International Communications in Heat and Mass Transfer 65 (2015) 47–51

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Experimental investigation and development of new correlations for thermal conductivity of CuO/EG–water nanofluid☆

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ARTICLE INFO

Available online 19 April 2015

Keywords:
Thermal conductivity
Nanofluid
Heat transfer
CuO nanoparticles

ABSTRACT

In the present study, the thermal conductivity of CuO/EG–water nanofluid in different solid concentrations and temperatures has been experimentally investigated. Using a two-step method, the nanofluid has been produced in different solid concentrations ranging from 0.1% to 2% and temperatures up to 50 °C. The thermal conductivity of the nanofluid has been experimentally measured using the KD2 Pro instrument. Based on the experimental data, new correlations for predicting the thermal conductivity of CuO/EG–water at different temperatures have been proposed. The results show that with the increase of the solid concentration, the thermal conductivity of the nanofluid increases. Furthermore, the thermal conductivity of the nanofluid increases while the temperature increases. This increase is by far more noticeable in higher solid concentrations compared with lower solid volume fraction. This means that it is the presence of nanoparticles in the base fluid that causes the increase of the effect of temperature on the thermal conductivity.

1. Introduction

The extraordinary features and great potential of the nanofluids in heat transfer have made them more attractive for researchers. Adding the nanoparticles to base fluids such as water, ethylene glycol, and propylene glycol have a significant effect on the thermal conductivity enhancement. On these grounds, a number of studies have been done by different researchers [1–6].

Alipour et al. [7] conducted an investigation on the effect of interfacial nanolayers on the thermal conductivity of nanofluids. They proposed a new correlation for thermal conductivity and compared it with other proposed correlations. Hemmat et al. [8] conducted an experimental investigation on the thermal conductivity of Al_2O_3/water nanofluid. They measured the thermal conductivity of the nanofluid in different solid volume fractions up to 5% at various temperatures (ranging from 26 to 55 °C) and proposed a new correlation to predict the thermal conductivity as a function of solid concentration and temperature. Saeedinia et al. [9] experimentally studied the thermal and rheological behavior of CuO–Oil nanofluid. In another experimental study, the thermal conductivity of MgO/EG nanofluid with different sizes of particles (20, 40, 50, and 60 nm) was measured by Hemmat Esfe et al. [10]. They conducted the study at various temperatures (from 25 to 55 °C) and in different solid concentrations up to 5%. Using neural network, they presented a correlation for thermal conductivity improvement in terms of temperature, solid volume fraction, and size of the particle based on the measured data. Their results showed that the neural network is one of the most powerful tools for predicting the thermal conductivity of nanofluids. Using one-step physical method, Lee et al. [11] investigated the enhancement of the thermal conductivity of ZnO–EG nanofluid. Their results showed that this nanofluid shows the temperature-dependency at higher solid volume fractions. The effect of particle size on the thermal conductivity of TiO2 in water and polyvinyl alcohol has been experimentally investigated by Nisha and Philip [12]. Hemmat Esfe et al. [13] conducted an experimental investigation on the thermal properties of MWCNT-water nanofluid. They studied the thermal conductivity of the nanofluid in different solid volume fractions and temperatures. Their results showed that the thermal conductivity increases when temperature increases. Moreover, they observed that in the low concentrations, temperature has no considerable impact on the thermal conductivity while it is more considerable in higher solid concentrations. The effect of the solid volume fraction of MWCNT nanoparticles and temperature (28–60 °C) on the effective thermal

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☆ Communicated by W.J. Minkowycz.
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http://dx.doi.org/10.1016/j.icheatmasstransfer.2015.04.006
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conductivity has been experimentally studied by Indhuja et al. [14]. They declared that there is an inextricable connection between temperature and thermal conductivity, especially in the temperatures above 45 °C. Mariano et al. [15] conducted an experimental study on the thermal behavior of non-Newtonian ethylene glycol-based nanofluids. They measured the thermal conductivity of the nanofluids in different temperatures (283.15, 303.15, and 323.15 K) and solid concentrations up to 25%. They observed that the thermal conductivity increases with the increase of the solid volume fraction. Teng et al. [16] conducted an experimental study on the effect of the particle size on the thermal conductivity of alumina/water nanofluid. They investigated the effect of temperature, particle size, and solid volume fraction on the relative thermal conductivity of the nanofluid. Recently, Hemmat Esfe et al. [17,18] experimentally investigated the thermal conductivity of $Mg(OH)_2$–EG and MgO–water nanofluid at different concentrations and temperatures. They conclude that with the increase of temperature and solid volume fraction, thermal conductivity of nanofluid increases. Also, lately some studies on modeling of thermal conductivity by ANN [19,20] method have been carried out.

