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INVESTIGATION ON SILVER-WATER NANOFLUID FOR DEVELOPMENT OF NEW VISCOSITY CORRELATION

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ABSTRACT. The present study addresses an experimental investigation on the influence of the concentration of nanoparticles and temperature on nanofluid's viscosity and establishes a numerical correlation for predicting the nanofluid's viscosity. In this study, silver nanoparticles (Ag) with a size of 20 nm were used to prepare the nanofluid with water as the base fluid. The concentrations of silver nanoparticles were fixed as 0.01, 0.05, and 0.1% by volume in the range of temperature from 20 to 60 °C. The findings of the current investigations report that the nanofluid's viscosity increases with volume fractions of nanoparticles and decreases as the temperature increases. The theoretical correlations in the literature under predict the viscosity of silver-water nanofluids, which has led to the development of a new relationship for determining the nanofluids' effective viscosity from the experimental findings of this research. The proposed model as outcome of the current investigation confirms a reasonable agreement with the experimental data.

KEY WORDS: Silver nanoparticles, Nanofluid, Viscosity, Volume Concentration, Temperature

INTRODUCTION

Nanofluids have been studied experimentally and numerically for the past two decades in many practical applications due to their better thermophysical characteristics, specifically enhanced thermal conductivity compared to the usual fluids for heat transfer applications such as water, oil, and ethylene glycol. Like thermal conductivity, the viscosity of a heat transfer fluid is also an important parameter concerning the investigation of the requirement of pumping power and convective heat transfer for practical applications. Nanofluid's viscosity and rheological characteristics are vital for thermal and energy applications. Indeed, the viscosity of nanofluids affects pumping power in any energy or thermal system, but viscosity also affects the pressure drop directly in every flow system. Furthermore, nanofluids' viscosity impacts heat transfer improvement from convective heat transfer, and it is incredibly significant in many non-dimensional numbers such as the Prandtl number, Reynolds number, and Rayleigh number used in thermal and fluids sciences [1]. The viscosity of a nanofluid is the most critical thermophysical parameter, as it is primarily controlled by convective heat transfer and pumping power requirements. It is evident that the heat transfer coefficient of nanofluid increases with the addition of the concentration of nanoparticles. Furthermore, adding nanoparticles increases the pumping power demand. Henceforth, for industrial applications of nanofluids, precise data on the effective viscosity is essential [2]. It is challenging to attain increased thermal conductivity and reduced viscosity in nanofluids simultaneously. It is well known from the past research that adding solid nanoparticles to heat transfer fluids will increase thermal conductivity and viscosity, resulting in

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*Corresponding author. E-mail: siyahraja@gmail.com increased pumping power. As a result, optimizing heat transfer capability and nanofluid viscosity is necessary, as it directly impacts the design of flow and heat transfer equipment.

The viscosity of nanofluids containing metal oxide-based nanoparticles has been studied experimentally on several variables such as the nanoparticle's size and concentration and the nanofluids' temperature using different fluids. The outcome of the experimental research on the viscosity of different metal oxide based nanofluids like Al_2O_3 [3-6], TiO_2 [4, 7], ZnO [8], Fe_2O_3 [9] presented that the viscosity of the nanofluid increases considerably with particle volume fraction but decreases with the temperature. This type of phenomenon on viscosity had increased serious concerns on the use of nanofluids for heat transfer enhancement [4]. Sunil *et al.* examined the thermal properties NiO based nanofluids as lubricants and reported very good chemical stability and the enhancement of thermal stability up to 210 ºC [10]. Minakov *et al.* studied the viscosity of more than thirty different nanofluids with distilled water, ethylene glycol, and engine oil as base fluids containing nanoparticles of Al_2O_3, TiO_2, ZrO_2, CuO, Fe_2O_3, and Fe_3O_4, and nano diamonds for the volume concentrations from 0.25 to 8% and the sizes of nanoparticles ranging from 5 to 150 nm at the temperature range from 25 to 60 ºC. They found that the viscosity coefficient of nanofluids decreased with an increase in the size of nanoparticles, and the viscosity of nanofluids depends on the material of the nanoparticles [11]. Similar investigations have been conducted on the use of metal based nanofluids with Cu [12], Ag [5, 13]. Sharma *et al.* examined the viscometric properties of various hybrid nanofluids having Cu with oxides of Ce, Al, Ti, and Si with different concentrations and temperatures and compared with various models for the viscosity of nanofluids. They reported dissimilarity between the experimental hybrid viscosities of nanofluids compared with that of the hypothetical values [14]. The experimental and theoretical study of Huminic *et al.* reported the increase in viscosity of graphene oxide-silicon oxide hybrid nanofluid for the higher mixture ratio of graphene oxide [15]. Garg *et al.* evaluated the viscosity of multi-wall carbon nanotube (MWCNT) based nanofluids and reported the increase of viscosity of the nanofluids with the sonication time until a maximum value was reached and decreased thereafter [16]. In general, the viscosity of nanofluid increases with nanoparticle concentration but decreases with its temperature. Moreover, researchers have reported numerical investigations to understand the effect of different variables on the viscosity of the different nanofluids [17-25]. They proposed new viscosity models to predict the viscosity of the nanofluids and showed relatively good agreement with the experimental results. The review articles of experimental and numerical investigations of viscosity of the nanofluids have been found in the literature which demanded the need for more investigations on the viscosity of the nanofluids [26-30].

