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Dynamic Viscosity of Indium Oxide–Ethylene Glycol (In_2O_3–EG) Nanofluids: An Experimental Investigation

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Nanofluids, which are suspensions of nanoparticles, are interesting engineering materials, which might find numerous applications in industry. Unfortunately, there is no coherent theoretical model describing viscosity of nanofluids and further experimental and theoretical studies of this issue should be performed. This paper makes a contribution to this field. Dynamic viscosity of ethylene glycol based nanofluids containing indium oxide nanoparticles was measured in shear rate range from 10 s^{-1} to 1000 s^{-1} at constant temperature. It was presented that those materials exhibit Newtonian nature. Viscosity increases with the volume fraction of particles in nanofluids, and the Krieger–Dougherty equation could be applied to describe this increase. Additionally, a dependence of viscosity on temperature was examined in the range from 278.15 K to 338.15 K with constant shear rate 100 s^{-1}.

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1. Introduction

Since its development at the end of twentieth century, nanofluids are intensively studied. Main areas of investigation are thermal conductivity [1–3] and viscosity [4–7]. It is connected with potential application of those materials in heat exchangers system, where those properties are most important [8]. However, other physical properties like surface tension [9] and optical properties [10, 11] are also examined.

There are many papers on those basic physical properties, but still there is no coherent theoretical model which describes viscosity of nanofluids. For example in recent review paper by Mishra et al. [4] over 20 various, sometimes very sophisticated, models has been presented. There are many models which describe viscosity of nanofluids, but they are mostly applied only for one type of nanosuspensions. Many researchers emphasize need of detailed experimental data obtained at strictly controlled conditions which might be used to prepare theoretical model. This paper makes some contribution to this field.

According to the best knowledge of the authors, there is only one study on thermophysical properties of indium oxide (In_2O_3)–ethylene glycol (EG) nanofluids. Latha et al. [12] presented a paper in which thermal conductivity, density, viscosity, specific gravity, electrical conductivity, and optical properties were examined. They prepared few types of samples containing one volume fraction of nanoparticles (1 vol.%) with various fractions of surfactant (polyvinylpyrrolidone — PVP). On the basis of that study they concluded that this material is interesting from the point of view of possible applications as cooling fluid.

This paper presents results of study on dynamic viscosity of indium oxide–ethylene glycol nanofluids prepared with various fraction of particles and without any surfactant.

2. Materials and methods

Nanoparticles used in this study are commercially available indium oxide and it was purchased from PlasmaChem GmbH (Berlin, Germany). As declared by manufacturer, average particle size is 4 nm. To evaluate size of particles a JEOL JSM-6700F field emission scanning electron microscope (JEOL, Tokyo, Japan) was used. A backscattering electron image was obtained with operating accelerator voltage 10.0 kV and magnification 250000×. Result of this examination is presented in Fig. 1. It could be noticed that nanoparticles exhibit tendency to create agglomerates, so each measurements were performed immediately after sample preparation.

Samples were prepared with mass fractions from 0.01 to 0.05 with 0.01 step, and it was later recalculated to the volume fractions. Nanofluids preparation procedure was the same one that we previously used for other nanosuspensions and it has been described in detail elsewhere [13, 14].

Dynamic viscosity of nanofluids was investigated with HAAKE MARS 2 rheometer (Thermo Electron Corporation, Karlsruhe, Germany) coupled with Peltier system and Phoenix 2 thermostat (Thermo Electron Corporation, Karlsruhe, Germany). Cone-plate measuring geometry with cone angle of 2° and 60 mm diameter was used. Two types of measurements were performed:

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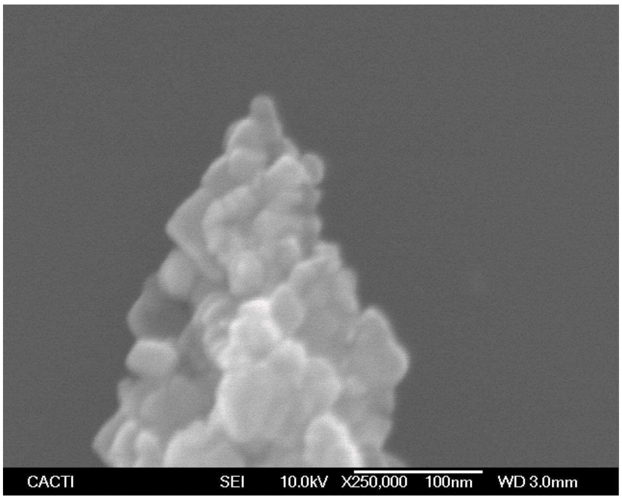

Fig. 1. Scanning electron microscope (SEM) picture of dry In_2O_3 nanoparticles.

