Periodica Polytechnica
Chemical Engineering

62(1), pp. 43-50, 2018
https://doi.org/10.3311/PPch.9741

RESEARCH ARTICLE

The Investigation of Effects of Temperature and Nanoparticles Volume Fraction on the Viscosity of Copper Oxide-ethylene Glycol Nanofluids

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Received 14 July 2016; accepted after revision 12 November 2016

Abstract
In the present article, the effects of temperature and nanoparticles volume fraction on the viscosity of copper oxide-ethylene glycol nanofluid have been investigated experimentally. The experiments have been conducted in volume fractions of 0 to 1.5 % and temperatures from 27.5 to 50 °C. The shear stress computed by experimental values of viscosity and shear rate for volume fraction of 1% and in different temperatures show that this nanofluid has Newtonian behaviour. The experimental results reveal that in a given volume fraction when temperature increases, viscosity decreases, but relative viscosity varies. Also, in a specific temperature, nanofluid viscosity and relative viscosity increase when volume fraction increases. The maximum amount of increase in relative viscosity is 82.46% that occurs in volume fraction of 1.5% and temperature of 50 °C. Some models of computing nanofluid viscosity have been suggested. The greatest difference between the results obtained from these models and experimental results was down of 4 percent that shows that there is a very good agreement between experimental results and the results obtained from these models.

Keywords
dynamic viscosity, nanofluid, solid volume fraction, ethylene glycol

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1 Introduction

Ethylene glycol is an organic combination that is used in thermal transformers, automobiles, air conditioners, and cooling systems operating in a temperature lower than water freezing point. This substance has a low thermal conductivity, so a lot of efforts have been made to increase its thermal conductivity. One way to do this is to add nanoparticles to this liquid [1-6]. However, when nanoparticles are added to the fluid to increase its thermal conductivity, the other thermophysical properties of the fluid change as well [7-10]. One of the properties that is likely to change with nanoparticles addition is viscosity. Therefore, changes in viscosity due to nanoparticles addition must be investigated in order to determine the pumping power and entropy generation in nanofluid flow in order to optimize the various devices [11]. In previous researches, the effect of adding different nanoparticles to ethylene glycol has been studied such as Al2O3 nanoparticles [12, 13], ZnO [14], and UDD (Ultra Dispersed Diamond) [15]. One of the nanoparticles used in different researches is copper oxide [16-21]. Some researchers have been conducted on CuO/EG nanofluid so far. Liu et al. [22] investigated this nanofluid relative thermal conductivity for different volume fractions of copper oxide nanoparticles. Zhu et al. [23] experimented specific thermal capacity for different volume fractions and suggested a model for the obtained experimental data. Quack and Kim [24] investigated the variations in zero shear viscosity for different volume fractions and compared the obtained results with present models. They also studied the way nanofluid viscosity changes with different shear rates for nanofluid various volume fractions. However, in none of these researches the effect of temperature variations on viscosity and shear rate of CuO/EG nanofluid has been investigated. The measurement of variations of nanofluid viscosity for different temperatures was first conducted by Masuda et al. [25] and continued by other researchers subsequently. Some researchers in their works reported that nanofluid relative viscosity increased with an increase in temperature [26]. In some other researches, a decrease in relative viscosity has been reported [27].

The rheological behaviour of EG affected by nanoparticles can be complicated. In Pastoriza-Gallego et al. [28, 29] study, the Newtonian behaviour of Al2O3/EG and ZnO/EG was obvious. Also, Żyła [30] and Mariano et al. [31] investigated the viscosity of Y3Al5O12/EG and Co3O4/EG, respectively. Their results indicated that their nanofluids were Newtonian. On the other hand, some researchers such as Żyła et al. [32, 33], Li et al. [35], Mariano et al. [34] and Li et al. [35] observed non-Newtonian behaviour of Al2O3, AlN, SnO2, SiC nanoparticles dispersed in ethylene glycol.

In the present article, the effect of temperature variation and volume fraction on viscosity of Cuo/FG nanofluid has been investigated and a relationship has been presented for it.

In the Table 1, a summary of relationships suggested for viscosity variation of different nanofluids due to temperature variation has been presented.

