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Experimental investigation on viscosity and density of MWCNT- Transformer oil nanofluid : Developed a new correlation

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ABSTRACT

In the present study, the dynamic viscosity and density of multi-wall carbon nanotube (MWCNT) nanoparticles and transformer oil at 0.05 to 0.8 wt% and room temperature are investigated. The carbon nanotubes were functionalized by carboxyl groups (-COOH) and also sodium dodecyl sulfate (SDS) surfactant was used to stabilize the nanoparticles in the base fluid. The inner diameter and length of the nanoparticles are between 10-20 nm and 3-8 µm respectively and purity is 98%. A correlation for the dynamic viscosity and density relative to the weight fraction of nanoparticles at ambient temperature is proposed, which indicates that viscosity and density increase with increasing the weight fraction, and the highest enhancement of dynamic viscosity and density are 21% and 2%, respectively. Dynamic viscosity at various shear stress and speeds also are investigated and the results show that with increasing shear stress, the viscosity increases about an average of 40.9%. The results were compared with other existing models to evaluate the accuracy of the results and, a review of other research on the nanofluid viscosity and density is done and their results are mentioned.

1. Introduction

A fluid containing nanoparticles is called nanofluid and these fluids are obtained by colloidal particles of nanosize dimensions in a base fluid. Nanoparticles that use in nanofluids generally are metals, oxides, carbides, or carbon nanotubes and the base fluids most commonly are water, ethylene glycol, and oil. Nanofluids have new features that make them useful for heat transfer applications, and knowledge of the rheological behavior of nanofluids is crucial for deciding whether nanofluids are suitable for heat transfer applications. Nanofluids are considered single-phase fluids in computational fluid dynamics (CFD) analysis, however new papers include a two-phase assumption. When the physical properties of nanofluid can be a function of both the base fluid composition and the nano-particles, the theory of the single-phase assumption of nanofluid can be used. The movement of nanoparticles has a significant effect on the rheology and thermophysical properties of nanofluids, so investigating the movement of nanoparticles is essential to evaluate their performance when being added to the base fluid in the heat transfer medium. Fewer studies have been done on the viscosity and density of nanofluids than on thermal conductivity, and studies have shown that the viscosity and density of nanofluids are higher than base fluids, and that the viscosity and density, like the thermal conductivity coefficient, are directly related to the concentration, temperature, and other physical characteristics of the nanoparticles.Vakili-Nezhaad & Dorani in their study examined the viscosity of carbon

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nanotubes-lube oil nanofluid and observed a 33% enhancement [1]. Hammett et al. investigated the hybrid nanofluid viscosity of multiwall carbon nanotubes and silicon dioxide in SAE40 base fluid that volume fraction range was between 0 to 2% and their results showed that up to 1% nanofluid concentration shows Newtonian behavior and non-Newtonian behavior in higher volume fraction and with increasing volume fraction, the nanofluid viscosity increases [2]. In an experimental study, Chandrasekar et al. studied the dynamic viscosity of aluminum-water nanofluid and measured the dynamic viscosity of nanofluids at ambient temperature and different volume fractions and founded that as the volume fraction increases, the dynamic viscosity increases significantly. In addition, they proposed a correlation to estimate the dynamic viscosity of water-aluminum oxide nanofluids [3]. Lee et al. in their study examined the water-aluminum oxide nanofluids and concluded that there is a nonlinear relationship between nanofluid dynamic viscosity and volume fraction, especially in low volume fractions [4]. Table 1 presents some of the models used to determine the viscosity of nanofluids and their conditions.

Table 1- Overview of viscosity models of nanofluids

Ref.	**B. F**	**N. P**	**Vol %**	**Size (nm)**	**Model**
[1]	Lube oil	CNT	0.01-0.2	2	$\mu_{nf}=\mu_0(1+1.59\emptyset-16.36\emptyset^2+50.4\emptyset^3)$
[5]	Water	AL_2O_3	0.33-5	43	$\mu_{nf}=\mu_0(1+A\left(\frac{\emptyset}{1-\emptyset}\right)^n)$
[6]	EG/ Water	CUO	1-6.12	29	$Log(\mu_{nf})=1.8375\emptyset^2-29.643\emptyset+165.56\exp(-BT)$ $B=4*10^{-6}\emptyset^2-0.001\emptyset+0.00186$
[7]	Water	TiO_2	0.01-1	21-60	$\mu_{nf}=\mu_0(1+A\emptyset+B\emptyset^2)$
[8]	Gear oil	CUO	0.5-2.5	40	$\mu_{nf}=\mu_0(1-\frac{\emptyset}{0.5}\left(\frac{a_0}{a}\right)^{1.3})^{-1.25}$
[9]	EG	TiO_2	0-0.8	25	$\mu_{nf}=\mu_0(1+10.6\emptyset+(10.6)^2)$
[10]	Furfuryl alchol	NiO	0-40	-	$\mu_{nf}=\mu_0(1+2.5\emptyset+A\emptyset\left(\frac{\emptyset}{\emptyset_m-\emptyset}\right)^2)$
[11]	Water	AL_2O_3	0.15-13	47,36	$\mu_{nf}=\mu_0*0.904e^{0.1483\emptyset}$ $\mu_{nf}=\mu_0(1-0.025\emptyset+0.015\emptyset^2)$
	Water	CuO	0.15-12	29	$\mu_{nf}=\mu_0(1.475-0.319\emptyset+0.051\emptyset^2+0.009\emptyset^3)$
[12]	Ethanol	SiO_2	0-6	190	$\mu_{nf}=\mu_0(1+8.3\emptyset)$
[13]	Terpineol	Ni	3-10	300	$\mu_{nf}=\mu_0*0.4513e^{0.6965\emptyset}$
[14]	Water	Fe_3O_4	0-2	13	$\mu_{nf}=\mu_0(1+\frac{\emptyset}{12.5})^{6.356}$
[15]	Glycerol	Fe_2O_3	0.125-0.75	25-50	$\mu_{nf}=\mu_0*A*\exp(\frac{B}{T+T_0})$
[16]	Water	AL_2O_3	0-6	-	$\mu_{nf}=\mu_0(1+7.3\emptyset+123\emptyset^2)$

