at a moderate temperature and pressure. Plate heat exchangers are used in the diary, food and process industries. The advantages of plate heat exchangers include their higher efficiency, compactness and lower weight when compared to conventional heat exchangers of the same capacity.

Over the years, several studies focusing on heat transfer enhancements using nanoparticles have been published. For instance, Lee *et al.* [1] and Das *et al.* [2] measured thermal conductivity of Al_2O_3 and CuO nanoparticles suspended in ethylene glycol and water (EG/W) using a transient hot wire method. They found that a 4% volume concentration of CuO nanoparticles increased the thermal conductivity by 20%. They determined that thermal conductivity increased linearly with volume concentration.

Similar studies conducted by Eastman *et al.* [3] show the enhancement of thermal conductivity up to 41% with copper nanoparticles. The experiments performed with less than 100 nm of copper nanoparticles by Li and Xuan [4,5] gave a larger heat transfer coef-

Correspondence: S.P. Manikandan, Department of Chemical Engineering, Kongu Engineering College, Erode-638 060, India.
E-mail: sriperiasamy@gmail.com
Paper received: 20 December, 2019
Paper revised: 31 May, 2020
Paper accepted: 5 June, 2020

https://doi.org/10.2298/CICEQ191220020P

ficient than that calculated from the experimental data. Garg *et al.* [6] reported that thermal conductivity of larger size copper nanoparticle dispersed nanofluids showed moderate increase in thermal conductivity with increasing of the copper nanoparticle concentration. They have used 200 nm copper nanoparticles. Li *et al.* [7] investigated convective heat transfer and flow characteristics of copper-water nanofluid and observed considerable improvement in rate of heat transfer. In the last few decades, large number of investigations were reported which mainly focused on the preparation, characterization and measurement of thermo-physical properties of nanofluids and were summarized by Ghadimi *et al.* [8]. Researchers widely employed EG and its aqueous mixtures as base fluids for nanofluids and research showed that the heat transfer performances of these nanofluids are significantly higher than those of base EG and EG/W [9-12]. Only a few heat transfer studies have been reported on EG based CuO nanofluids, even though copper has higher thermal conductivity. Also, the works with respect to mixed base fluids is lacking in the literature.

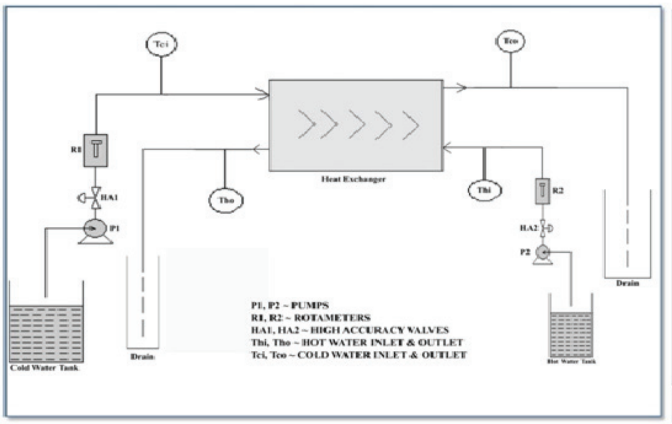
The main objective of this present study is to investigate the heat transfer performance in the plate heat exchanger by suspending copper nanoparticles in the two different mixed base fluids of volume fractions with 5%EG + 5%PG + 90%W and 15%EG + 5%PG + 80%W. The result obtained from the experimental studies is compared with the McCabe and Kim model selected from literature.

MATERIALS AND METHODS

Experimental setup

The plate heat exchanger consists of corrugated plates assembled into a frame. The hot fluid flows in one direction in alternating chambers while the cold fluid flows in true counter-current flow in the other alternating chambers [13].

The schematic diagram and photographic view of the experimental setup (plate heat exchanger) of the present study is shown in Figure 1.



(a) Schematic diagram

(b) Photographic view

Figure 1. Schematic diagram and photographic view of the experimental setup.