Table 1 Research on modelling the properties of nanofluids

Authors	Base fluid	Dispersed particles	Correlation
Hemmat et al. [13]	EG	ZnO	$\frac{\mu_{nf}}{\mu_{bf}} = 0.9118\exp\left(5.49\varphi - 0.00001359T^2\right) + 0.0303\ln\left(T\right)$
Nguyen et al. [24]	water	Al_2O_3	For $\varphi = 1\%$ $\frac{\mu_{nf}}{\mu_{bf}} = 1.125 - 0.0007\ T$ For $\varphi = 1\%$ $\frac{\mu_{nf}}{\mu_{bf}} = 2.1275 - 0.0215\ T + 0.0002\ T^2$
Jamshidi et al. [25]	EG/water	SiO_2	$\mu_{nf} = \mathrm{Exp}\left(aT + b\right)$ $a = -0.03959 - 0.01523\varphi$ $b = 3.53267 + 6.3848\varphi$
Kulkarni et al. [26]	water	CuO	$\ln\left(\mu_{nf}\right) = A\left(\frac{1}{T}\right) - B$ $A = 20587\varphi^2 + 15857\varphi + 1078.3$ $B = -107.12\varphi^2 + 53.548\varphi + 2.8715$
Namburu et al. [16]	EG/water	CuO	$\mathrm{Log}\left(\mu_{nf}\right) = Ae^{-BT}$ $A = 1.8375\varphi^2 - 29.643\varphi + 165.56$ $B = 4 \times 10^{-6}\varphi^2 - 0.001\varphi + 0.0186$
Masoumi et al. [27]	water	Al_2O_3	$\frac{\mu_{nf}}{\mu_{bf}} = 1 + \frac{\rho_p V_B d_p^2}{72C\delta\mu_{bf}}$ $V_B = \frac{1}{d_p}\sqrt{\frac{18k_bT}{\pi\rho_p d_p}}$ $C = \mu_{bf}^{-1}\left[\left(C_1d_p + C_2\right)\varphi + \left(C_3d_p + C_4\right)\right]$
Singh et al. [28]	toluene	magnetite	$\frac{\mu_{nf}}{\mu_{bf}} = \left(1 + 308.7\varphi + 0.9649\varphi^3\right) \times$ $\left(1 - 20.55\ \exp\left(-36.94\ T_r + 137.7\ T_r^{-1} - 108.6\ T_r^{-2}\right)\right)$ $T_r = \frac{T}{298}$

2 Experimental

2.1 Dynamic viscosity measurement

In current study the viscosity of the CuO–Ethylene glycol was measured by Brookfield viscometer equipped with a temperature bath. Referred apparatus enable us to adjust the temperature at every proposed value. It is worth to note that the accuracy of measured value is ±1.0% with ±0.2% repeatability. Before using the viscometer it regulate by using the glycerine and ethylene glycol at room temperature. Every test was repeated more than two times for each volume fraction to assure its repeatability, and then the average values was recorded.

2.2 CuO-ethylene glycol nanofluids preparation

In this investigation two-step method was used method for preparing of nanofluids. In refereed method, in first step the nanoparticles are synthesized, followed by their dispersion in base fluid as the second step. In addition, probe ultra-sonication, Surfactants, high-shear mixing and stirring are also used in order to reach to the acceptable nanoparticle dispersion. As it is well known amount of used surfactant, and applying time of ultra-sonication and mixing time can influence strongly the properties and stability of nanofluids. CuO–ethylene glycol nanofluid was prepared with very low concentration of surfactant-less. In this work CuO nanoparticles with average diameter of 40 nm were dispersed in ethylene glycol using shear homogenization and probe ultra-sonication (1200 W, 20 kHz, Kimia nano danesh). For each volume fraction required CuO nanopowder was added to ethylene glycol and exposed to shear homogenization for 15 min at low speeds and followed by higher speeds. The sample was then ultrasonicated using a probe ultrasonicator (1200 W, 20 kHz, Kimia nano danesh). In order to obtain the optimum ultra-sonication time the thermal conductivity and viscosity at different time periods were measured. For preparing the lower nanofluids concentration the CuO–ethylene glycol nanofluid was diluted.

3 Results and discussion

3.1 Comparison between the results obtained from theoretical models and experimental results

In Fig. 1, a comparison of the results obtained from theoretical models (Einstein [41], Wang et al. [12] and Batchelor [42]) and experimental results has been shown. As is evident, there is a big difference between experimental results and the results obtained from these models, and these models are not able to estimate the viscosity of copper oxide-ethylene glycol nanofluid.