[17]	Water	TiO_2	5-12	7-20	$\mu_{nf} = \mu_0 * 13.47e^{35.98\emptyset}$
[18]	Water	AL_2O_3	0-10	-	$\mu_{nf} = \mu_0(1 + 39.11\emptyset + 533.9\emptyset^2)$

Despite the researchers' efforts to date to establish a precise formula for determining the viscosity of nanofluids, no comprehensive and unified equation for determining the thermophysical properties of nanofluids has been established, and the equations presented vary depending on the type of base fluid, as well as its concentration and temperature. However, investigations on models reveal that in nanofluids including spherical and cylindrical nanoparticles, the ratio of nanofluid to base fluid thermal conductivity increases as the concentration and temperature of the nanoparticles increases, as does the viscosity ratio of nanofluid to base fluid.Indhuja et al. investigated the effect of multiwall CNTs on the viscosity of nanofluids and observed that multiwalled carbon nanotubes prepared by acid-functionalized method have a lower viscosity than multiwall carbon nanotubes [19]. Abbasi et al. simulated the role of base fluids type and nanoparticle shape on nanofluid density and founded that the particle shape is more important than the base fluid type. They studied rod-shaped, block, planar and spherical particle on water and argon base fluid and reported that planar nanoparticle has the highest density and with increasing diameter, the density of spherical and planar shape nanoparticles increases [20]. Said et al. synthesized rGO/Co_3O_4 and examined the role of temperature and concentration on density at temperature range of 20-60 °C and weight fraction of 0.05%, 0.1% and 0.2 wt% and also reported that density was increased 0.115%, 0.23%, and 0.451% at 0.05%, 0.1% and 0.2% concentration respectively [21]. In other research, Sharifpur et al. experimentally studied the role of nanolayer on the density of SiOx-EG/water, CuO–glycerol, SiO_2–water and MgO–glycerol nanofluids at the temperature range of 10 to 40 °C and volume concentration of 1% to 6%. They stated that nanolayer has a significant effect on density more than base fluid type and size [22]. The lack of study on density and viscosity was felt due to the engineering and industrial applications of this nanofluid. The goals of the present research are studying the nanoparticles loading on viscosity and density of MWCNT- Transformer oil nanofluid and present correlations for estimating them. So the functionalized multiwall carbon nanotube with carboxylic acid was added on transformer oil, and viscosity and density of nanofluid were determined.

2. Experimental

Multilayer carbon nanotubes are purchased by US Research Nanomaterials and have an inner diameter of 10-20 nm and a length of 3-8 µm and purity of over 98% and the amount of carboxyl groups is 2-4 Wt%. Infrared spectroscopy was used to identify the functional groups and Fig.1 shows FTIR analysis and is commonly used to study functionalization. The rate of functionalization of carbon nanotubes changes their wettability in different surfactants and alter their toxicity. The base fluid, which is the transformer oil in this research, was purchased from Eram Chemical Company of Azerbaijan. Results show that there are nine peaks, the peak of 1459 cm^{-1} related to the carbon nanotubes, as well as the presence of bending O-H having moderate bond strength indicating the initiation of carboxylic group formation due to surface oxidation. Because carboxylic acids occur around 2500 and 3300 cm^{-1}, the presence of peaks at 2726, 2856, and 2924 cm^{-1} indicates these groups, which form a strong bond, as well as the peak at 1605 cm^{-1}, which implies C=C stretching, indicating the nanofluid's industrial uses. The purpose of this study is to examine the influences of nanoparticles on the viscosity and density of MWCNT-Transformer oil nanofluid, as well as the current correlations for estimating them. The viscosity and density of the nanofluid were assessed when a functionalized multiwall carbon nanotube containing carboxylic acid was added into transformer oil.presence of carbon double bonds and is related to the aromatic ring. The peak of 1160 cm^{-1} is due to the strong bond between C-O and peak 812 cm^{-1} is to C = C bending and peak 727 cm^{-1} is to the strong bond C=C. Peaks at 1449 and 1605 cm^{-1} related to MWCNT vibration modes. G-band is the most intensive mode of CNTs which is observed at ~1600 cm^{-1} and the atomic disarticulation occurs along the circumferential direction in this mode. On the other hand, the presence of G-band after functionalization indicates that the structure of the nanotubes is preserved. Carbon nanotubes showed a decrease in G band intensity after oxidation and this may be due to the proper attachment of oxygen-based functional groups to the nanotube surface. Chemically functionalized nanotubes exhibit hydrophilic behavior because the acid cleaning process results in the formation of OH groups on the surface of the nanotubes leading to hydrogen bonding with water molecules. Therefore, according to FTIR analysis, the formation of O-H, C-O, and C-H functional on the surface of carbon nanotubes was confirmed and the desired functional groups were created.