In the present study, the thermal conductivity of CuO/EG–water (40%–60%) has been experimentally investigated. The nanofluid in different solid concentrations and temperatures has been studied and several new correlations for predicting the thermal conductivity of the nanofluid have been proposed. Based on the authors' knowledge, there is no comprehensive and thorough investigation to predict the thermal conductivity of the nanofluid.

2. Thermal conductivity measurement

In the present study, thermal conductivity of the studied nanofluid, in different solid volume fractions and temperatures, was measured using a KD2 Pro instrument manufactured by Decagon Devices, USA. The KD2 Pro measures thermal conductivity based on the transient hot wire technique. In this method, a KS-1 sensor is used for measuring the thermal conductivity. It is 60 mm long and 1.27 mm in diameter and is made from stainless steel. The KD2 Pro instrument has an accuracy of ±5%. In order to stabilize the temperature, a hot water bath is used. Furthermore, for measuring the temperature, a thermometer is used which has an accuracy of 0.1 °C.

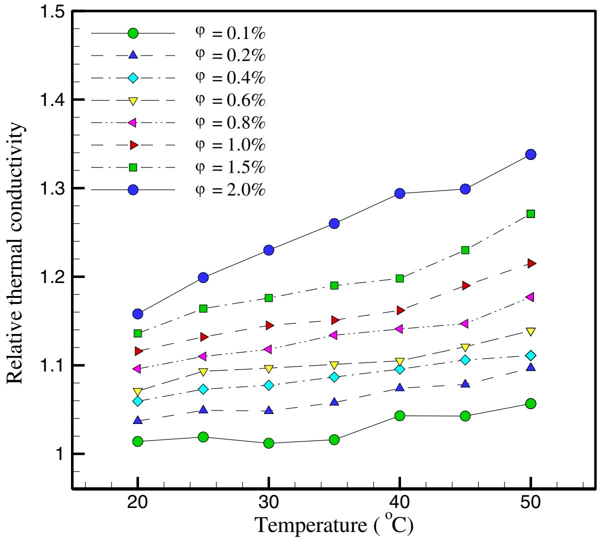


Fig. 2. Relative thermal conductivity of nanofluid versus temperature at different concentrations.

3. Results and discussion

In the present study, the thermal conductivity of CuO/EG–water (40%–60%) in different solid concentrations (up to 2%) and temperatures (up to 50 °C) has been evaluated. The figures of relative thermal conductivity as well as the diagrams of the enhancement's percentage have been presented in order to make better understanding of the nanofluid's behavior in such solid volume fractions and temperatures (Fig. 1).

Fig. 2 shows the relative thermal conductivity of CuO/EG–water (40%–60%) against temperature in all the studied solid concentrations.