3.2 Newtonian behaviour

It should be initially recognized if copper oxide-ethylene glycol nanofluid has Newtonian or non-Newtonian behaviour. For this purpose, the following relationship can be used which shows Newtonian fluid behaviour.

$$\tau = \mu \frac{\partial u}{\partial y} = \mu \, \gamma \tag{1}$$

In this relationship, τ is shear stress, м is dynamic viscosity, and ϒ is shear rate. According to this relationship, when shear stress has a linear relationship with shear rate, the fluid is Newtonian. Figure 2 shows variations in shear stress in terms of shear rate for volume fraction of 1% and in different temperatures. It is evident in this figure that copper oxide-ethylene glycol nanofluid with volume fraction of 1% and in different temperatures has a Newtonian behaviour.

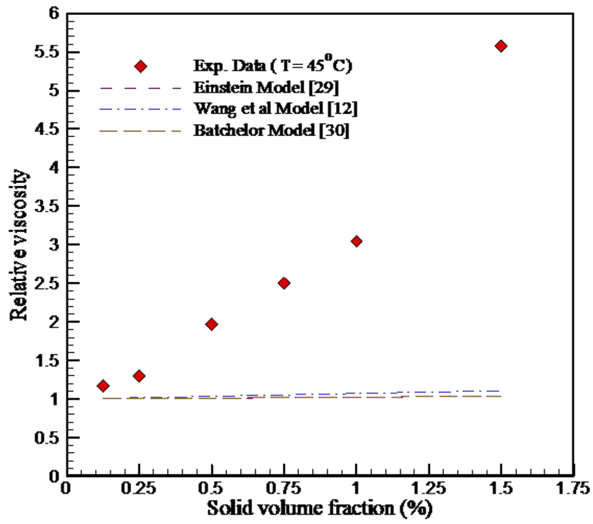

Fig. 1 The comparison between experimental data and the results obtained from theoretical models

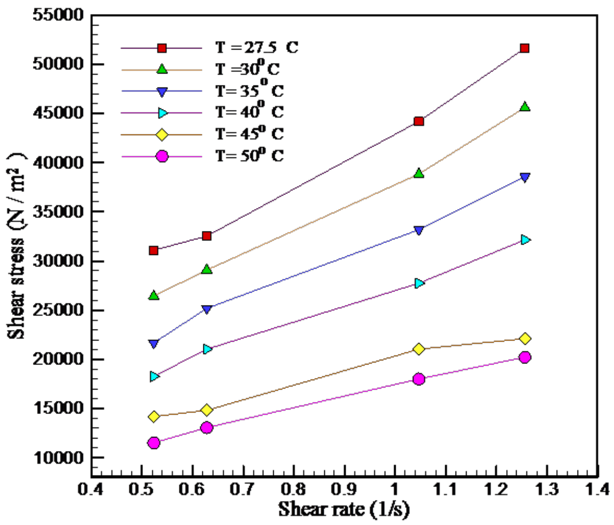

Fig. 2 Shear stress in terms of shear rate for copper oxide-water nanofluid with volume fraction of 1% in different temperatures

3.3 The effect of volume fraction and temperature on dynamic viscosity

In Fig. 3, the variations of dynamic viscosity in terms of volume fraction in different temperatures have been shown. From this figure, one can realize that nanofluid viscosity increases with an increase in nanofluid volume fraction in all investigated temperatures. Also, variations of viscosity in a given volume fraction in lower temperatures are greater compared to higher temperatures. In addition, in a volume fraction, viscosity decreases when temperature increases.

With adding nanoparticles into base fluid, internal shear stress increases. In the other words, when solid volume fraction is increased, fluid resistance against the movement rises and then it is expected that the dynamic viscosity is increased.

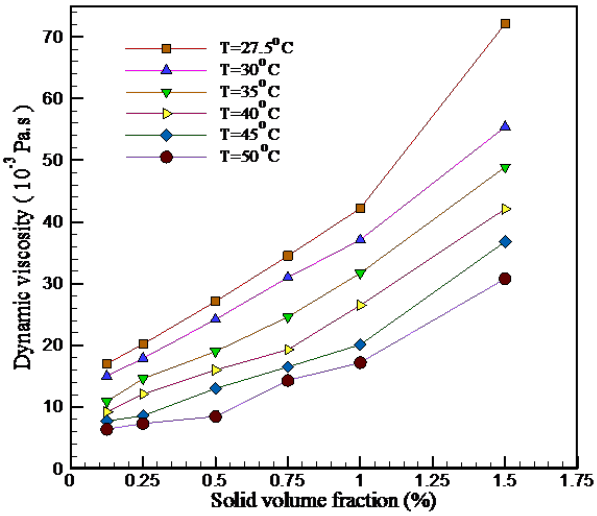

Fig. 3 Variations of viscosity in terms of volume fraction in different temperatures