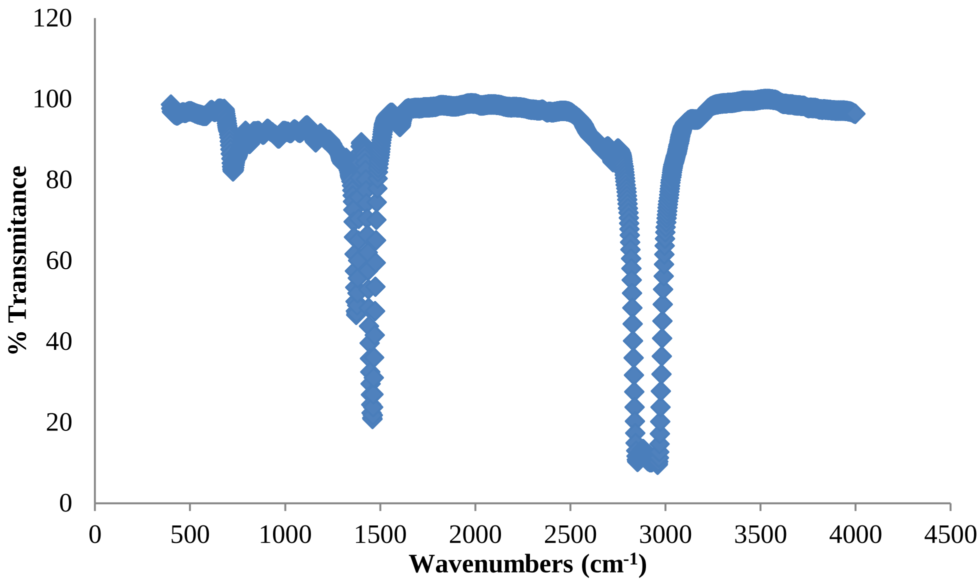

Fig 1- MWCNT COOH FTIR spectra result

The results of TEM and SEM of nanoparticles are shown in Figures 2.a and 2.b, respectively. The most common method for determining the morphology and dimensions of multiwall carbon nanotubes is scanning electron microscopy, which is currently being used to determine the overall morphology of multiwall carbon nanotube samples, quantify the purity of the samples, and characterize the nanotube dimensions. Transmission electron microscopy (TEM) is one of the most efficient methods for determining particle size, providing both quantitative and qualitative data. The nanoparticles have a length of 10-30 m and a diameter of 20-30 nm, according to the findings.

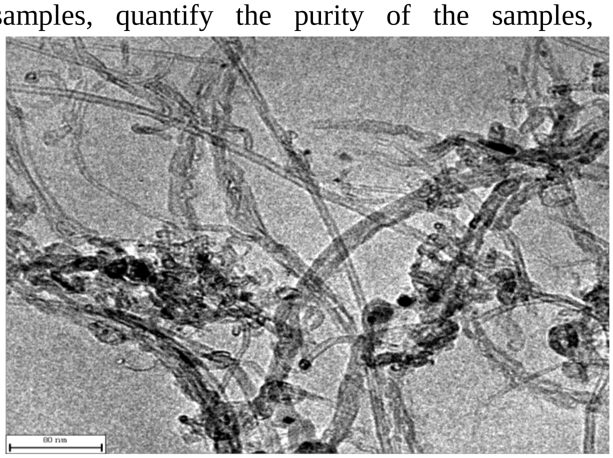

Fig. 2.a- TEM result

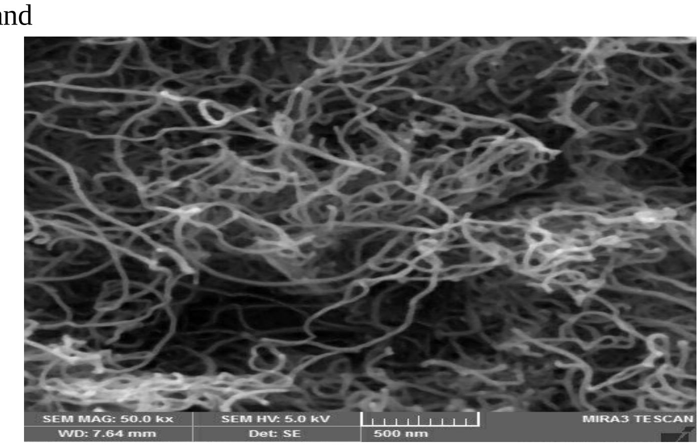

Fig. 2.b- Results of SEM

Raman spectrometry is a common way to determine chemical bonds. Although it is difficult to accurately measure the amount of a link or function group in a sample by this method, it can be used to check for the presence or absence of a link or group of functions or to compare that link with a sample. In a Raman spectrometer, a laser beam is emitted into the sample and a wavelength detector records the intensity and intensity of the radiation emitted from the sample. The difference between the wavelengths encountered in the sample and the wavelengths emitted from it is slightly different. This difference is due to the effect of the bond on light energy. Therefore, by measuring the difference between the input and output wavelengths of the sample and its output, the type of bonds in the sample can be determined. Fig.3 presents the result of the Raman test and the first spectrum shows a major peak at around 1300 cm^{-1} which is indicative of sp^3 bonded carbon and this is characteristic of graphite like and the second spectrum shows a major peak at around 1600 cm^{-1} which shows the presence of graphite or sp^2 carbon.

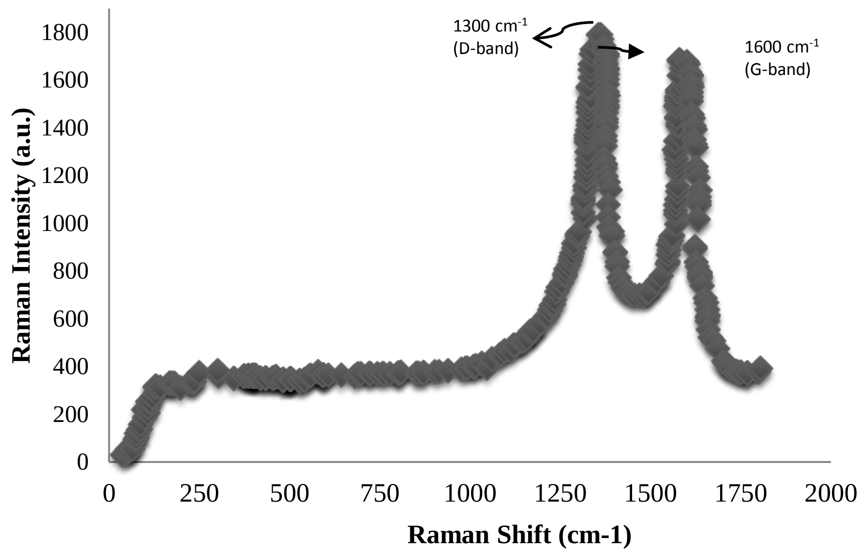

Fig. 3- Raman Spectrum of MWCNTs

2.1. Nanofluid preparation

A two-step method was used to prepare the samples, which a certain amount of MWCNT-COOH nanoparticles were added to transformer oil and then the samples were placed on a magnetic stirrer for 1 hour and after that 15 minutes into the ultrasonic bath to disperse the nanoparticles and finally, the SDS surfactant at a weight ratio of 2:1 was used and placed on a magnetic stirrer for 1 hour again. Fig.4 shows the nanofluid fabrication and formula 1 was used to determine the weight fraction of carbon nanotubes:

