



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-2355

EFFECT OF TEMPERATURE AND NANOPARTICLES CONCENTRATION ON THERMAL CONDUCTIVITY AND VISCOSITY OF OIL-BASED NANOFLUIDS: AN EXPERIMENTAL STUDY

Ítalo Franco Guilherme

Daniel Alberto Flórez Morales

Abdul Orlando Cárdenas Gómez

Enio Pedone Bandarra

Federal University of Uberlândia, Mechanical School. Uberlândia (MG), Brazil. Av. Joao Naves de Avila, 2121.

italoengmec95@gmail.com

esdanielflorez@gmail.com

orlandocardenas1589@gmail.com

bandarra@ufu.br

Abstract. *In this experimental investigation, nanofluids are prepared with different types of nanoparticle and solid concentration. Multi-walled carbon nanotubes (MWCNT), silver (Ag), titanium dioxide (TiO₂) and zirconium dioxide (ZrO₂) nanoparticles are used in this work. Thermal conductivity and dynamic viscosity of the base fluid and all nanofluids were measured at different temperatures and the effect of the type, temperature and solid concentration on the heat transfer properties of the nanofluids is investigated. The results show an increase of up to 18% in the value of the thermal conductivity of nanofluids of multi-walled carbon nanotubes (MWCNT) compared to the base fluid. A maximum increase of 1.7% in dynamic viscosity was observed for the maximum concentration of carbon nanotubes (MWCNT). The results obtained are compared with different authors.*

Keywords: *Thermal conductivity. Dynamic viscosity. Thermodynamic properties. Nanofluids. Oil.*

1. INTRODUCTION

Heat transfer fluids such as water, ethylene glycol and oil are used in many fields of applications, but they have poor heat transfer properties compared with most solids, this can be seen in Tab. 1. How to improve their thermo-physical properties is one of the greatest challenges to their application. Therefore, many researchers have focused their efforts on the development of high-performance heat transfer fluids in recent decades. So, advancement in nanotechnology gives an opportunity to disperse nanoparticles (1-100 nm) in based liquid, which is called nanofluids by (Choi,1995).

Table 1. Thermal conductivity of some additives and conventional fluids

Materials	Symbol	Thermal Conductivity (W/m.K)
Metallic materials		
Cooper	Cu	401
Silver	Ag	428
Gold	Au	318
Iron	Fe	83.5
Non-metallic materials		
Aluminium oxide	Al ₂ O ₃	40
Cooper oxide	CuO	76,5
Carbon nanotubes	MWCNT	~ 3000
	SWCNT	~ 6000
Diamond	C	~ 2300
Conventional fluids		
Water	H ₂ O	0.613
Ethylene glycol	EG	0.215
Oil	TO	0.145

Thermo-physical properties of a nanofluid such as dynamic viscosity and thermal conductivity play a more significant role in thermohydraulic performance. Higher thermal conductivity means higher heat transfer performance, while lower viscosity results in lower pumping power and lowering pressure (Asadi et al., 2018). The exponential increase in the number of publications in this field shows that the issue of nanofluids has attracted much attention in recent years. A wide range of experimental and theoretical studies on thermal conductivity and dynamic viscosity of nanofluids have been carried out in the last decade. Table 2 shows a summary of some works published by other authors and discussed in this investigation.

Table 2. Summary of the published literature of the thermal conductivity and dynamic viscosity of oil-based nanofluids.