Many literature articles have suggested a variety of theoretical models to evaluate the thermophysical characteristics of the nanofluids, particularly thermal conductivity modeling. However, only few works exist on the effective viscosity models. Compared to metal oxide nanoparticles, there is also a scarcity of literature on nanofluids with metallic nanoparticles. Silver is a valuable material for thermal applications since it is a familiar and reliable substance having a higher thermal conductivity of 429 W/m-K under ambient conditions. Iyahraja and Selwin Rajadurai conducted experiments to improve Ag-water nanofluids' stability and thermal conductivity with a result of 52% rise in the nanofluid's thermal conductivity using silver nanoparticles of 20 nm having a 0.1% volume fraction. Also, the addition of surfactant improved the stability of the nanofluid [31, 32]. Higher thermal conductivity enhancement of nanofluids with less concentration of silver nanoparticles can make the silver-water nanofluid cost-effective for the application of energy systems. Hence, an effort has been made to investigate the influence of Ag nanoparticles' concentration and temperature on nanofluids' viscosity. Most previous research has been conducted with nanoparticle concentrations of 0.1% or above. But tiny volume fractions ranging from 0.01 to 0.1% of nanoparticles were employed in the current study since low volume concentrations may not influence the pumping power requirement. For better stability of the nanofluids, polyvinylpyrrolidone (PVP) was utilized as a surfactant. From this perspective, this research is deemed necessary.

EXPERIMENTAL

Nanofluid was prepared with spherical-shaped silver nanoparticles with an average particle size of 20 nm and 99.9% purity coated with 0.2 wt.% PVP bought from M/s. US Research Nanomaterials, Inc. (Houston, USA). Figure 1 shows a TEM image of Ag nanoparticles used for this study. Polyvinylpyrrolidone of analytical grade, purchased from M/s. Sigma Aldrich Chemicals Ltd. has been used in the condition as received without any additional purification. The nanofluid was prepared using a magnetic stirrer and an ultrasonic cleaning bath (100 W, 40 kHz, 3-liter capacity). The concentration of the surfactant was restricted to one-tenth of the nanoparticles added by mass. This investigation was conducted with concentrations of 0.01, 0.05, and 0.1% nanoparticles by volume. Nanofluid preparation was initiated by mixing nanoparticles in distilled water kept in a magnetic stirrer for 30 min and followed by ultrasonication for 3 hours in an ultrasonic bath. Figure 2 shows the sample Ag-water nanofluid prepared for the current study.

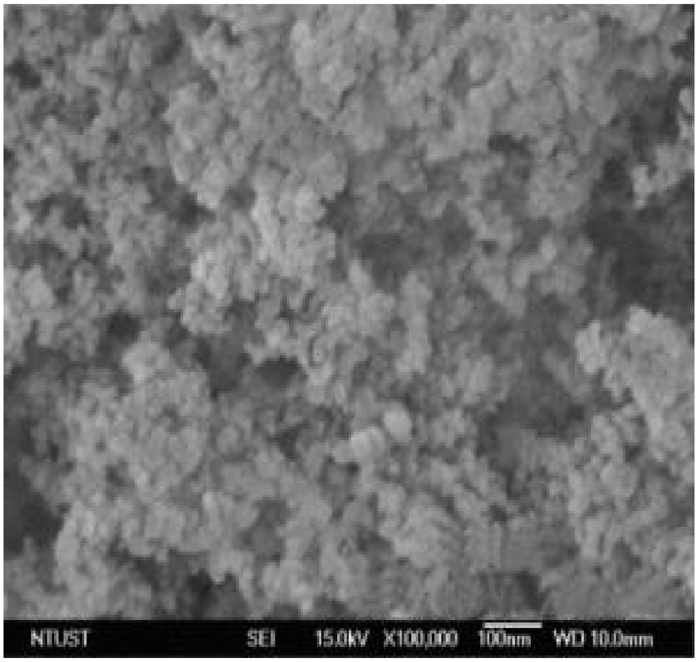

Figure 1. TEM image of silver nanoparticles.