$$\emptyset_m = \frac{m_{CNT}}{m_{CNT} + m_{OIL}} * 100 \qquad (1)$$

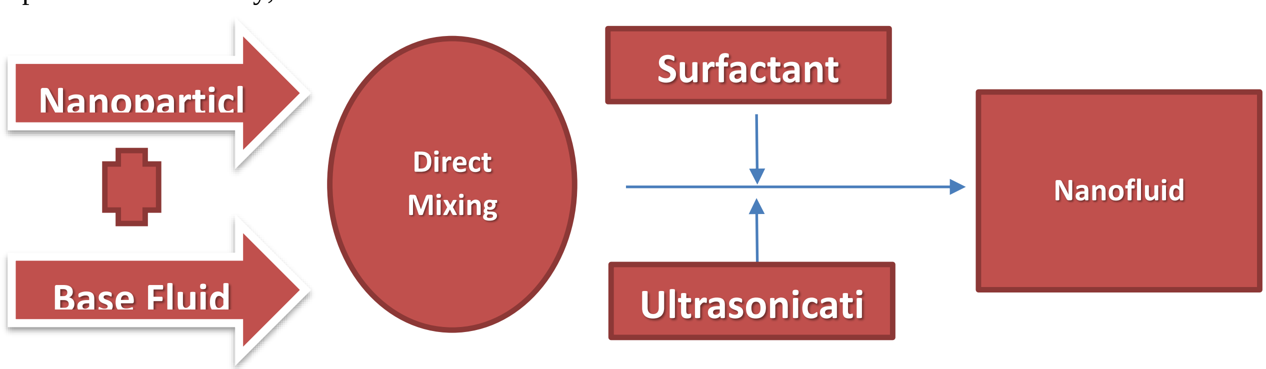

Fig. 4- Nanofluids fabrication procedure

3. Results

UV–visible spectroscopy was used to measure the wavelength of absorption, identify the compound's stability, and quantitative estimation of nanoparticle dispersions. As light passes through the sample, the sample absorbs certain wavelengths, which reduces the intensity of some wavelengths in the light emitted from the sample. There are a number of absorption mechanisms in each substance, each of which can absorb a specific wavelength. Fig.5 shows UV-visible spectra results of base-fluid and nanofluid. The highest peak is approximately around 5% and experiments were done at a wavelength of 190 to 450 nm. In conventional cells electrode spacing is large, and liquids of very low dielectric constant like transformer oil applied electric field is so weak that particles do not move in the field. As a result, it is recommended that for dark colores samples, UV- visible test may not be a suitable test. Moreover, by diluting the samples for stability tests is erroneous, because nanofluid is colloids, and colloids are a very delicate and complicated system. The aggregation of particles is not directly proportional to the concentration. Hence, diluting the samples for UV measurements will be very tricky and misleading and it is not recommended.