Reference	Studied nanofluid	Temperature	Solid concentration	Remarks of thermal conductivity	Remarks of viscosity
Pakdaman et al. (2012)	MWCNT -heat transfer oil	40 - 70 °C	0.1, 0.2, and 0.4 wt.%	Maximum thermal conductivity enhancement of 15 % at solid concentration of 0.4 wt.% and temperature of 70 °C	Maximum viscosity increase of 67% @ T= 40 °C e ϕ =0.4 wt.%
Ettefaghi et al. (2013)	MWCNT -heat transfer oil (20 W50)	40 - 100 °C	0.1, 0.2, and 0.5 wt.%	Maximum thermal conductivity enhancement of 22.7 % at solid concentration of 0.5 wt.%	Maximum viscosity increase of 1.7 % @ T=40 °C and ϕ =0.5 wt.% and Maximum viscosity decrease of 0.25 % @ T=100 °C and ϕ =0.1 wt.%
Aberoumand et al. (2016)	Ag/heat transfer oil	40 - 100 °C	0.12, 0.36, and 0.72 wt.%	The Brownian motion is the responsible mechanism for the thermal conductivity enhancement by increasing the temperature	Maximum viscosity increase of 41 % @ T=25 °C and ϕ =0.72 wt.%
Ilyas et al. (2017)	MWCNT /heat transfer oil	25 - 90 °C	0 to 1 wt.%	The thermal conductivity of the pure oil decrease as the temperature increased. . The maximum enhancement was 28.7 % at the ϕ = 1 wt.% and T=60 °C	Non-linear decrease of the viscosity by increasing the temperature has been reported
Li et al. (2017)	SiC and TiO ₂ / oil	30 °C	0.025 to 0.3 vol.%	Adding 3 vol.% dispersant results in 5 % enhancement in the thermal conductivity	Both the studied nanofluids showed lower viscosity compared to the base fluid.
Wei et al. (2017)	SiC- TiO ₂ /Diat hermic oil	17 to 43 °C	0.1 to 1 wt.%	Maximum thermal conductivity enhancement of 8.39 % at T=43 °C and ϕ =1 vol.%	They reported an increasin trend in the dynamic viscosity by increasing the solid concentration and decreasing trend by increasing the temperature
Asadi et al. (2016)	MWCNT - MgO/Eng ine oil	20 to 50 °C	0.25 to 2 vol.%	Maximum thermal conductivity enhancement of 62 % at T=50 °C and ϕ =2 vol.%	Maximum viscosity increase of 65 % @ T=40 °C and ϕ =2 vol.% and minimum viscosity increase of 14.4 % T=25 °C and ϕ =0.25 vol.%
Asadi et al. (2018)	MWCNT - Mg(OH) ₂ /Engine oil	25 to 60 °C	0.25 to 2 vol.%	Maximum thermal conductivity enhancement of 50 % at T=60 °C and ϕ =2 vol.%	Maximum viscosity increase of 50 % @ T=60 °C and ϕ =2 vol.% and minimum viscosity increase of 5 % @ T=25 °C and ϕ =0.25 vol.%

Researchers widely reported that increasing the solid concentration of nanoparticles as well as the temperature leads to enhancing the thermal conductivity of nanofluids. Although the thermal conductivity and viscosity of nanofluids plays a crucial role in heat transfer enhancement, there is a limited number of studies devoted to investigating the thermal conductivity and viscosity of oil-based nanofluids. For example, Choi et al. (2001) reported that 1 vol.% of MWCNT based heat transfer oil nanofluids shows up to 150% enhancement in thermal conductivity compared to that of the pure oil. Liu et al (2005) showed 30 % enhancement in the thermal conductivity of synthetic engine oil in the presence of MWCNT at a volume fraction of 0.02 using a two-step method. Pakdaman et al. (2012) worked on thermo physical characteristics of MWCNT based heat transfer oil nanofluids in weight fractions of 0.1 %, 0.2 % and 0.4 % and they reported that the viscosity of nanofluid with 0.4% of weight concentration is 67 % greater than that of the base fluid at 40 °C, while the corresponding result for the enhancement of thermal conductivity is 15 % at 70 °C.

Aberoumand et al., (2016) recently reported their experimental data of conductivity and viscosity of Ag/TO nanofluids. They reported that the thermal conductivity of the base fluid showed a decreasing trend as the temperature increased, but the thermal conductivity of the nanofluids showed an inverse trend; it increases as the temperature increased. This increasing trend has been repeated for all the concentrations. They saw enhancements of around 40 % and 27 % for thermal conductivity and viscosity, respectively. In addition, they reported that the non-Newtonian behavior of their applied nanofluids was occurred for applied nanofluids.

Current experimental research prepares thermal oil-based nanofluids with different concentrations and types of nanoparticles. To explore the thermal performance of fluids containing nanoparticles and use them in a place of application, it is important to study their thermophysical properties deeply. Therefore, thermal conductivity and dynamic viscosity were measured and the effect of nature and the concentration of four types of nanoparticles (MWCNT, Ag, TiO₂ and ZrO₂) suspended in thermal oil were examined, analyzed and discussed.

2. METHODS

2.1 Materials

The TiO₂/TO and ZrO₂/TO nanofluids used in the present work were produced by *LIEC-UFSCar*, using the thermal oil (*LUBRAX UTILE OT* grade *ISO 100*), supplied by *PETROBRAS*. The diameter of the nanoparticles of TiO₂ and ZrO₂ are 5.85 nm and 1.13 nm, respectively. With the same oil as base fluid, the Ag/TO and MWCNT/TO nanofluids were synthesized in this work. Silver nanoparticles and multiple wall carbon nanotubes were purchased from the company *Nanostructured & Amorphous Materials, Inc.*, powder, without any surface treatment, both with spherical morphology, the diameter of the MWCNT being between 20-30 nm and of silver 80 nm.