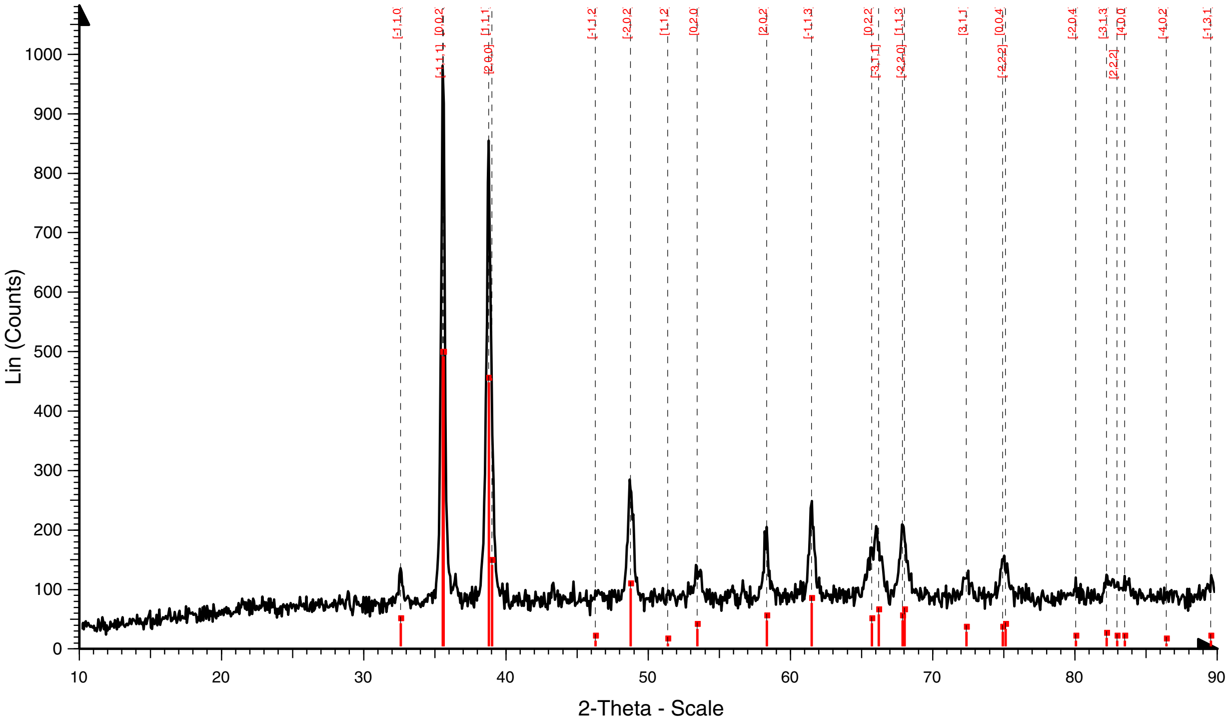


Fig. 1. XRD pattern of CuO nanoparticles.

Table 1
The percentage of enhancement in relative thermal conductivity of the nanofluids in different temperatures with respect to the thermal conductivity of the fluid in different temperatures.

	25	30	35	40	45	50
0.1%	0.47	0.55	0.62	2.78	2.75	4.13
0.2%	1.16	1.09	2.00	3.57	3.98	5.77
0.4%	1.35	1.71	2.58	3.43	4.48	4.88
0.6%	2.01	2.34	2.75	3.12	4.61	6.32
0.8%	1.28	2.02	3.50	4.07	4.63	7.37
1%	1.46	2.59	3.18	4.15	6.60	8.85
1.5%	2.51	3.57	4.77	5.49	8.30	11.95
2%	3.50	6.18	8.79	11.73	12.16	15.51

As it can be seen, while temperature increases, the relative thermal conductivity increases too. This increase in higher solid concentrations is by far more noticeable. The primary reason that the thermal conductivity increases with temperature can be explained by the increase in interactions among the particles and Brownian motion. On the other hand, the number of suspended nanoparticles increases when the solid volume fraction increases. The increase in particles apart from increase in interactions among the particles can cause the creation of chains of particles in fluid and ease the thermal conductivity.

Regarding the importance of the effect of temperature on thermal behavior of nanofluids, the percentage of enhancement in relative thermal conductivity of the nanofluid in various temperatures against the thermal conductivity of the fluid in the temperature of 20 °C at the same solid concentrations has been presented in Table 1. As can be seen, the largest effect occurs when the temperature is 50 °C, there is a change of 15.5% in the maximum solid concentrations of 2%. This means that in the solid volume fraction of 2%, when the temperature increases from 20 to 50 °C, the relative thermal conductivity increases by 15.5%.

Fig. 3 shows the relative thermal conductivity of the nanofluid against solid volume fractions of the nanoparticles at different temperatures. As is mentioned, the relative thermal conductivity increases while the solid concentration increases, and this increase is more tangible in higher temperatures than lower temperatures.