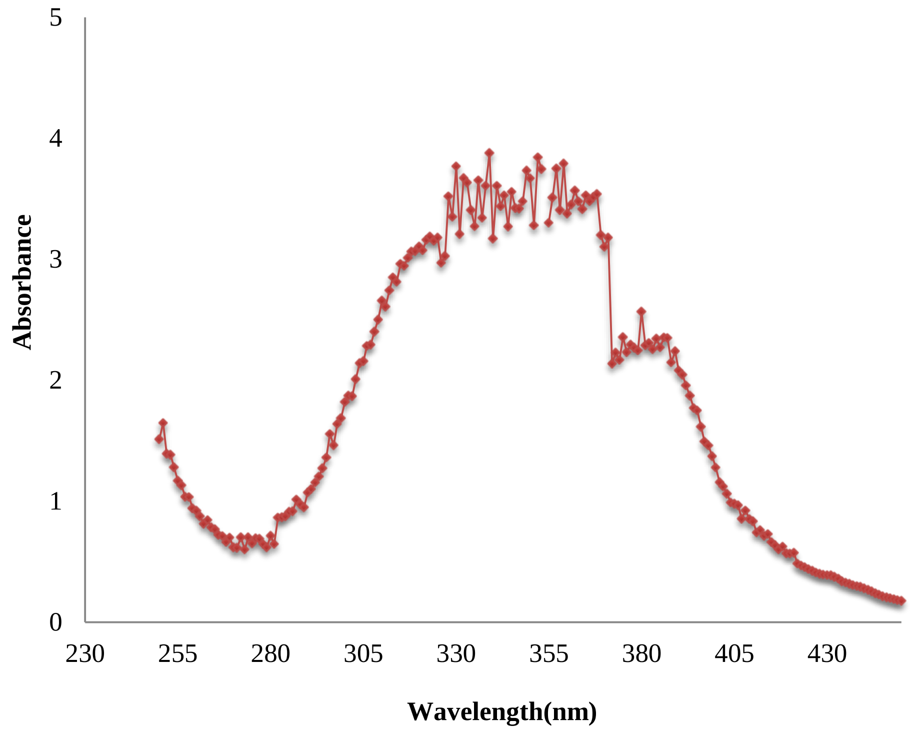

Fig. 5- Uv-visible result of nanofluid

The Brookfield viscometer was used to measure the nanofluid viscosity and the Archimedes law and solid metal cylinders were used to determine the density of nanofluid. The influence of carbon nanotube nanoparticles on transformer oil-based nanofluid viscosity at ambient temperature is investigated, and a graph of dynamic viscosity variations relative to the weight fraction is plotted. In the studied range, a 21% enhancement in viscosity was observed, which is consistent with other studies on nanofluid viscosity [23-31]. As shown in Fig.6, it is observed that with increasing particle loading, the dynamic viscosity also increases and the highest viscosity enhancement is for weight fraction at 0.8 wt%. The viscosity of nanofluids is determined by their geometry and surface properties, and particle aggregation raises viscosity due to structural limitations for Brownian, rotational, and transient motions, according to the study. Increasing viscosity affects heat conductivity and fluid flow characteristics, and a tiny relative increase in viscosity implies that particles do not accumulate in the base fluid; in this case, a modest rise suggests no accumulation of nanoparticles.

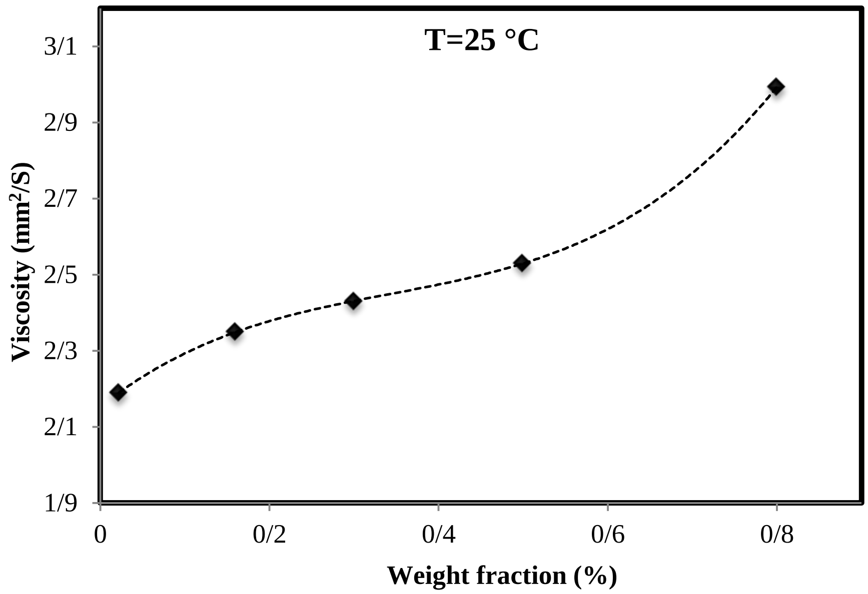

Fig. 6- The effect of carbon nanotubes on the viscosity of the transformer oil verss weight fraction

A correlation is shown in this paper to predict the nanofluid viscosity by fitting the experimental data, which is in agreement with Equation 2:

$$\mu_{eff} = 3.704\,\varphi^3 - 3.824\varphi^2 + 1.737\,\varphi + 2.158 \quad R^2 = 1 \qquad (2)$$

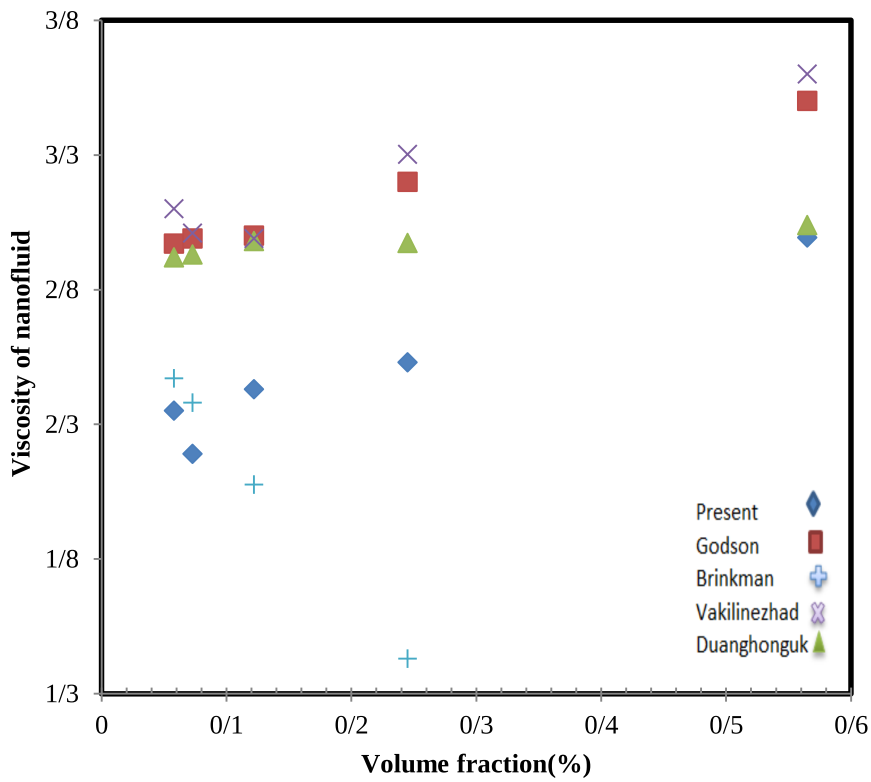

Fig. 7- Comparison between nanofluid viscosity results

Fig.7 also shows a comparison of the results obtained with other experimental investigations in the field of nanofluid viscosity. Although every experimental research and the type of nanofluids and nanoparticles used should be investigated and there is no single model for predicting the viscosity of nanofluids, the trend of changes can be compared.