2.2 Preparation of nanofluid

To prepare the nanofluids the two-step method is used as can be seen in detail in Fig. 1, which presents each of the steps performed for the production of the nanofluids. The routine applied begins with measuring and separating the masses base fluid (TO) and nanoparticles comply with previously established concentrations, the different mass fractions were suspended in the thermal oil (TO) and they were calculated using Eq. (1).

$$wt. \% = \frac{m_p}{m_p + m_f} \quad (1)$$

Where *wt* is the mass fraction of nanofluid, *m* is the mass and the subscripts *p* and *f* represent nanoparticle and base fluid, respectively. Table 3 shows the solid concentration values by nanoparticles used in this work.

Table. 3 Mass concentration of the four nanofluids used in this work.

Nanofluids	Mass concentration (wt.%)		
TiO ₂ /TO	0.10	0.50	1.00
ZrO ₂ /TO	0.10	0.50	1.00
Ag/TO	0.06	0.12	0.59
MWCNT/TO	0.01	0.02	0.12

In this process, the carbon nanotube nanoparticles from functionalized solution is first subjected to a process of drying for the separation of nanoparticles. The drying process is checked with the aid of a digital scale where the mass of the

dried sample is checked periodically until it reaches a stable value of the dry mass of nanoparticles. Next, the dry mass of nanoparticle is ground and sifted to powder form. Due to the high viscosity of the thermal oil a mechanical stirrer is used to facilitate dispersion of nanoparticles within the base fluid. A once this first process is completed, each sample is sonicated by applying a power of 750 W at a frequency of 20kHz. This sonication process is performed from 30 to 35 minutes. Once the sonication process is finished, the samples are submitted to a low power (50 W) and high duration (3 hours) ultrasonic bath sonication process. The mass concentration of the nanofluids are presented at the Tab. 3.

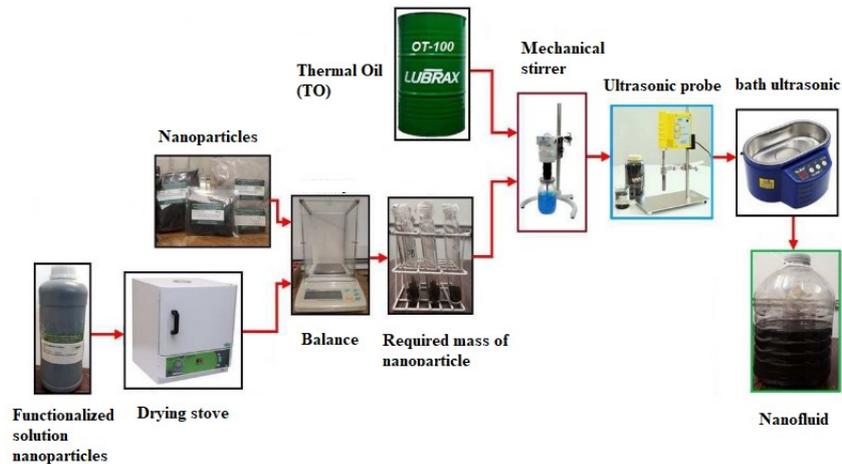


Figure 1. Nanofluid production process

2.3 Thermal conductivity measurement

The thermal conductivity of the nanofluids was measured using a conductivity meter from the company LINSEIS model THB-1, showed on Fig. 2-A, that uses the transient hot bridge method to determine the thermal conductivity of solid and liquid materials. It has uncertainty less than 3% of the measured value and full scale up to 1 W/m.K. The main components of the equipment are the probe, shown in Fig. 2-B, made of a kapton tape insulated nickel wire resistor that acts as a continuous heat source, and also serves as a temperature sensor.

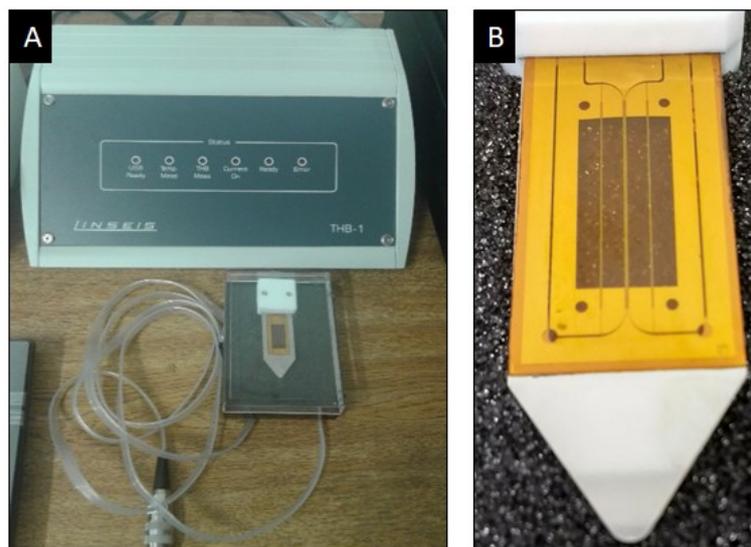


Figure 2. LINSEIS conductivity meter THB-1 and approximate view of the THB sensor.