In order to investigate the effect of solid volume fraction of the nanoparticles thoroughly, the percentage of enhancement of the relative thermal conductivity of the nanofluid at different solid concentrations and at the same temperatures with respect to the solid volume fraction of 0.1% has been presented in Table. 2. As can be seen, with the increase of solid concentration, the relative thermal conductivity with respect to the thermal conductivity of the nanofluid, with solid concentration of 0.1%, increases. This increase in the solid concentration of 2% in the temperatures of 20 and 50 °C is 14.24% and 26.71%, respectively. Furthermore, at the temperature of 50 °C, the percentage of enhancement increases from 5.22% in solid concentrations of 0.4%, to 26.71% in solid concentration of 2%.

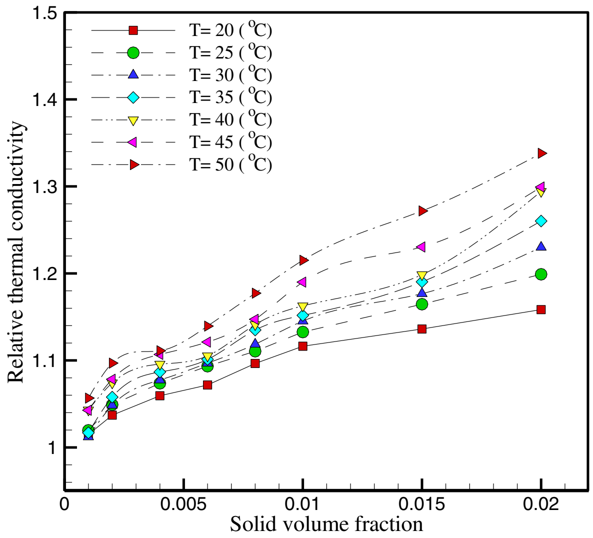


Fig. 3. Relative thermal conductivity of nanofluid with respect to solid volume fraction at different temperatures.

Table 2
The enhancement of the relative thermal conductivity of the nanofluid in different solid concentrations at the same temperature with respect to solid volume fraction of 0.1%.

φ (%)	20	25	30	35	40	45	50
0.004	4.48	5.37	6.43	6.94	5.05	6.23	5.22
0.006	5.70	7.30	8.33	8.36	5.97	7.60	7.91
0.008	8.14	8.99	10.47	11.67	9.41	10.10	11.49
0.01	10.09	11.16	13.08	13.33	11.47	14.21	15.07
0.015	12.05	14.29	16.17	17.11	14.92	18.08	20.44
0.02	14.24	17.67	21.40	23.97	24.09	24.69	26.71

Regarding the aforementioned analysis and in order to present the data completely in this study, Fig. 4 has been presented. Fig. 4 shows the percentage of enhancement in thermal conductivity of CuO/Eg–water (40%–60%) nanofluid with respect to water against temperature at different solid concentrations. As can be seen, when the temperature increases to 50 °C and solid concentrations of 2%, the thermal conductivity of the nanofluid at the temperatures of 20 and 50 °C increases by 15.84% and 36.97%, respectively, in regard to the water.

4. Proposed correlation

Regarding the importance of predicting the thermal conductivity of CuO/EG–water (40%–60%) nanofluid, several correlations have been proposed based on the experimental data.

Due to the necessity of presenting the correlations with acceptable accuracy, the correlations have been proposed separately at different temperatures. This way, these correlations can be more accurate and they can be used to predict thermal conductivity in various applications as easy as possible.

Fig. 5 presents the data related to curve fitting on the experimental data in various temperatures.

In order to develop correlations that predict thermal conductivity of nanofluids, some accurate correlations based on experimental measurements have been proposed in Table 3.