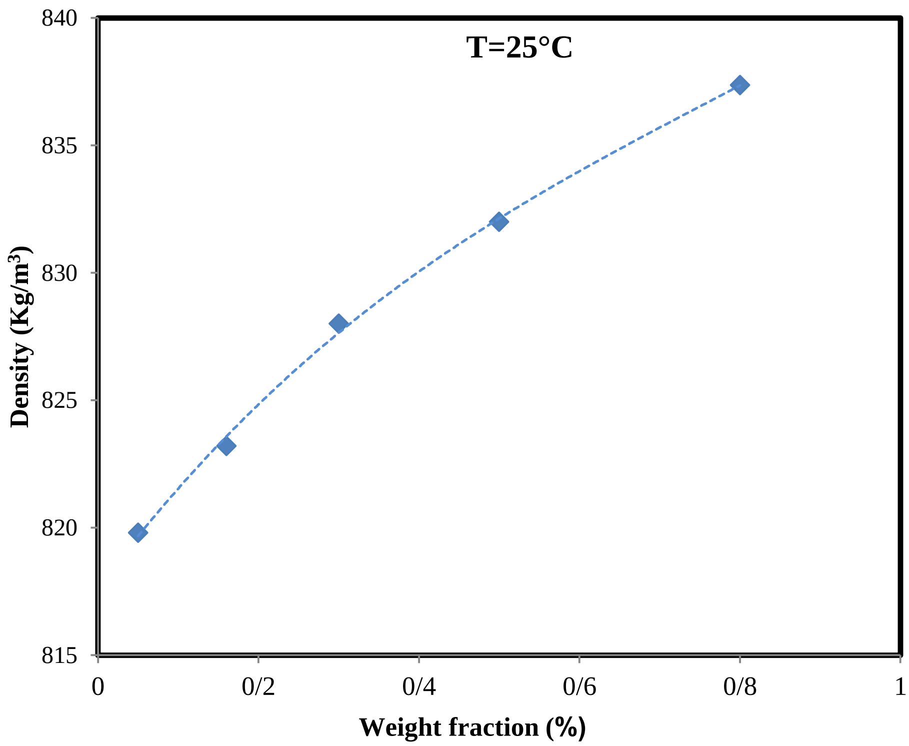

Fig. 8- Effect of carbon nanotubes concentration on nanofluid density

Fig. 8 shows the density changes versus weight fraction at ambient temperature and the results show that the density enhancement is very low relative to the base fluid and enhancement of about 2% was observed in the study range and by increasing the weight fraction also density increased.

By fitting the experimental data obtained through the experiment, a correlation can be proposed to predict the nanofluid density behavior obtained in this study (Eq. 3):

$$\rho_{eff} = 14.514\varphi^3 - 33.33\varphi^2 + 41.99\varphi + 817.65 \qquad R^2 = 0.998 \qquad (3)$$

Density is a crucial feature of oils and other fluids that are utilized in various viscosity calculations and plays a vital part in natural heat transfer because density is the source of natural convection and gradient force.

Because viscosity is the only important attribute of oil, the density must be calculated before any mathematical computations involving this parameter. As the density of an oil increases, the fluid thickens, lengthening the time necessary for suspended particles to settle. To improve the ability to suspend, transport, and remove particles of certain specific contaminants, high-density fluids are more prone to become polluted.

By increasing shear stress from 36.88 to 7.2 D/cm^2, the dynamic viscosity decreases approximately 40.9% and for a sample of 0.8 %wt, viscosity changes from 18.7 to 14.5 cP.

Nanofluid and base fluid show non-Newtonian behavior and their viscosity do not depend on the time of shear stress and depend only on the magnitude of the shear force and shear stress. Fig.9

presents the viscosity of the nanofluids and base fluid versus shear stress at various weight fractions and it is observed that, as the weight fraction of nanofluids increases, the dynamic viscosity of nanofluids also increases that the highest value was obtained at the weight fraction of 0.8 %wt.

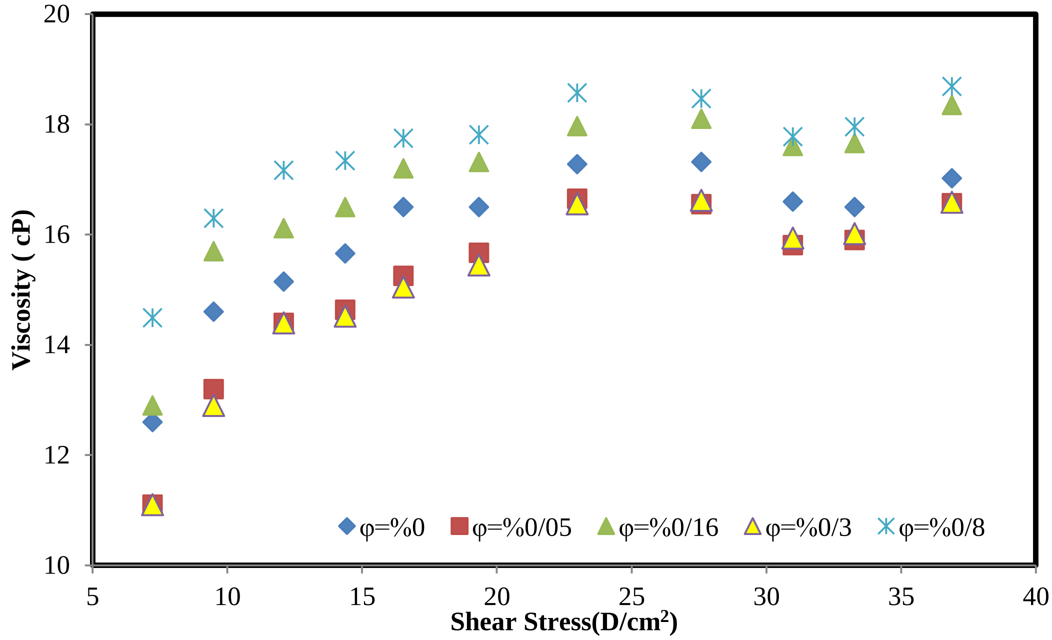

Fig.9- Viscosity of the MWCNTs-Transformer oil nanofluids vs. shear stress

The results of this study show that at a constant temperature, with increasing concentration of nanoparticles, the dynamic viscosity also increases, which can be explained by the fact that as the number of nanoparticles increases, more atoms from the base fluid are affected by nanoparticles and Van der Waals forces are formed more between the particles, which prevents the transfer of heat between the layers and thus increases the dynamic viscosity. The findings of viscosity changes of samples as a function of speed for different concentrations are shown in Fig.10, and the dynamic viscosity reduces when the speed is reduced from 20 to 160 rpm.