The effect of the temperature was evaluated by means of a small vessel, designed to maintain a ~5 ml sample at constant temperature. There were used a tub that acts as a heat exchanger that receives heated water from a thermostatic bath that allows the control and keeps the temperature of the sample constant during the measurement. The thermostatic

bath used was MQBMP-01, it controls the temperature between 0 and 80 °C, with stability up to 0.02 °C and accuracy of 0.1 °C. The entire experimental apparatus is shown in Fig. 3, which contains the thermal bath used to ensure constant temperature, the stainless steel vat in which the nanofluid sample was placed, the conductivity meter and a computer with the data acquisition program. The probe is inserted into the nanofluid sample contained in the stainless steel vat attached to a thermal bath. Through software in a coupled computer, 10 measurements were performed per cycle, from 2 to 3 cycles per sample, by means of an automatic measurement.

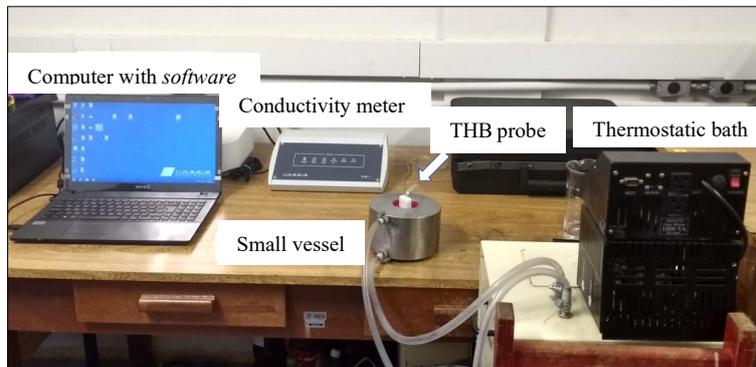


Figure 3. Experimental setup for measuring thermal conductivity of nanofluids.

In the present work, the tests were performed by varying the temperature in the interval of 10-60 °C, ranging from 10 at 10 °C.

2.4 Dynamic viscosity measurement

The dynamic viscosity was measured with the aid of a Stanbinger SVM 3000/G2 viscometer from Anton-Paar, with an accuracy of 0.1% and a measurement range between 0.2 and 20.000 mPa.s. This instrument has a Peltier cell that controls the temperature of the sample, allowing measurements from 10 °C to 100 °C with maximum stability of 0.005 °C and accuracy of 0.2 °C. Figure 4 shows the apparatus used for the measurement of dynamic viscosity.



Figure 4. Stabinger SVM 3000 / G2 viscometer used for dynamic viscosity measurements of nanofluids.

In order to evaluate the effect of temperature and nanoparticle concentration on the dynamic viscosity of nanofluids, four measurements were made for each condition, varying the temperature from 20 °C to 80 °C with 20 °C increments. Between the measurement of each nanofluid sample the viscometer was cleaned with soap and water, and before inserting the next fluid the base oil was injected into the viscometer to prevent water, soap, or other impurity from damaging the measurement.

3. RESULTS

3.1 Measurement of Thermal Conductivity

Experimental results of thermal conductivity were obtained for the nanofluid samples in oil, these were compared with data found in the literature and with mathematical models that predict the behavior of nanofluids.

Fig. 5 shows a comparison of the results obtained for Ag/TO thermal conductivity measurements with a model proposed by Xue (2006) presented in the Eq. (2), with the objective of validating and analyzing possible effects of interfacial layer, nanoparticle shape and the effect of concentration.

$$0 = 9 \cdot (1 - \phi) \cdot \frac{k_{nf} - k_{fb}}{2 \cdot k_{nf} - k_{fb}} + \phi \cdot \left[\frac{k_{nf} - k_b}{k_{nf} + 0.14 \cdot \frac{d_{np}}{l_{np}} \cdot (k_b - k_{nf})} + 4 \cdot \left(\frac{k_{nf} - k_a}{2 \cdot k_{nf} + 0.5 \cdot \frac{d_{np}}{l_{np}} \cdot (k_a - k_{nf})} \right) \right] \quad (2)$$

Where, k_a e k_b , are parameters, described by equations Eqs. (3) and (4), which represent the interfacial layer thermal conductivity associated with nanotube diameter and length, d_{np} e l_{np} , respectively.

$$k_a = \frac{k_{np}}{1 + 2 \cdot R_k \cdot \frac{k_{np}}{d_{np}}} \quad (3)$$

$$k_b = \frac{k_{np}}{1 + 2 \cdot R_k \cdot \frac{k_{np}}{l_{np}}} \quad (4)$$

The term R_k represents the thermal resistance of the interfacial layer. Using the value of $3 \cdot 10^{-8}$ for the MWCNT/TO nanofluid, and $3 \cdot 10^{-6}$ for the remaining nanofluids (Ag/TO, TiO₂/TO e ZrO₂/TO).