The experimental setup consists of a cold fluid container with a temperature controller, a hot fluid container with a temperature controller, two flow meters for controlling hot and cold fluid flows, two pumps along with the corrugated plate heat exchanger. The cold fluid was pumped into the chevron PHE, passing through a rotameter, and returned to the reservoir. Hot water used as a hot fluid passes through a control valve and a rotameter and then enters the PHE in a counter flow direction. The flow rate was monitored and controlled by the flow meters [14,15]. The inlet and outlet temperatures of the fluid were measured by four K-type thermocouples inserted additionally within the PHE. The PHE provided by Alfa Laval consists of 13 stainless-steel corrugated plates, creating 7 flow channels for the hot fluid and 6 flow channels for the cold fluid. The corrugation angle is 60°, which is the angle between the corrugation and the axis parallel to the plate length. The plate length is 0.154 m and the thickness of the plate is 0.25 mm.

Nanofluid preparation

Nanofluid is prepared by two step sol-gel method [16]. First the copper nanoparticle is prepared then dissolved in two different mixed base fluids of volume fractions of 15%EG + 5%PG + 80%W, and 5%EG + 5%PG + 90%W and used in the PHE as cold fluid. The SEM image of prepared copper nanoparticle is shown in Figure 2.

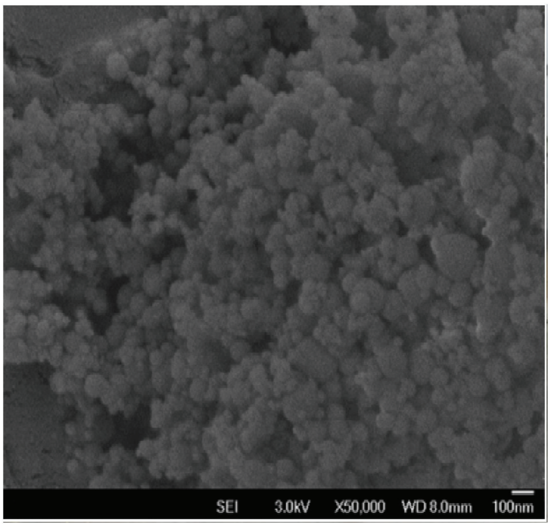


Figure 2. SEM image of copper nanoparticles.

Formulas used in heat transfer studies

Determination of experimental Nusselt number. Eqs. (1)-(6) are used to evaluate the Nusselt number of the nanofluid experimentally:

$$\frac{1}{U}=\frac{1}{h_{hot}}+\frac{\Delta x}{k_m}+\frac{1}{h_{nano}} \quad (1)$$

$$U=\frac{Q}{A\Delta TLMTD} \quad (2)$$

$$Q=mc_{pnf}(Tc_{,out}-Tc_{,in}) \quad (3)$$

$$A=NLW \quad (4)$$

$$\Delta TLMTD=\frac{\left(T_{hot,in}-T_{cold,in}\right)-\left(T_{hot,out}-T_{cold,out}\right)}{\ln\left(\frac{T_{hot,in}-T_{cold,in}}{T_{hot,out}-T_{cold,out}}\right)} \quad (5)$$

$$Nu=\frac{h_{nano}D_H}{K_{nano}} \quad (6)$$

For all the calculations, the fluid properties such as thermal conductivity, viscosity, density, specific heat capacity, as well as the Reynolds number and Prandtl number, are evaluated at bulk mean temperatures of hot and cold fluids [17-20].

Determination of Nusselt number using models. Eqs. (7) and (8) are used to evaluate the Nusselt number of the nanofluid using the McCabe model [13] and the Kim model [21], respectively.

$$Nu=0.37\left(N\mathrm{Re}\right)^{0.67}\left(N\mathrm{Pr}\right)^{0.33} \quad (7)$$

$$Nu=0.295\left(N\mathrm{Re}\right)^{0.64}\left(N\mathrm{Pr}\right)^{0.32}\left(\left(\frac{\Pi}{2}-\beta\right)\right) \quad (8)$$

RESULTS AND DISCUSSION

Effect of copper nanoparticle concentration on Nusselt number of mixed base fluid of 5% EG + 5% PG + 90%W at different hot fluid temperatures

The Nusselt number is the significant factor in evaluating heat transfer performance of nanofluids. In order to study the heat transfer performance of the copper nanoparticle, the Nusselt number was determined by observing the effect of nanoparticle volume fraction (0.2, 0.4, 0.6, 0.8 and 1.0%), hot fluid inlet temperature (55, 65 and 75 °C) for the proposed base fluid concentrations and the results are presented in Figures 3-5. The obtained experimental Nusselt number enhancement results were validated with theoretical models proposed by Mc Cabe *et al.* and Kim *et al.* The experiments were repeated by arbitrarily selecting nanoparticle concentration to ensure reproducibility of the results and observed that the deviation is negligible.