In general, there are several methods for determining viscosity experimentally, including concentric cylinders, cone, and plate methods. Brookfield cone and plate viscometer (Make: LVDV-I PRIME C/P, Brookfield Engineering Laboratories, USA) shown in Figure 3 has been used to evaluate nanofluid's viscosity in this study. It measures the absolute viscosity of the fluids. To begin, the viscometer calibration was carried out using distilled water for temperatures ranging from 20 to 60 ºC. Five sets of readings were taken for each sample fluid to ascertain the repeatability of the measurements. The viscosity of nanofluids was then measured at various temperatures and particle volume concentrations. The volume concentration of Ag nanoparticles of size 20 nm in the nanofluid was varied as 0.01, 0.05, and 0.1%. Surfactant concentration is limited to 1/10th mass fraction, so the thermal conductivity enhancement was not affected much.

Figure 2. Photograph of sample silver water nanofluid.

Figure 3. Photograph of viscometer.

Hence, the nanofluid with 20 nm silver nanoparticles and 1/10th mass fraction of PVP was taken for this analysis and the temperature of the nanofluid varied from 20 to 60 ºC. The viscosity measurement of nanofluid with this instrument had an uncertainty of less than 3% of the mean value throughout the entire range.

RESULTS AND DISCUSSION

Water's viscosity was measured at temperatures of 20, 30, 40, 50, and 60 ºC. The comparison of measured values of water with their reference values is shown in the Figure 4. The error in viscosity measurement using this device is less than 3.5%. A good agreement of the reference and measured values are exhibited in the figure.

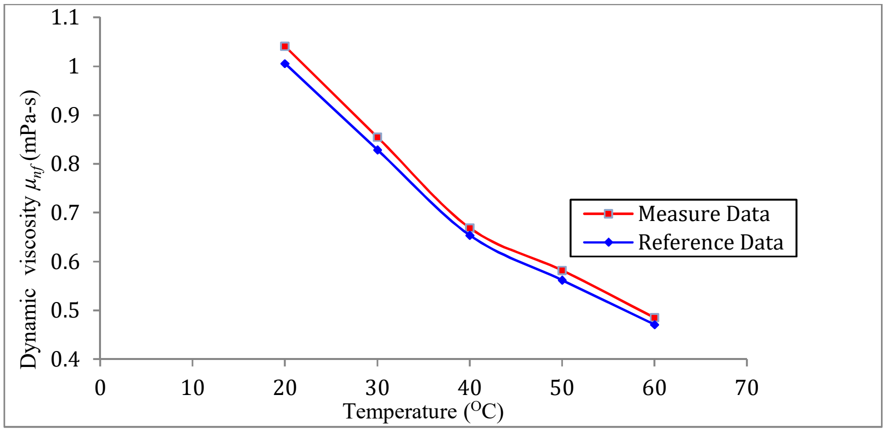

Figure 4. Validation of experimental data with reference data.

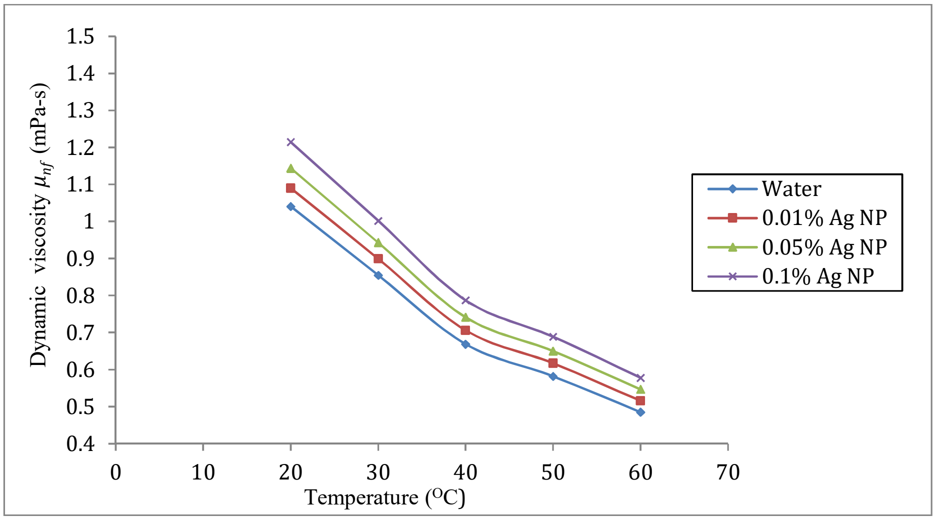

Figure 5. Effect of temperature and particle volume concentration on nanofluid viscosity.