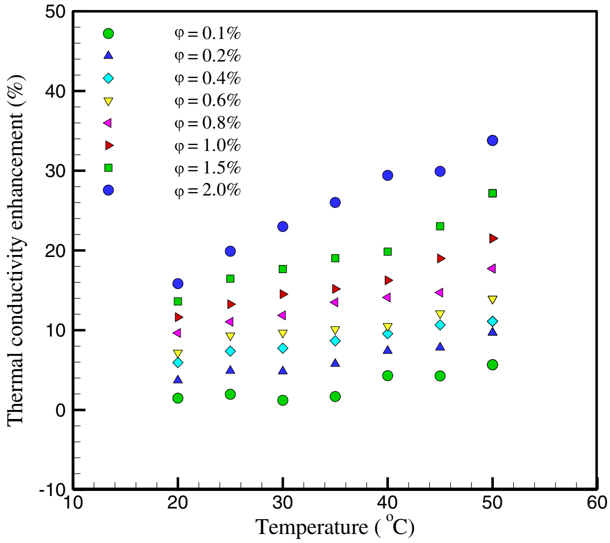


Fig. 4. Thermal conductivity enhancement percentage versus temperature at different solid volume fractions.

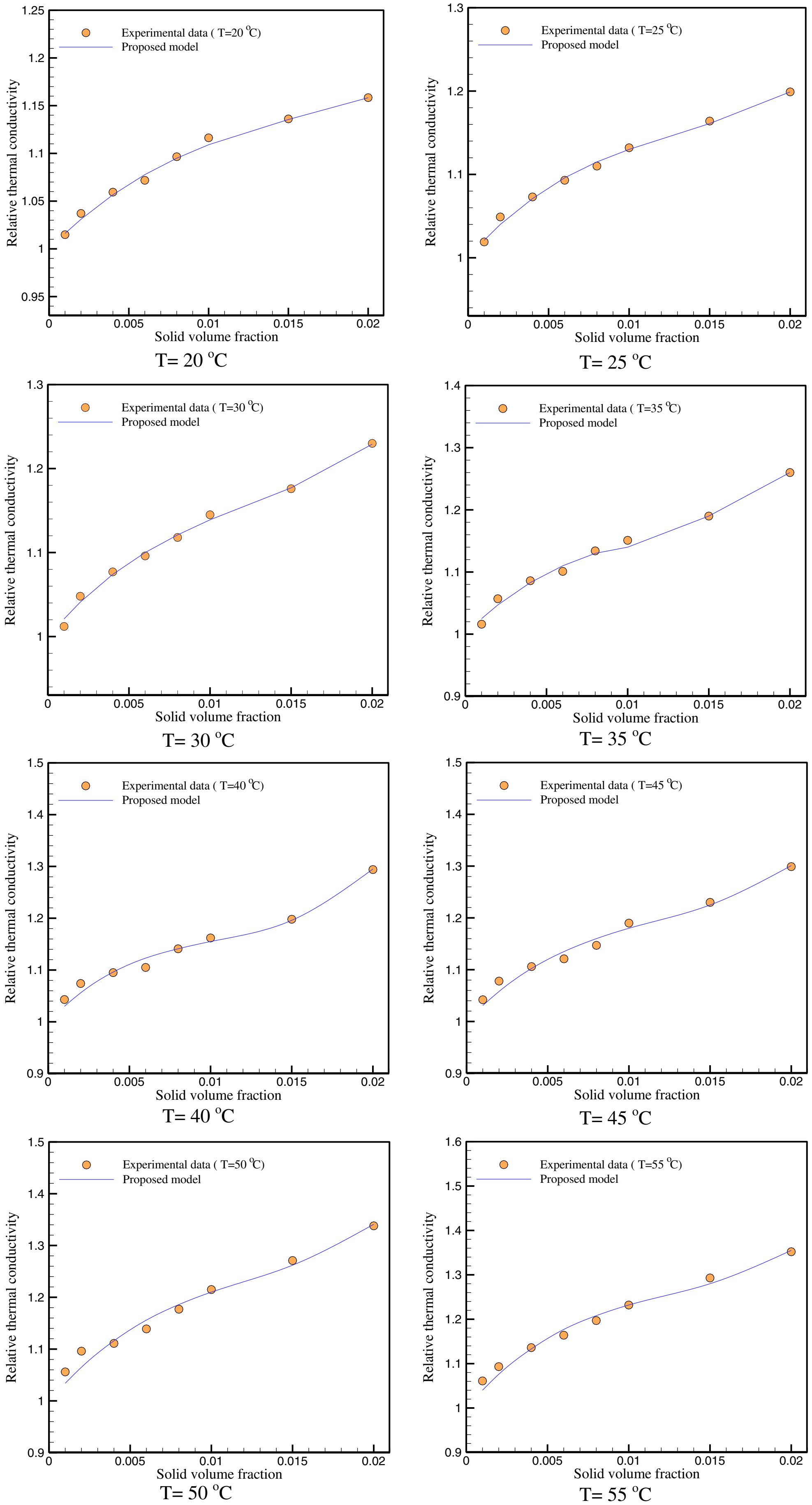
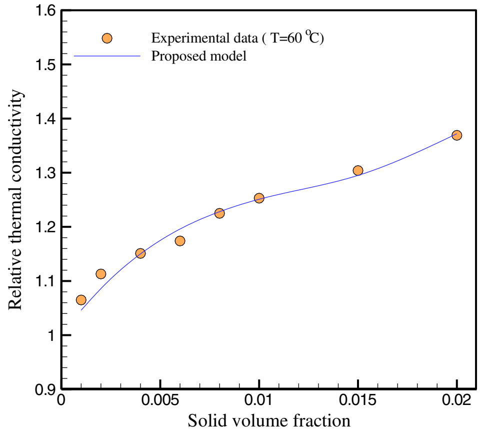