From Figure 3, it is observed that the Nusselt number increases significantly at a hot fluid inlet temperature of 55 °C, with the increase in nanoparticle concentration. The percentage increases of the Nusselt number are 4, 5.2, 6, 6.5 and 7 for the hot fluid inlet temperatures of 55 °C at the nanofluid concentrations of 0.2, 0.4, 0.6, 0.8 and 1.0 vol.%, respectively. This may be due to the thermal conductivity enhancement with increasing volume concentration [22,23].

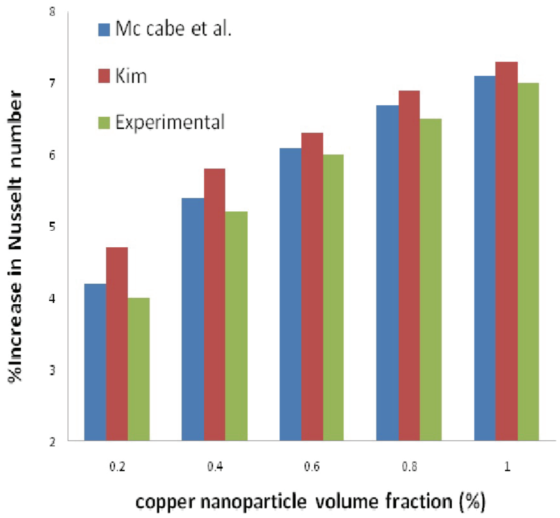


Figure 3. Effect of copper nanoparticle concentration on Nusselt number enhancement for a mixed base fluid of 5% EG + 5% PG + 90% W at a hot fluid inlet temperature of 55 °C.

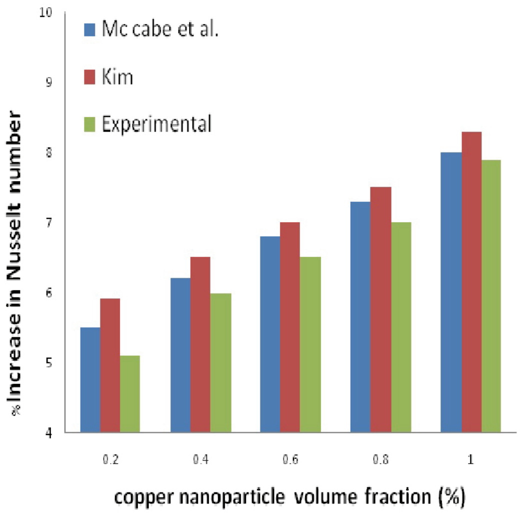


Figure 4. Effect of copper nanoparticle concentration on Nusselt number enhancement for a mixed base fluid of 5% EG + 5% PG + 90% W at a hot fluid inlet temperature of 65 °C.

It is evidenced from Figure 4 that, at the variation of hot fluid inlet temperature at 65 °C, the base fluid exhibits linear increase in the Nusselt number with increasing concentration and temperature.

The effect of copper nanoparticle addition on further increase in the hot fluid inlet temperature to 75 °C is reported in Figure 5. It was noted that the Nusselt number increases further with increasing temperature and nanoparticle concentration and maximum Nusselt number enhancement of 9.0% was observed at 1.0 vol.% of nanoparticle concentration. Enhancement in the Nusselt number is due to the inclusion of high thermal conductivity copper nanoparticle.