Figure 4 shows the effect of temperature on viscosity in different volume fractions. According to this figure, in each volume fraction, viscosity decreases with an increase in temperature, and in a given temperature, viscosity increases when volume fraction increases. Due to increase temperature, the motion of particles in nano oil will be more intense and the molecular force will be reduced. Therefore, fluid becomes easier to move. Hence, it is expected that an increase in temperature, reduce viscosity.

Figures 5 and 6 show the proportion of nanofluid viscosity to base fluid viscosity in terms of nanoparticles volume fraction and temperature, respectively. It is observed that the greatest and smallest increase in proportion of nanofluid viscosity to base fluid viscosity were 82.46 % and 10.58% that occurred in volume fraction and temperature of 1.5%, 50 °C, and 0.125%, 27.5 °C, respectively.

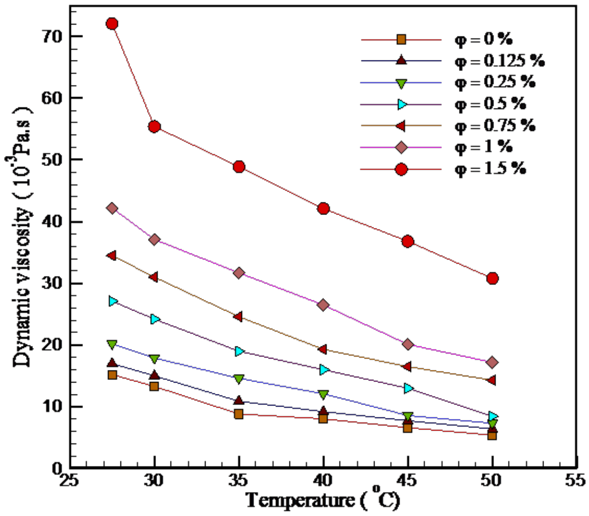

Fig. 4 Variations of viscosity in terms of temperature in different volume fractions

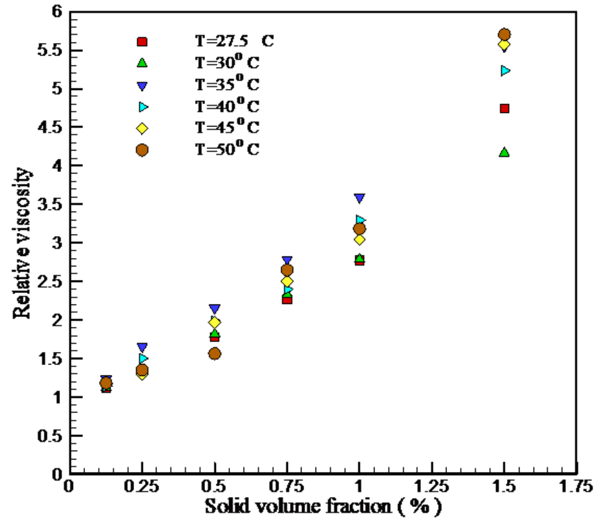

Fig. 5 Variations of relative viscosity in terms of volume fraction in different temperatures

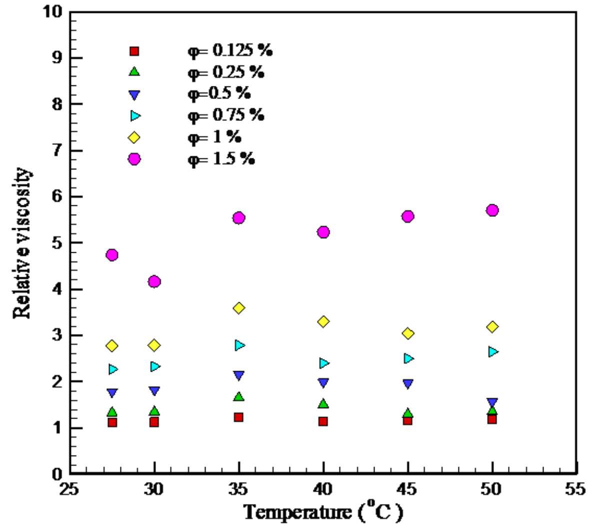

Fig. 6 Variations of relative viscosity in terms of temperature in different volume fractions

In a given temperature, relative viscosity increases when nanoparticles volume fraction increases, but in a given volume fraction, relative viscosity fluctuates when temperature increases.