Furthermore, the data are also compared with the model presented by Maxwell (1873) presented in the Eq. (5). This model involves only the volume concentration of nanoparticles ϕ , the thermal conductivity of the nanoparticles k_{np} and of the base fluid k_{fb} .

$$\frac{k_{nf}}{k_{fb}} = 1 + 3\phi \cdot \frac{k_{np} - k_{fb}}{2k_{fb} + k_{np} - \phi(k_{np} - k_{fb})} \quad (5)$$

The results obtained by Aberoumand et al. (2016) under the same temperature conditions (40.0, 50.0 and 60.0 °C) varying the mass concentration of the samples were exhibited in the graph as well.

Therefore, it is possible to verify in Fig. 5 that, among the increments obtained in this work, the most significant was obtained for the temperature of 40 °C in the mass concentration of 0.12%, reaching approximately 3% improvement over the base oil in the same temperature. In addition, it is evident that the presented data have a maximum point, from which the addition of silver nanoparticles becomes disadvantageous; this point would be close to 0.1% of mass concentration.

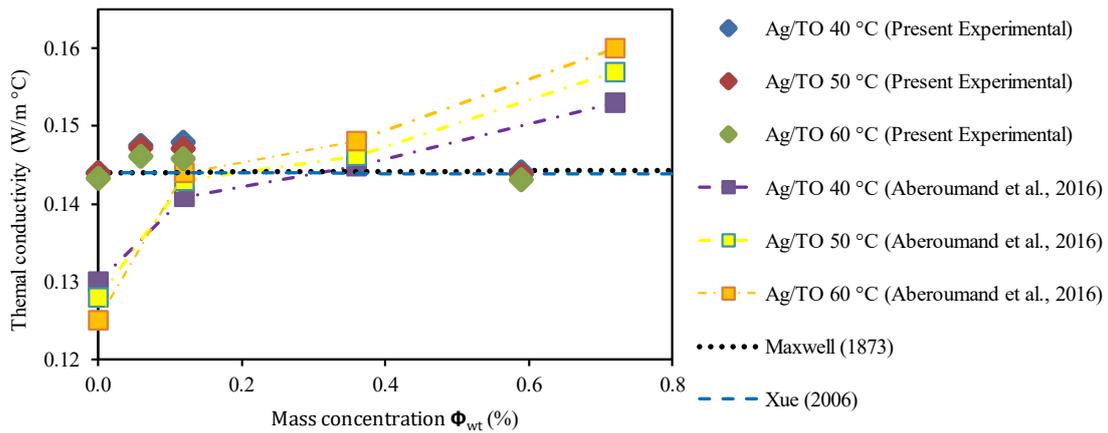


Figure 5. Thermal conductivity of Ag/TO nanofluids of the present experiment compared to data obtained by Aberoumand et al. (2016) as a function of the mass concentration, at 40, 50 and 60 °C.

In other hand, the thermal conductivities of the four nanofluids studied in the present experiment relative to the pure oil are shown in Fig. 6, varying the mass concentrations, all for the 40.0 °C temperature condition.

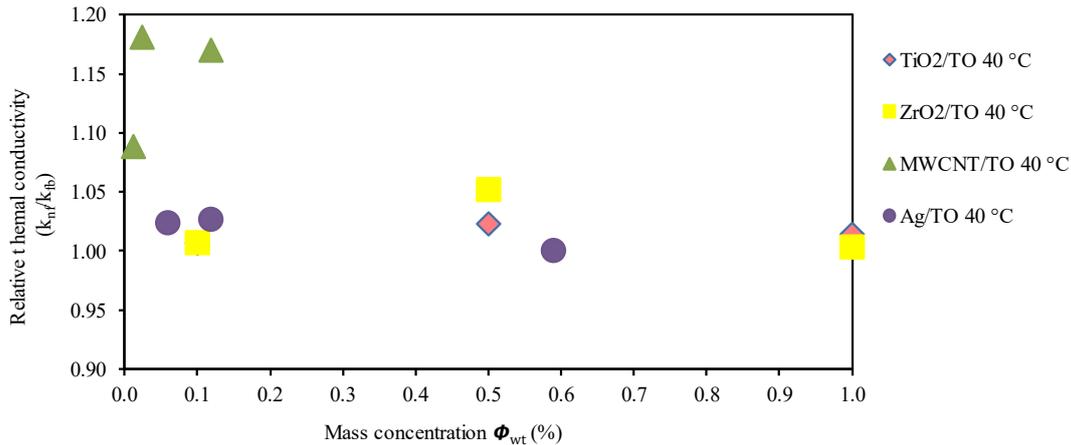


Figure 6. Thermal conductivity of the nanofluids tested in the present work as a function of the mass concentration, at 40 °C.