(a) viscosity curves determination, in which dynamic viscosity was investigated at constant temperature 298.15 K and shear rate was changed from 10 s^{-1} to 1000 s^{-1}, and (b) dependence of viscosity on temperature in which constant shear rate 100 s^{-1} was applied and temperature was changed from 278.15 K to 338.15 K with 10 K step. Before collecting each measuring points sample was kept at constant temperature for 300 s to obtain steady state conditions.

3. Results and discussion

Figure 2 presents results of experimental study on dynamic viscosity of In_2O_3–EG. Viscosity of those materials does not depend on shear rate, so they might be classified as Newtonian fluids. Values of viscosity, calculated as an average of all measuring points from each examined nanofluid, were summarized in Table I.

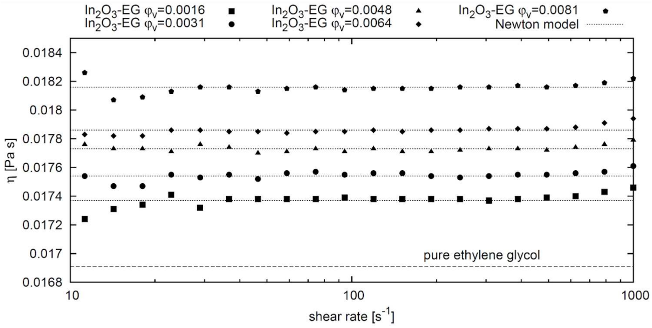

Fig. 2. Viscosity curves of In_2O_3–EG nanofluids containing various volume fractions of nanoparticles at 298.15 K.

One might notice that the value of viscosity increases with the fraction of particles in those materials, and the ratio of nanofluids viscosity and base fluid viscosity increases with the fraction of particles as presented in Table I.

TABLE I

Experimental values of the thermal dynamic viscosity, η_{nf}, of In_2O_3–EG nanofluids at 298.15 K.

φ_m –	φ_v –	η_{nf} [Pa s]	η_{nf}/η_{bf} –
0.000	0.0000	0.01690	1.0000
0.010	0.0016	0.01737	1.0278
0.020	0.0031	0.01754	1.0379
0.030	0.0048	0.01773	1.0491
0.040	0.0064	0.01786	1.0568
0.050	0.0081	0.01816	1.0746

Historically first model of viscosity of suspensions connected with the volume fraction of particles, was presented by Einstein as

$$\frac{\eta_{nf}}{\eta_{bf}} = 1 + [\eta]\varphi_v, \qquad (1)$$

where η is dynamic viscosity, $[\eta]$ is the intrinsic viscosity with the value of 2.5 for spherical particles, φ is fraction, and nf, bf, v subscripts correspond to nanofluid, base fluid, and volume, respectively.

In subsequent years many models has been introduced. Among them a modified Krieger–Dougherty (K-D) equation, which is often used for nanofluids viscosity [15], of the form

$$\frac{\eta_{nf}}{\eta_{bf}} = \left[1 - \frac{\varphi_v}{\varphi_c}\left(\frac{d_a}{d_p}\right)^{3-D}\right]^{-[\eta]\varphi_c}, \qquad (2)$$

where φ_c is critical particle packing fraction with the value approximately 0.605, D is fractal index with the value in the range from 1.8 to 2.5, d_a and d_p are radius of aggregates and particles, respectively. Therefore, for spherical particles, K-D model could be reduced to

$$\frac{\eta_{nf}}{\eta_{bf}} = \left[1 - \frac{\varphi_v}{0.605}\left(\frac{d_a}{d_p}\right)^{1.2}\right]^{-1.5125}. \qquad (3)$$

This model was fitted to the experimental data, as presented in Fig. 3. The value of $\frac{d_a}{d_p}$ parameter obtained from fitting is 6.199.

Figure 3 presents experimentally evaluated viscosity ratio and predictions of both presented theoretical models as well. It might be noticed that Einstein model (1) underestimates experimental values of viscosity. On the other hand, modified K-D model (3) presents good agreement with obtained experimental results. Taking into account viscosity measurements uncertainty one might notice that this model works correctly for In_2O_3–EG nanofluids as presented in Fig. 3.

Dependence of viscosity on temperature was also investigated in this study, and results have been presented in Fig. 4. As expected, viscosity decreases with the temperature in examined temperature range. It might be noticed that influence of temperature on viscosity is much more visible than impact of the fraction of particles.