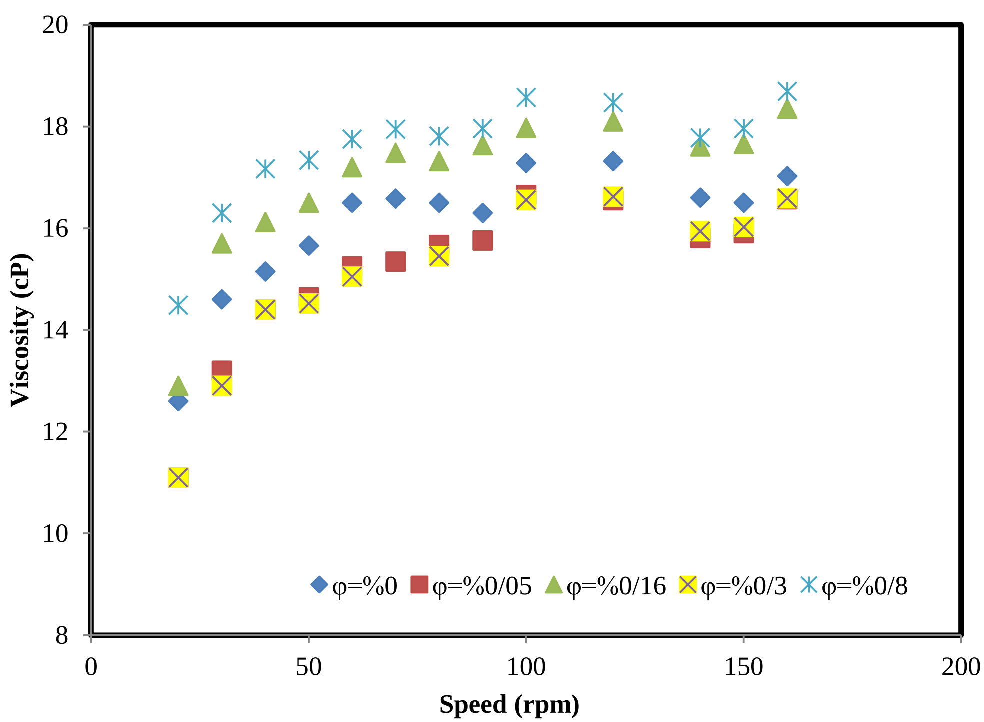

Fig. 10- Viscosity of the MWCNTs-Transformer oil nanofluids vs. speed of viscometer

4. Conclusion

In this study, the viscosity and density of nanofluid of transformer oil-carbon nanotubes were studied at ambient temperature and the results regarding the role of the weight fraction on these thermophysical properties were investigated. The results indicated that the viscosity and density of nanofluids increased with increasing weight fraction, ranging from 0.05 to 0.8 nm and a diameter of 10-20 nm. In addition, some models for nanofluid viscosity were presented in this study, but based on the existing research, it can be concluded that there is no comprehensive model for predicting the thermophysical properties of nanofluids, and each model differs depending on the type of base fluid and type of nanoparticles, as well as their weight fraction, length, and diameter.

Reference

[1] G.R.Vakili-Nezhaad, A.Dorany, Investigation of the effect of multiwalled carbon nanoyubes on the viscosity index of lube oil cuts, Chemical Engineering Communications, November 2014.

[2] M.Hemmat Esfe, M.Afrand, W.M.Yan, H.Yarmand, D.Toghraie, M.Dahari, "Effects of Temperature and Concentration on Rheological Behavior of MWCNTs/SiO_2(20–80)-SAE40 Hybrid Nano-Lubricant", Int. Commun. Heat Mass Transf. Vol. 76, pp. 133-138, 2016.

[3] M.Chandrasekar, S.Suresh, A.Chandra Bose, "Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/water nanofluid, Experimental Thermal and Fluid Science, vol. 34, pp. 210-216, 2// 2010.

[4] J.H.Lee, K.S.Hwang, S.P.Jang, B.H.Lee, J.H.Kim, S.U.S.Choi, Ch.J.Choi, Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al_2O_3 nanoparticles, International Journal of Heat and Mass Transfer, Volume 51, Issues 11–12, June 2008, Pages 2651-2656.

[5] M.Chandrasekar, S.Suresh, A.C.Bose, Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/water nanofluid, Experimental Thermal and Fluid Science, vol. 34, no. 2, pp. 210–216, 2010.

[6] P.K.Namburu, D.P.Kulkarn, D.Misra, D.K.Das, Viscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture, Experimental Thermal and Fluid Science, vol. 32, pp. 397–402, 2007.

[7] S.Bobbo, L.Fedele, A.Benetti, L.Colla, M.Fabrizio, C.Pagura, S.Barison, Viscosity of water based SWCNT and TiO_2 nanofluids, Experimental Thermal and Fluid Science, vol. 36, pp. 65–71, 2012.

[8] M.Kole, T.K.Dey, Effect of aggregation on the viscosity of copper oxide-gear oil nanofluids, International Journal of Thermal Sciences, vol. 50, no. 9, pp. 1741–1747, 2011.

[9] H.Chen, Y.Ding, Y.He, C.Tan, Rheological behaviour of ethylene glycol based titania nanofluids, Chemical Physics Letters, vol. 444, pp. 333–337, 2007.