As expected, the relative thermal conductivity of all the tested nanofluids were higher than one, which means that the four types of nanoparticles enhanced the thermal conductivity of the pure oil. Furthermore, the nanoparticle that generated the best thermal conductivity results comparing to the results of the base fluid was that of carbon nanotubes, in the mass concentration of approximately 0.02%, reaching about 18% of increment, as in the work presented by Pakdaman et al. (2012) for the same mass concentration of MWCNT in oil. However, the results showed for approximately 0.1% of mass concentration, reaching just over 15% increment, were significantly lower than that presented by Ilyas et al. (2017), that founded 28.7% increase over base fluid for MWCNTs / thermal oil nanofluids with 0.1% nanoparticle mass concentration. Note that, different from some affirmations made by several authors, that the thermal conductivity of the nanofluids increase with the addition of nanoparticles (Ahmadi et al., 2018), for all nanofluids in this study the addition of nanoparticle reaches a point of maximum increase in relative thermal conductivity and then begins to fall. For the nanofluids of TiO₂ and ZrO₂ this mass concentration is close to 0.5%, while for MWCNT and Ag it is about 0.02% and 0.1%, respectively.

3.2 Measurement of dynamic Viscosity

The experimental results found for the dynamic viscosity of oil nanofluids were compared with data found in the literature and with mathematical models that predict the behavior of nanofluids. Therefore, Fig. 7 and Fig. 8 makes a comparison between the relative viscosity as a function of temperature, for Ag/TO and MWCNT/TO nanofluids tested in the present work with data obtained by Aberoumand et al. (2016) and Ilyas et al. (2017), respectively. The mass concentrations of the review silver nanofluids ranged from 0.12 % to 0.72 %, and MWCNT nanofluids in the range 0.1% to 1 %.

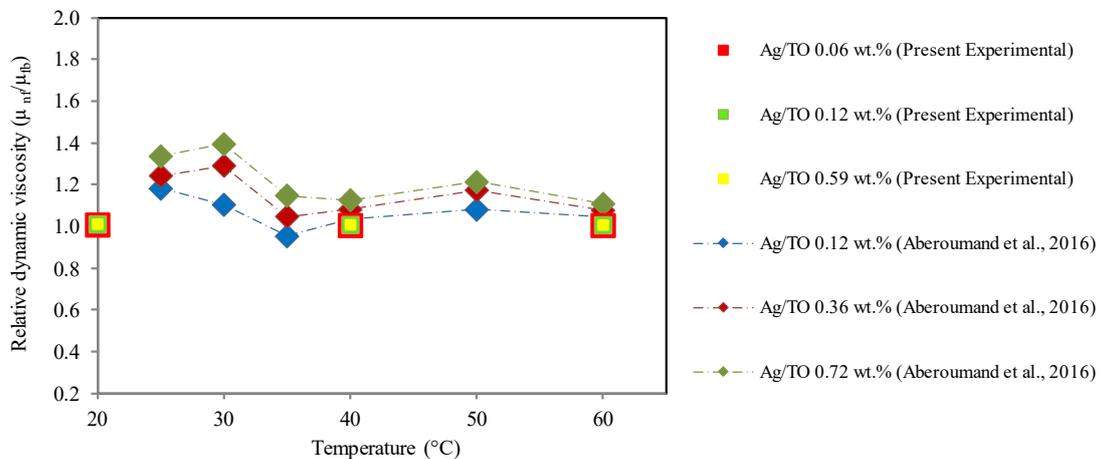


Figure 7. Relative viscosity of Ag/TO nanofluid compared to data obtained by Aberoumand et al. (2016) as a function of temperature.