3.4 The proposed viscosity model

Some models in terms of nanoparticles volume fraction have been proposed to compute viscosity of copper oxide-ethylene glycol nanofluid in tested temperatures. From these models, the viscosity of copper oxide-ethylene glycol nanofluid can be obtained separately in each temperature. These models are generally expressed in the following way.

$$\frac{\mu_{nf}}{\mu_{bf}} = a_0 + a_1\varphi + a_2\varphi^2 + a_3\varphi^3 + a_4\varphi^4 \tag{2}$$

Where м is dynamic viscosity and ф is nanoparticles volume fraction in terms of %. The coefficients available in this relationship in different temperatures have been presented in Table 2.

Table 2 The coefficients of the proposed viscosity model in different temperatures

T (°C)	a_0	a_1	a_2	a_3	a_4
27.5	0.9706	0.9047	2.767	-3.334	1.470
30	0.9876	0.8065	3.148	-3.418	1.268
35	0.6737	5.537	-8.844	8.948	-2.713
40	0.4294	7.226	-14.65	14.88	-4.600
45	1.210	-1.581	10.95	-12.03	4.481
50	1.633	-4.958	16.50	-14.63	4.695

In order to examine the accuracy of the proposed models, the difference between experimental values of relative viscosity and the values obtained from these models has been computed from the following relationship and in Fig. 7 these differences have been shown in terms of volume fraction.

As this figure shows, the greatest amount of difference has been 4 percent and there is a very good agreement between experimental results and the results obtained from these models. Also, in Fig. 8, an agreement is observed between experimental results and the results obtained from these relationships [43]:

$$Dev = \left[\frac{\left(\frac{\mu_{nf}}{\mu_{bf}}\right)_{Exp} - \left(\frac{\mu_{nf}}{\mu_{bf}}\right)_{pred}}{\left(\frac{\mu_{nf}}{\mu_{bf}}\right)_{pred}}\right] \tag{3}$$

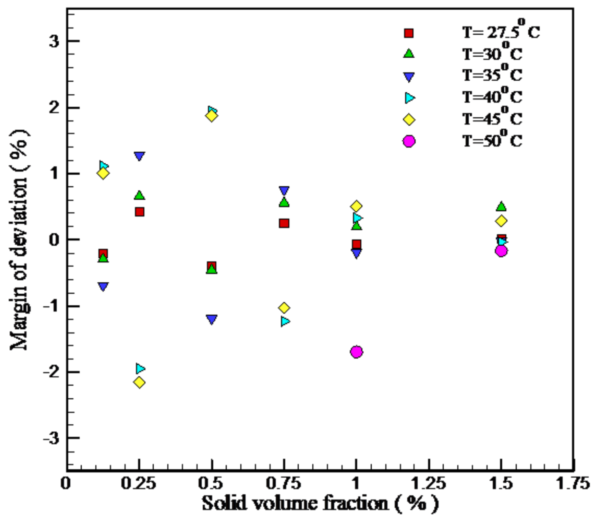

Fig. 7 Deviation of data obtained from the proposed models with experimental data

4 Conclusions

In the present research, dynamic viscosity of copper oxide-ethylene glycol nanofluid in temperatures from 27.5 to 50 °C and volume fractions of 0.125, 0.25, 0.5, and 1.5% has been measured experimentally. In this research, nanofluid behaviour (nanofluid being Newtonian or non-Newtonian) and effects of temperature and volume fraction on dynamic viscosity and relative viscosity have been investigated. The obtained results can be expressed in the following way:

1. The obtained values of shear stress for volume fraction of 1% and in different temperatures through experimental values of viscosity and shear rate show that this nanofluid has Newtonian behaviour.
2. The experimental results show that in a given volume fraction with an increase in temperature, viscosity deceases, but relative viscosity varies.
3. In a given temperature, nanofluid viscosity and relative viscosity increase when volume fraction increases. The greatest amount of increase in relative viscosity has been 82.46% that has occurred in volume fraction of 1.5% and temperature of 50 °C.
4. Some models have been proposed to compute nanofluid viscosity. The maximum difference between the results obtained from these models and experimental results has been 4 percent. It shows that there is a very good agreement between experimental results and the results obtained from these models.