Figure 5 shows the nanofluid's viscosity as a function of its temperature for various concentrations of nanoparticles. It is clear from the graph that the nanofluid's viscosity increases with the concentration of nanoparticles significantly. It increases up to 12.7% for 0.1% concentration of nanoparticles by volume at 20 ºC. Nevertheless, while the nanofluid's temperature increases, the nanofluid's viscosity decreases significantly; this is because when the temperature increases, the density of the fluid drops, reducing the shearing force between the succeeding fluid layers.

Figure 6 shows the variation of relative viscosity, which is known as the ratio of nanofluid's viscosity to the viscosity of the base fluid as a function of temperature and volume concentration of nanoparticles. Increasing the temperature of nanofluids from 20 to 60 ºC, the relative viscosity of the nanofluid increases from 4.7% to 6.3% for 0.01% volume concentration of silver nanoparticles. Further, the relative viscosity of nanofluid increases from 9.9% to 12.7% for 0.05% concentration and from 16.7% to 19.2% for volume concentration of 0.1%. The current investigation shows that the relative viscosity of nanofluids rises with the increase of nanoparticle concentration. Furthermore, at all temperatures, the nanofluid's viscosity is higher than that of the basic fluid. As the working temperature of the heat transfer fluid is closer to 60 ºC normally in most of the applications, the temperature of the nanofluid has been limited to 60 ºC.

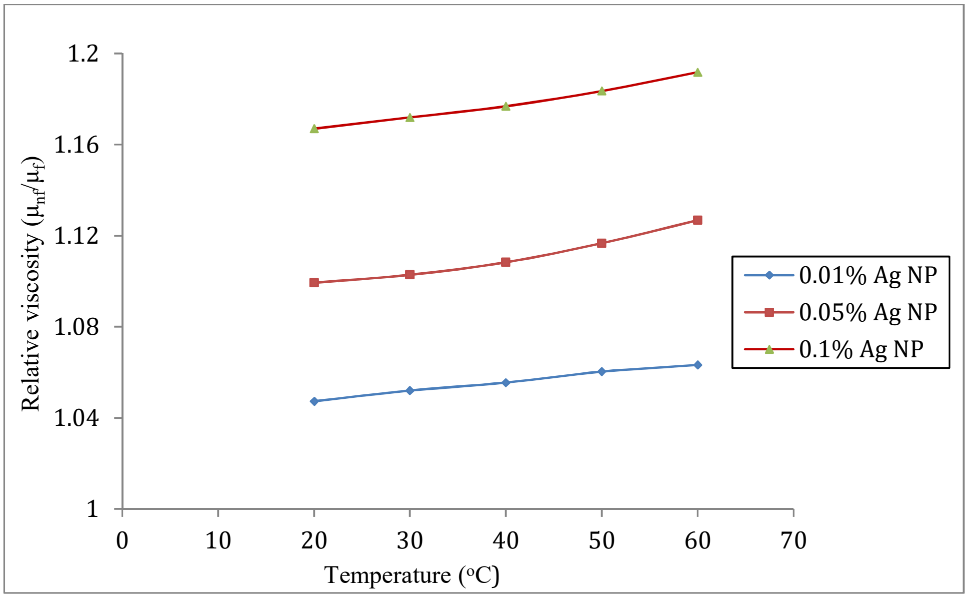

Figure 6. Variation of relative viscosity with respect to temperature of nanofluid.

Various researchers have presented numerous theoretical connections for predicting the viscosity of nanofluids. Some of the commonly used correlations are given below.

1. Einstein's model

$$\mu_{nf} = \mu_f(1 + 2.5\varepsilon) \quad (1)$$

2. Batchelor Model [33]

$$\mu_{nf} = \mu_f(1 + 2.5\varepsilon + 6.2\varepsilon^2) \quad (2)$$

3. Wang *et al.* Model [34]

$$\mu_{nf} = \mu_f(1 + 7.3\varepsilon + 123\varepsilon^2) \tag{3}$$

where μ_{nf} is viscosity of nanofluid, μ_f is viscosity of base fluid, and ε is volume concentration of nanoparticles.