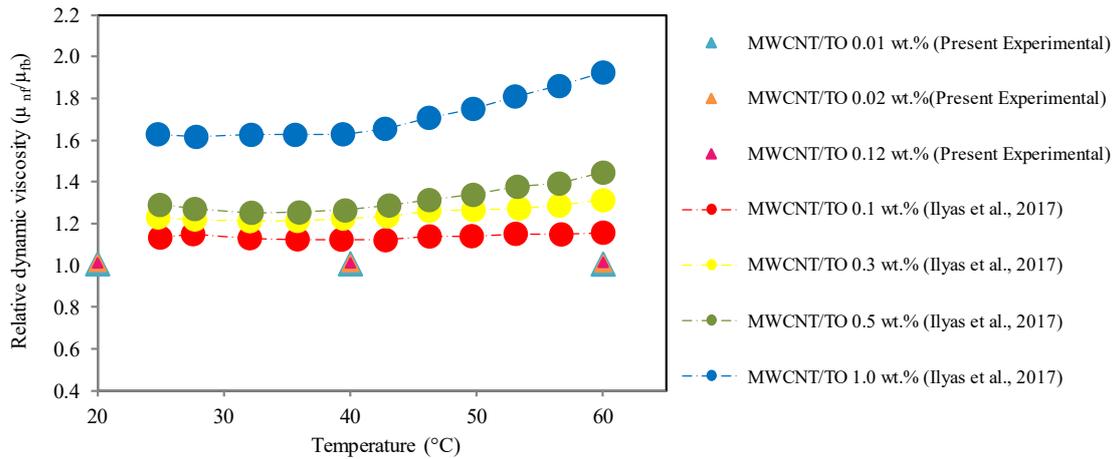


Figure 8. Relative viscosity of MWCNT/TO nanofluid compared to data obtained by Ilyas et al. (2017) as a function of temperature.

Therefore, when comparing the results obtained in each work, it can be noted that, differently of what can be seen for the data of both reviews, where there was an evident increment tendency in dynamic viscosity with the increase of temperature, mainly for nanofluids with higher mass concentrations (Ilyas et al., 2017), the dynamic viscosity of the tested nanofluids did not vary significantly compared to the pure oil for all the temperature conditions.

Furthermore, the Fig. 9 compares the results obtained for the dynamic viscosity measurements of Ag/TO, MWCNT/TO, ZrO₂/TO and TiO₂/TO nanofluids under the same temperature conditions (40.0 °C) with Einstein's model (Einstein, 1906), presented in the Eq. (6), used to determine the viscosity of diluted suspensions with volume concentrations of less than 5%.

$$\mu_{nf} = (1 + 2,5\phi)\mu_{fb} \tag{6}$$

The data were arranged in order to analyze the relative viscosity as a function of the mass concentration of nanoparticles. Thus, it is possible to verify that the zirconium nanofluids and carbon nanotubes showed an increasing trend in relative viscosity with the increment of nanoparticles, in addition to the fact that all the samples exhibited viscosity close to the base fluid, with the highest increase observed in MWCNT/TO in the mass concentration of 0.12%, presenting little more than 1% increase. However, zirconium dioxide and titanium nanofluids showed lower dynamic viscosity results than pure thermal oil. This effect may be associated with the possibility that thermal oil-based nanofluids exhibited some non-Newtonian fluid behavior characteristic that changed viscosity as a function of shear stress.

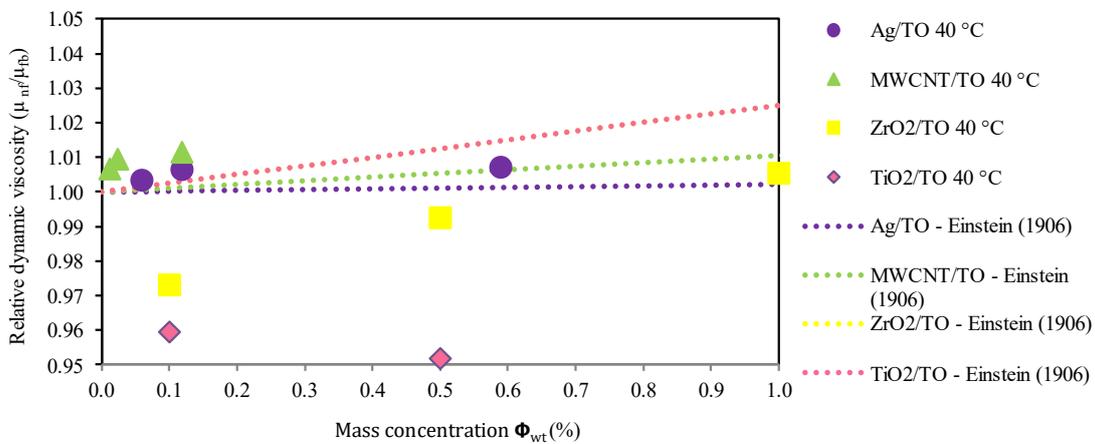


Figure 9. Relative viscosity of the nanofluids of the present work as a function of the mass concentration, at 40 °C.