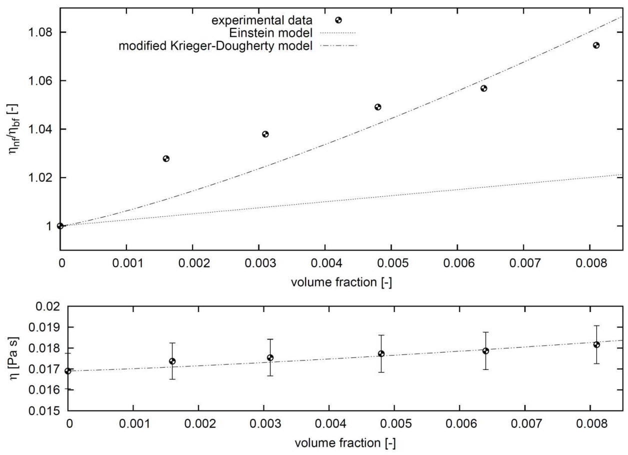

Fig. 3. Dependence of viscosity ratio and viscosity on fraction of nanoparticles for In_2O_3–EG nanofluids at 298.15 K. Symbols present experimental data, lines — theoretical models.

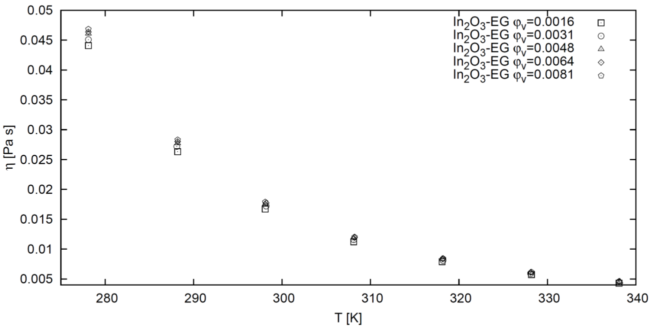

Fig. 4. Dependence of viscosity on temperature for In_2O_3–EG nanofluids at constant shear rate 100 s^{-1}.

4. Conclusions

This paper presents results of experimental study on dynamic viscosity of indium oxide–ethylene glycol nanofluids. It was presented that those materials exhibit Newtonian nature for each examined fraction of particles. Results show that viscosity increases with the fraction of nanoparticles and it could be modeled with modified Krieger–Dougherty equation. Finally, the dependence of viscosity on temperature was investigated, and results show that temperature has strong influence on viscosity of those materials.

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References

[1] H.S. Aybar, M. Sharifpur, M.R. Azizian, M. Mehrabi, J.P. Meyer, *Heat Transf. Eng.* **36**, 1085 (2015).

[2] S.S. Murshed, C.N. de Castro, *Appl. Energy* **184**, 681 (2016).

[3] K. Bashirnezhad, M.M. Rashidi, Z. Yang, S. Bazri, W.M. Yan, *J. Therm. Anal. Calorim.* **122**, 863 (2015).

[4] P.C. Mishra, S. Mukherjee, S.K. Nayak, A. Panda,*Int. Nano Lett.* **4**, 109 (2014).

[5] A.K. Sharma, A.K. Tiwari, A.R. Dixit, *Renew. Sustain. Energy Rev.* **53**, 779 (2016).

[6] S.S. Murshed, P. Estellé, *Renew. Sustain. Energy Rev.* **76**, 1134 (2017).

[7] A.A. Nadooshan, H. Eshgarf, M. Afrand, *Powder Technol.* **338**, 342 (2018).

[8] D. Wen, G. Lin, S. Vafaei, K. Zhang, *Particuology* **7**, 141 (2009).

[9] P. Estelle, D. Cabaleiro, G. Zyla, L. Lugo, S.S. Murshed, *Renew. Sustain. Energy Rev.* **94**, 931 (2018).

[10] O. Mahian, A. Kianifar, S.A. Kalogirou, I. Pop, S. Wongwises, *Int. J. Heat Mass Transf.* **57**, 582 (2013).

[11] S.K. Verma, A.K. Tiwari, *Energy Convers. Manage.* **100**, 324 (2015).

[12] C.K. Latha, Y. Aparna, R. Merugu, D. Ravinder, *Int. J. Eng. Res. Appl.* **6**, 94 (2016).

[13] G. Zyla, J. Fal, *Thermochim. Acta* **650**, 106 (2017).

[14] G. Zyla, J. Fal, P. Estellé, *Int. J. Heat Mass Transf.* **113**, 1189 (2017).

[15] H. Chen, Y. Ding, C. Tan, *New J. Phys.* **9**, 367 (2007).