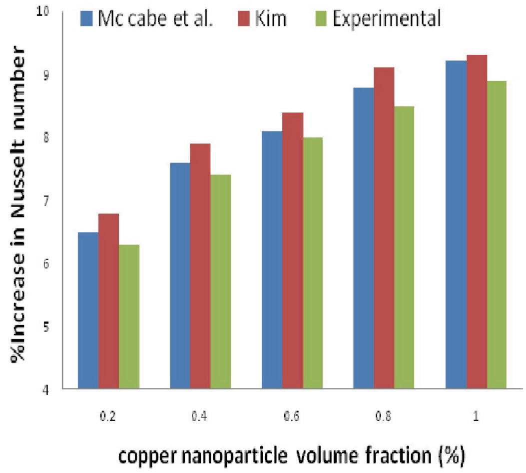


Figure 5. Effect of copper nanoparticle concentration on Nusselt number enhancement for a mixed base fluid of 5% EG + 5% PG + 90% W at a hot fluid inlet temperature of 75 °C.

Effect of copper nanoparticle concentration on the Nusselt number of mixed base fluid of 15% EG + 5% PG + 80%W at different hot fluid temperatures

Figures 6-8 show the effect of copper nanoparticle on the Nusselt number for a base fluid of 15%EG + 5%PG + 80%W at a hot fluid inlet temperature of 55, 65 and 75 °C, respectively.

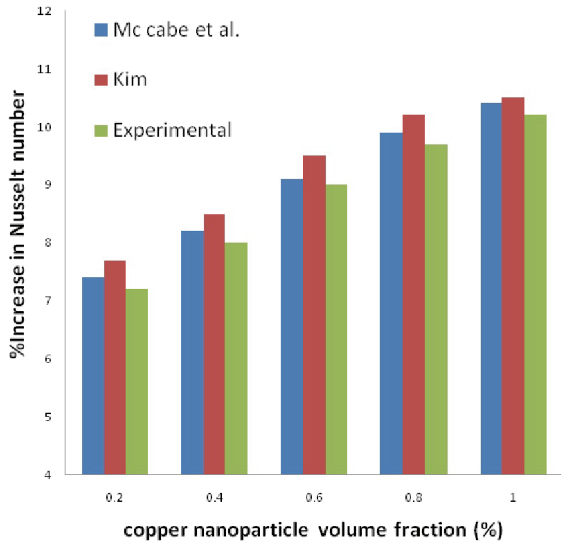


Figure 6. Effect of copper nanoparticle concentration on Nusselt number enhancement for a mixed base fluid of 15% EG + 5% PG + 80% W at a hot fluid inlet temperature of 55 °C.

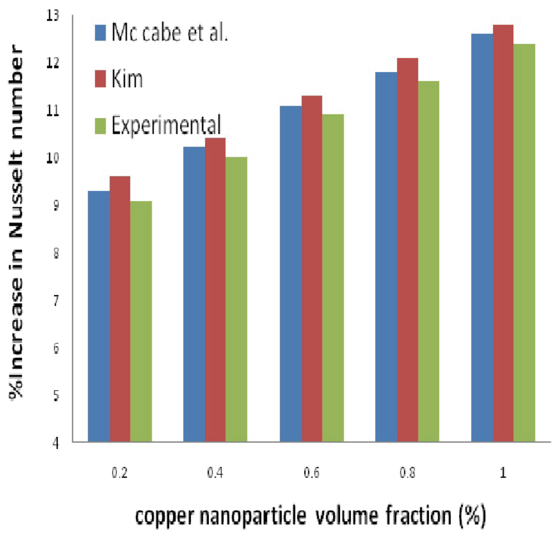


Figure 7. Effect of copper nanoparticle concentration on Nusselt number enhancement for a mixed base fluid of 15% EG + 5% PG + 80% W at a hot fluid inlet temperature of 65 °C.