Fig. 5. Curve fitting on experimental data at different temperatures.



T= 60 °C

Fig. 5 (*continued*).

Table 3
Proposed correlations to predict thermal conductivity at different temperatures.

Temperature	Proposed correlation
@ T = 20	$\frac{k_{nf}}{k_{bf}} = 1 + 16.94(\varphi) - 755.2(\varphi^2) + 15200(\varphi^3)$
@ T = 25	$\frac{k_{nf}}{k_{bf}} = 1 + 22.41(\varphi) - 1249(\varphi^2) + 31410(\varphi^3)$
@ T = 30	$\frac{k_{nf}}{k_{bf}} = 1 + 22.95(\varphi) - 1236(\varphi^2) + 33120(\varphi^3)$
@ T = 35	$\frac{k_{nf}}{k_{bf}} = 1 + 26.88(\varphi) - 1705(\varphi^2) + 50560(\varphi^3)$
@ T = 40	$\frac{k_{nf}}{k_{bf}} = 1 + 32.94(\varphi) - 2566(\varphi^2) + 82850(\varphi^3)$
@ T = 45	$\frac{k_{nf}}{k_{bf}} = 1 + 33.02(\varphi) - 2102(\varphi^2) + 60190(\varphi^3)$
@ T = 50	$\frac{k_{nf}}{k_{bf}} = 1 + 37.13(\varphi) - 2219(\varphi^2) + 60760(\varphi^3)$
@ T = 55	$\frac{k_{nf}}{k_{bf}} = 1 + 43.21(\varphi) - 2718(\varphi^2) + 72360(\varphi^3)$
@ T = 60	$\frac{k_{nf}}{k_{bf}} = 1 + 49.25(\varphi) - 3287(\varphi^2) + 87740(\varphi^3)$

5. Conclusion

In the present study, the thermal conductivity of CuO/EG–water (40%–60%) in different solid volume fractions and temperatures has been experimentally investigated. The results have been presented in the form of various figures and tables. The results of the present study show that when the temperature and solid concentration increases, the thermal conductivity of the nanofluid increases. On the other hand, the effect of the temperature in higher solid concentrations is more noticeable compared with those of the lower solid concentrations. In the rest of the study and based on the experimental data, several correlations have been proposed in order to predict the thermal conductivity of the nanofluid. In order to keep the simplicity and accuracy of the proposed correlations at the same time, these correlations have been proposed separately in different temperatures. The extension of this paper and our previous work [21–23] affords engineers a good option for nanofluid in applications where improved heat transfer or efficient heat dissipation is required.

Acknowledgments

The authors gratefully acknowledge High Impact Research Grant UM.C/HIR/MOHE/ENG/23 and Faculty of Engineering, University of Malaya, Malaysia for their support in conducting this research work. The sixth author would like to thank the “Research Chair Grant” National Science and Technology Development Agency (NSTDA), the Thailand Research Fund (IRG5780005) and the National Research University Project for the support.

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