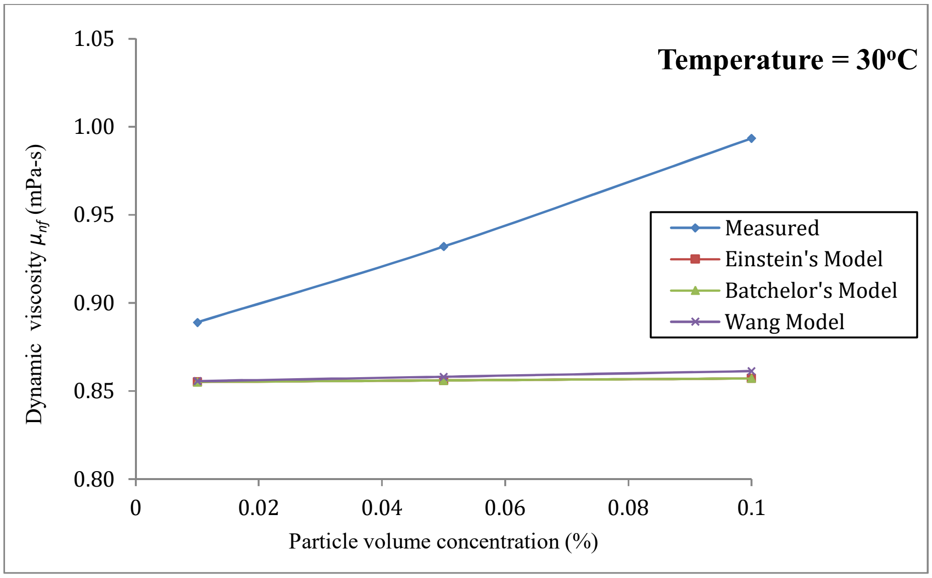

Figure 7. Comparison of measured viscosity and predicted viscosity using different correlations.

Figure 7 compares the measured values of nanofluid's viscosity with their predicted values using the above correlations at a temperature of 30 °C. The measured values of nanofluid's viscosity are substantially greater than their estimated values with these correlations, which is recognized from the above graph. Hence, the existing correlations underpredict the viscosity of Ag-water nanofluids. The deviation between the two values can be high because several researchers have used the above correlations to predict the viscosity of nanofluids containing metal oxide nanoparticles.

From the literature on the formulation of correlations for evaluating nanofluids' viscosity, it is observed that the proposed models are based on the use of metal oxide nanoparticles and with volume concentrations of more than 1%. The correlation for the viscosity prediction of nanofluids having metallic nanoparticles with significantly lower concentrations of nanoparticles is seldom found. With the help of these experimental data, an attempt has been made in this study to establish a novel correlation to predict the viscosity of Ag-water nanofluids for different volume concentrations of nanoparticles at various temperatures. In the development of the correlation, the harmony search algorithm has been applied to formulate the correlation of nanofluid viscosity. The proposed model has considered not only the volume concentrations of nanoparticles but also the temperature of nanofluid, which are the key influencing factors for the viscosity of nanofluid. The developed model is given below.

$$\mu_{nf} = \mu_f(T^{-0.089} + 0.5 + 0.04\varepsilon + 2\varepsilon^2) \tag{4}$$

where T is the temperature of nanofluid in K.