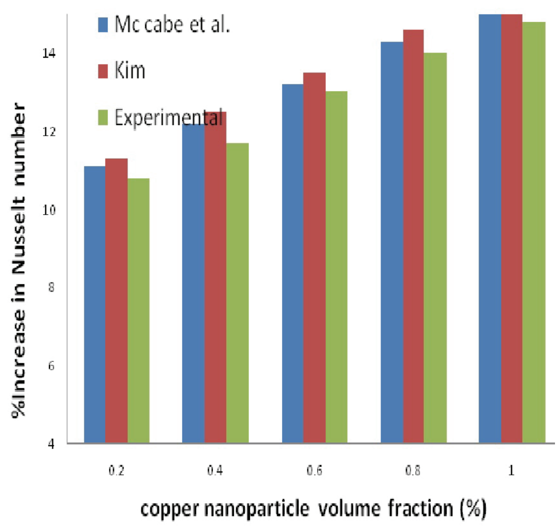


Figure 8. Effect of copper nanoparticle concentration on Nusselt number enhancement for a mixed base fluid of 15% EG + 5% PG + 80% W at a hot fluid inlet temperature of 75 °C.

From Figures 6-8, the similar trend of effect is observed, *i.e.*, increasing the nanoparticle concentration increases the Nusselt number and a 10.2, 12.4 and 14.9% increase in the Nusselt number for the nanoparticle concentration of 1.0 vol.% and hot fluid inlet temperatures of 55, 65 and 75 °C, respectively, is observed. There is good agreement between the results calculated from these experimental values and the correlation. It was noticed that the calculated Nusselt number falls within ±6% deviation with experimental results for 5%EG + 5%PG + 90%W nanofluids and ±8% deviation for 15%EG + 5%PG + 80%W nanofluids. Hence, there exists better agreement between the correlation results and experimental results, which shows the accuracy of the results of the experiment.

CONCLUSION

The present study focused on the benefits of using copper nanoparticles in a plate heat exchanger. The following were the conclusions that were drawn from heat transfer studies of a mixed base fluid by adding copper nanoparticle:

i. 1.0 vol.% of copper nanoparticle has increased the Nusselt number by 9% and 14.9% for the base fluid 5%EG + 5%PG + 90%W and 15%EG + 5%PG + 80%W, respectively.

ii. Among the three operating temperatures selected, the Nusselt number enhancement was high at a hot fluid inlet temperature of 75 °C.

iii. The experimental result of the Nusselt number was validated with McCabe *et al.* and Kim *et al.* models. A good agreement between the measured values with selected models at all mixed base fluid concentrations was obtained.

iv. The employed mixed base fluid could be easily recovered and reused for the process. Hence, the mixed base fluid can be used as an energy efficient heat transfer fluid.

Nomenclature

U	Overall heat transfer coefficient, W/m^{2}K
h	Convective heat transfer coefficient, W/m^{2}K
Cp	Specific heat capacity, J/(kg K)
Q	Heat flux, W/m^2
A	Heat transfer area, m^2
LMTD	Logarithmic Mean Temperature Difference
m	Mass of fluid, kg
T	Temperature, K
N	Number of channels, dimensionless
L	Plate width, m
Re	Reynolds number, dimensionless
Pr	Prandtl number, dimensionless
D_H	Hydraulic radius, m

Greek symbols

κ	Thermal conductivity, W/(m K)
μ	Viscosity, Pa s
ρ	Density, kg/m^3
β	Corrugation angle

Subscripts

nano	Nanofluid
p	Particle
in	Inlet
out	Outlet
cold	Cold fluid

hot Hot fluid

Acknowledgment

The authors thank the management of Kongu Engineering College for utilizing and carrying out the research work in the laboratory.

REFERENCES

[1] S.U.S. Choi, S. Lee, S. Li, J.A. Eastman, J. Heat Transfer 121 (1999) 280-289

[2] S.K. Das, N. Putra, P. Thiesen, W. Roetzel, J. Heat Transfer 125 (2003) 567-574

[3] J.A. Eastman, S.U.S. Choi, S. Li, W. Yu, L.J. Thompson, App. Phys. Lett. 78 (2001) 718-720

[4] Y. Xuan, Q. Li, Int. J. Heat Fluid Flow 21 (2000) 58-64

[5] Y. Xuan, Q. Li, J. Heat Transfer 125 (2003) 151-155

[6] J. Garg, B. Poudel, M. Chiemsa, J.B. Gordan, J.J. Ma, J.B. Wang, J. App. Phys. 103 (2008) 074301-074306