4. CONCLUSIONS

In order to improve the thermo-physical properties of conventional fluids for heat transfer application, this study investigated the thermal conductivity and rheological behavior of different nanofluids. In the experiment, the nanofluids were prepared by two step methods. The stabilized nanofluids were measured in thermal conductivity and dynamic viscosity. The results show that with increasing volumetric fraction, the thermal conductivity value of nanofluids becomes larger, until a certain point that the maximum enhance is reached and this property fstart to suffer a decrease with the increment of nanoparticles. Therefore, the maximum increases in thermal conductivity of the studied nanofluids were found at MWCNT/TO, reaching approximately 18% compared to the pure oil, in the mass concentration of approximately 0.02%. Among the increments obtained at thermal conductivity of Ag/TO, the most significant was approximately 3% improvement over the base oil, at the temperature of 40.0 °C in the mass concentration of 0.12%. Furthermore, the dynamic viscosity of the tested nanofluids did not vary significantly compared to the pure oil for all the mass concentration and temperature conditions. And the greatest increase of the dynamic viscosity was registered for MWCNT nanofluids.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of CAPES, FAPEMIG and CNPq.

6. REFERENCES

- Aberoumand, H., Jafarimoghaddam, A., Javaherdeh, K., Moravej, M., and Aberoumand, S. "Experimental study on the rheological behavior of silver-heat transfer oil nanofluid and suggesting two empirical based correlations for thermal conductivity and viscosity of oil based nanofluids". *Appl. Therm. Eng.*, vol. 101, pp. 362–372, 2016.
- Ahmadi, M. H. et al. "A review of thermal conductivity of various nanofluids". *Journal of Molecular Liquids*, v. 265, p. 181–188, 2018.
- Asadi, M. Asadi, M. Rezaei, M. Siahmargoi, F. Asadi, "The effect of temperature and solid concentration on dynamic viscosity of MWCNT/MgO (20-80)-SAE50 hybrid nano-lubricant and proposing a new correlation: An experimental study. *Heat and mass transfer*. 2016
- Asadi, A. et al. "Heat transfer efficiency of Al₂O₃-MWCNT/thermal oil hybrid nanofluid as a cooling fluid in thermal and energy management applications: An experimental and theoretical investigation". *Int. J. Heat Mass Transf.* vol. 117, pp. 474–486, 2018.
- Choi, S. U. S.; Eastman, J. A. "Enhancing thermal conductivity of fluids with nanoparticles". *ASME International Mechanical Engineering Congress and Exposition*, v. 66, n. January 1995, 1995.
- Choi, S. U. S.; Eastman, J. A. "Anomalous thermal conductivity enhancement in nanotube suspensions". *ASME International Mechanical Engineering Congress and Exposition*, 2001.
- Einstein, A. Eine neue Bestimmung der Moleküldimensionen. *Annalen der Physik*, v. 324, n. 2, p. 289–306, 1906.
- E. Etefaghi, H. Ahmadi, A. Rashidi, A. Nouralishani, S.S. Mohtasebi, "Preparation and thermal properties of oil-based nanofluid from multi-walled carbon nanotubes and engine oil as nanolubricant, *int. Commun. Heat and mass transf.* 2013
- Ilyas, S. U.; Pendyala, R.; Narahari, M. "Stability, rheology and thermal analysis of MWCNT-thermal oil-based nanofluids". *Colloids Surfaces A Physicochem. Eng. Asp.* vol. 527, no. March, pp. 11–22, 2017.
- Maxwell, J. C. "A treatise on electricity and magnetism". An unabridged republication of the last. *Journal of the Franklin Institute*, v. 258, n. 6, p. 534, December 1873. ISSN 0016-0032.
- W. Li, C. Zou, X. Li, "Thermo-physical properties of waste cooking oil-based nanofluids". 2017
- Liu, M., Cheng, M.; Huang. T.; Wang, C. "Enhancement of thermal conductivity with carbon nanotubes for nanofluids". *International Communications in Heat Mass Transfer*, v.32, n.9, p.1202-1210, 2005.
- Pakdaman, F. M.; Akhavan-Behabadi, M. A.; RAZI, P. "An experimental investigation on thermo-physical properties and overall performance of MWCNT/heat transfer oil nanofluid flow inside vertical helically coiled tubes". *Exp. Therm. Fluid Sci.* vol. 40, pp. 103–111, 2012.
- Saeedinia, M.; Akhavan-behabadi, M. A.; Razi, P. "Thermal and rheological characteristics of CuO-Base oil nanofluid flow inside a circular tube". *International Communications in Heat and Mass Transfer*, v. 39, n. 1, p. 152–159, 2012.
- Xue, Q. Z. "Model for thermal conductivity of carbon nanotube-based composites". *Nanotechnology*, v. 17, n. 6, p. 1655–1660, February 2006. ISSN 0957-4484.

Ítalo Franco Guilherme, Daniel Alberto Flórez Morales, Abdul Orlando Cárdenas Gómez, Enio Pedone Bandarra
Effect of the type and concentration of nanoparticles on the heat transfer properties of nanofluids

Wei, B.; Zou, C.; Li, X. “Experimental investigation on stability and thermal conductivity of diathermic oil based TiO₂ nanofluids”. *Int. J. Heat Mass Transf.* vol. 104, pp. 537–543, 2017.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.