[10] B.A.Horri, P.Ranganathan, C.Selomulya, H.Wang, A new empirical viscosity model for ceramic suspensions, Chemical Engineering Science, vol. 66, no. 12, pp. 2798–2806, 2011.

[11] C.T.Nguyen, F.Desgranges, N.Galanis, G.Roy, T.Maré, S.Boucher, H.Angue Mintsa, T.Maré, H.A.Mintsa, Viscosity data for Al_2O_3-water nanofluid - hysteresis: is heat transfer enhancement using nanofluids reliable, International Journal of Thermal Sciences, vol. 47, no. 2, pp. 103–111, 2008.

[12] J.Chevalier, O.Tillement, F.Ayela, Rheological properties of nanofluids flowing through microchannels, Applied Physics Letters, vol. 91, no. 233103, pp. 1–3, 2007.

[13] W.J.Tseng, C.Chen, Effect of polymeric dispersant on rheological behavior of nickel-terpineol suspensions, Materials Science and Engineering: A, vol. 347, no. 1, pp. 145–153, 2003.

[14] L.Syam Sundar, M.K.Singh, A.C.M.Sousa, Investigation of thermal conductivity and viscosity of Fe3O4 nanofluid for heat transfer applications, International Communications in Heat and Mass Transfer, vol. 44, pp. 7–14, 2013.

[15] M.Abareshi, S.H.Sajjadi, S.M.Zebarjad, E.K.Goharshadi, Fabrication, characterization, and measurement of viscosity of α-Fe2O3-glycerol nanofluids, Journal of Molecular Liquids, vol. 163, no. 1, pp. 27–32, 2011.

[16] S.E.Maïga, S.J.Palm, C.T.Nguyen, G.Roy, N.Galanis, Heat transfer enhancement by using nanofluids in forced convection flows, International Journal fo Heat and Fluid Flow, vol. 26, pp. 530–546, 2005.

[17] W.J.Tseng, K.Lin, Rheology and colloidal structure of aqueous TiO2 nanoparticle suspensions, Materials Science and Engineering: A, vol. 355, pp. 186–192, 2003.

[18] J.Buongiorno, Convective transport in nanofluids. J. Heat Transf. 2006, 128, 240–250.

[19] A.Indhuja, K.S.Suganthi, S.Manikandan, K.S.Rajan, Viscosity and thermal conductivity of dispersions of gum arabic capped MWCNT in water: Influence of MWCNT concentration and temperature, Journal of the Taiwan Institute of Chemical Engineers, Vol. 44, pp. 474–479, 2013.

[20] M.Abbasi, M.M.Heyhat, A.Rajabpour, Study of the effects of particle shape and base fluid type on density of nanofluids using ternary mixture formula: A molecular dynamics simulation, Journal of Molecular Liquids Volume 305, 1 May 2020, 112831.

[21] Z.Said, L.S.Sundar, H.Rezk, A.M.Nassef, H.M.Ali, M.Sheikholeslamigh, Optimizing density, dynamic viscosity, thermal conductivity and specific heat of a hybrid nanofluid obtained experimentally via ANFIS-based model and modern optimization, Journal of Molecular Liquids Volume 321, 1 January 2021, 114287.

[22] M.Sharifpur, S.Yousefi, J.P.Meyer, A new model for density of nanofluids including nanolayer, International Communications

in Heat and Mass Transfer, Volume 78, November 2016, Pages 168-174.

[23] K.Jafari, M.H.Fatemi, A new approach to model isobaric heat capacity and density of some nitride-based nanofluids using Monte Carlo method, Advanced Powder Technology,Volume 31, Issue 7, July 2020, Pages 3018-3027.

[24] R.D.elvakumar, J.Wu, A comprehensive model for effective density of nanofluids based on particle clustering and interfacial layer formation, Journal of Molecular Liquids, Volume 292, 15 October 2019, 111415.

[25] S.Porgar, L.Vafajoo, N.Nikkam, Gh.Vakili-Nezhaad, A comprehensive investigation in determination of nanofluids thermophysical properties, Journal of the Indian Chemical Society, Volume 98, Issue 3, 2021, 100037, ISSN 0019-4522, https://doi.org/10.1016/j.jics.2021.100037.

[26] D.Chavan, A.Pise, Experimental Investigation of Effective Viscosity and Density of Nanofluids, Materialstodays:proceedings, Volume 16, Part 2, 2019, Pages 504-515.

[27] F.Yousefi, Z.Amoozandeh, A new model to predict the densities of nanofluids using statistical mechanics and artificial intelligent plus principal component analysis, Chinese Journal of Chemical Engineering, Volume 25, Issue 9, September 2017, Pages 1273-1281.

[28] G.Żyła, J.P.Vallejob, L.Lugo, Isobaric heat capacity and density of ethylene glycol based nanofluids containing various nitride nanoparticle types: An experimental study, Journal of Molecular Liquids, Volume 261, 1 July 2018, Pages 530-539.

[29] S.Nabati Shoghl, J.Jamal, M.Keshavarz Moraveji, Electrical conductivity, viscosity, and density of different nanofluids: An experimental study, Experimental Thermal and Fluid Science, Volume 74, June 2016, Pages 339-346.

[30] M.Anish, J.Jayaprabakar, N.Joy, A.Prabhu, B.K.K.Reddy, E.G.Rajulu, Measurement of temperature-dependent thermal conductivity, viscosity and density of ZnO-Theminol 55 Nanofluids, Materialstodays:proceedings, Volume 21, Part 1, 2020, Pages 148-151.

[31] S.Porgar, L.Vafajoo, N.Nikkam, Gh.Vakili Nezhaad. Physiochemical studies of functionalized MWCNT/transformer oil nanofluid utilized in a double pipe heat exchanger. Canadian Journal of Chemistry. 99(6):510-18. https://doi.org/10.1139/cjc-2020-0297.