[7] Q. Li, Y. Xuan, Sci. China, Ser. E: Technol. Sci. 45 (2002) 408-416

[8] A. Ghadimi, R. Saidur, H.S.C Metselaar, Int. J. Heat Mass Transfer 54 (2011) 4051-4068

[9] S.M. Sohel Murshed, C.A. Nieto de Castro, Appl. Energy 184 (2016) 681-695

[10] R. Barzegarian, M.K. Moraveji, A. Aloueyan, Exp. Therm. Fluid Sci. 74 (2016) 11-18

[11] D. Huang, Z. Wu, B. Sunden, Exp. Therm. Fluid Sci. 72 (2016) 190-196

[12] J.R. Satti, D.K. Das, D. Ray, Int. J. Heat Mass Transfer 107 (2016) 871- 881

[13] W.L. McCabe, J.C. Smith, P. Harriot, Unit Operations in Chemical Engineering, 7th ed., McGraw-Hill International Edition, New York, 2006

[14] S.P. Manikandan, R. Baskar, Period. Polytech. Chem. Eng. 62 (2018) 317-322

[15] S.P. Manikandan, R. Baskar, Chem. Ind. Chem. Eng. Q. 24 (2018) 309-318

[16] M.S. Liu, M.C. Lin, C.Y. Tsai, C.C. Wang, Int. J. Heat Mass Transfer 49 (2006) 3028-3033

[17] Y. Xuan, W. Roetzel, Int. J. Heat Mass Transfer 43 (2000) 3701-3707

[18] R.S. Vajjha, D.K. Das, B.M. Mahagaonkar, Petrol. Sci. Technol. 27 (2009) 612-624

[19] J. Koo, C. Kleinstreuer, J. Nanoparticle Res. 6 (2004) 577-588

[20] B.C. Sahoo, R.S. Vajjha, R. Ganguli, G.A. Chukwu, D.K. Das, Petrol. Sci. Technol. 27 (2009) 1757-1770

[21] D. Kim, Y.H. Kwon, C.G. Li, J.K. Lee, D.S. Hong, J.G. Lee, S.H. Kim, J. Nanosci. Nanotechnol. 11 (2011) 5769--5774

[22] H.E. Patel, T. Sundararajan, S.K. Das, J. Nanopart. Res. 12 (2010) 1015-1031

[23] W. Yu, H. Xie, I. Chen, Y. Li, Powder Technol. 197 (2010) 218-221.

SRINIVASAN PERIASAMY MANIKANDAN[1]
RAJOO BASKAR[2]

[1]Department of Chemical Engineering, Kongu Engineering College, Erode, India
[2]Department of Food Technology, Kongu Engineering College, Erode, India

NAUČNI RAD

EKSPERIMENTALNO PROUČAVANJE PRENOSA TOPLOTE U NANOFLUIDIMA NA BAZI BAKRA U PLOČASTOM RAZMENJIVAČU TOPLOTE

Cilj ovog rada je proučavanje uticaja koncentracije nanočestica bakra na performanse prenosa toplote u smešama osnovnih tečnosti: etilen glikol (EG), propilen glikol (PG) + voda (V), u pločastom razmenjivaču toplote tipa ševron. Za pripremu nanočestica (100 nm) korišćena je sol-gel metoda; one su dispergovane u dve različite mešavine osnovnih tečnosti (vol. %): a) 5% EG + 5% PG + 90% V i b) 15% EG + 5% PG + 80% V. Eksperimenti su izvedeni promenom koncentracije nanočestica u opsegu 0,2-1,0 vol.%. Korišćene su tri različite ulazne temperature tečnosti (55, 65 i 75 °C). Utvrđeno je da se brzina prenosa toplote u smeši osnovnih tečnosti znatno povećava. Rezultat pokazuje da se na 75 °C postiže 9%, odnosno 14,9% poboljšanje Nuseltovog broja za smešu 5% EG, 5% PG i 90% V, odnosno 15% EG, 5% PG i 80% V, pri koncentraciji nanočestica od 1%.

Ključne reči: prenos toplote, nanofluid, pločasti razmenjivač toplote.