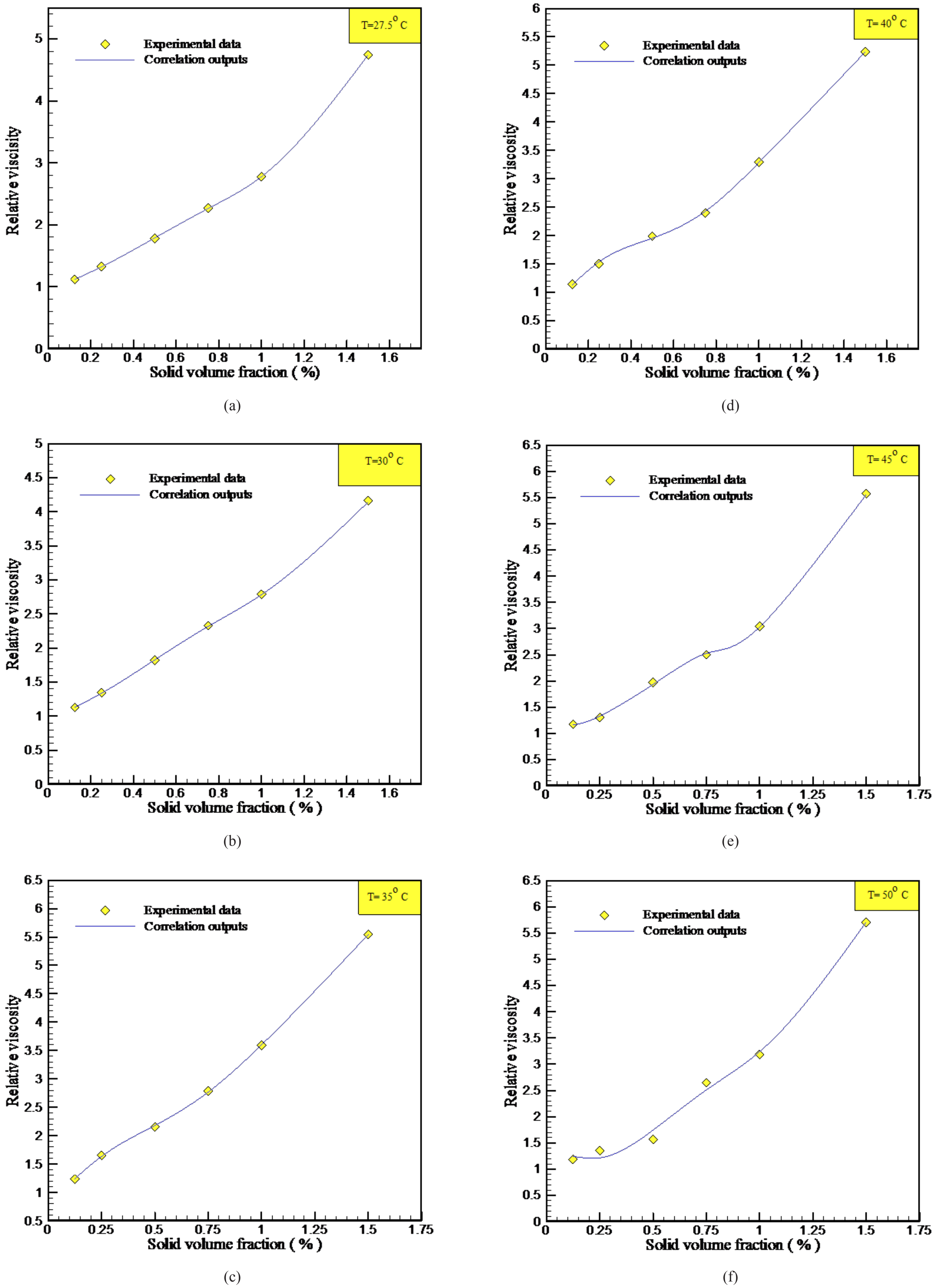

Fig. 8 A comparison between experimental data and the proposed models in (a) T = 27.5 °C (b) T = 30 °C (c) T = 35 0C (d) T = 40 °C (e) T = 45 °C (f) T = 50 °C

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