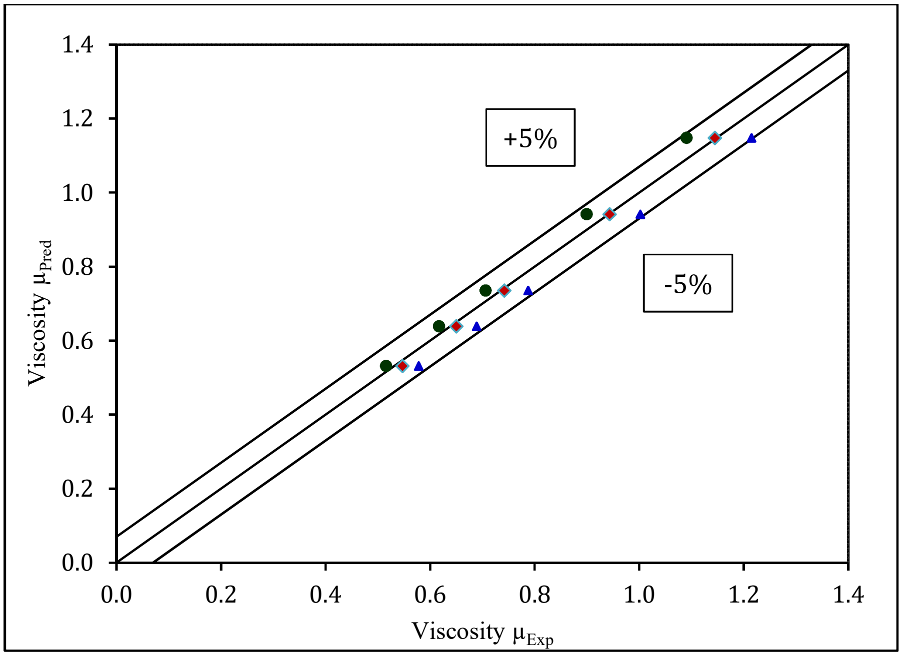

Figure 8. Comparison of experimental and predicted values of viscosity of nanofluid.

Figure 8 compares the experimental and predicted viscosity values of nanofluid. The figure shows that the proposed correlation and experimental results have an excellent agreement, with a maximum divergence of less than 5%. The proposed correlation can be used for the application of silver-water nanofluids suitably with higher accuracy. Also, the concentration of the nanoparticles was extremely low, there was only a slight increase in the viscosity of nanofluids. Hence, the increased viscosity of nanofluids may not have much effect on the friction and pressure drop of the nanofluids.

CONCLUSIONS

The impact of nanoparticle concentration and temperature on the viscosity of silver-water nanofluids was investigated experimentally in the present research. Silver-water nanofluids with the nanoparticles' size of 20 nm having particle volume concentrations of 0.1% and lower were employed by varying the temperature from 20 to 60ºC. The addition of silver nanoparticles increases the viscosity of nanofluids considerably. It increases up to 12.7% for 0.1% concentration of nanoparticles at the temperature of 20 ºC. An increase in the temperature of nanofluids reduces their viscosity. However, the relative viscosity of nanofluid increases with the increase of nanofluid's temperature and the concentration of nanoparticles. An increase in relative viscosity of silver-water nanofluid from 4.7% to 19.2% is exhibited with the increase of concentration of nanoparticles from 0.01 to 0.1% and the temperature from 20 to 60 ºC. Furthermore, a new correlation is proposed to predict the viscosity of nanofluid. A good agreement between the experimental results and the predicted results is reported using the proposed correlation. In general, the proposed correlation has better accuracy and precision.

REFERENCES

1. Murshed, S.M.S.; Estellé, P. A state of the art review on viscosity of nanofluids. *Renew. Sust. Energy Rev.* **2017**, 76, 1134-1152.
2. Yang, J.C.; Li, F.; Zhou, W.W.; He, Y.; Jiang, B.C. Experimental investigation on the thermal conductivity and shear viscosity of viscoelastic-fluid-based nanofluids. *Int. J. Heat Mass Transfer.* **2012**, 55, 3160-3166.
3. Nguyen, C.T.; Desgranges, F.; Galanis, N.; Roya, G.; Maré, T.; Boucher, S.; Angue Mintsa, H. Viscosity data for Al_2O_3–water nanofluid—hysteresis: is heat transfer enhancement using nanofluids reliable?. *Int. J. Therm. Sci.* **2008**, 47, 103.
4. Murshed, S.M.S.; Leong, K.C.; Yang, C.; Investigations of thermal conductivity and viscosity of nanofluids. *Int. J. Therm. Sci*. **2008**, 47, 560-568.
5. Maddah, H.; Rezazadeh, M.; Maghsoudi, M.; Kokhdan, S.N. The effect of silver and aluminum oxide nanoparticles on thermophysical properties of nanofluids. *J. Nanostruct. Chem.* **2013**, 3, 28.
6. Lotfizadeh Dehkordi, B.; Kazi, S.N.; Hamd, M.; Ghadimi, A.; Sadeghinezhad, E.; Metselaar, H.S.C. Investigation of viscosity and thermal conductivity of alumina nanofluids with addition of SDBS. *Heat Mass Transfer.* **2013**, 49, 1109-1115.
7. Duangthongsuk, W.; Wongwises, S.; Measurement of temperature-dependent thermal conductivity and viscosity of TiO_2-water nanofluids. *Exp. Therm. Fluid Sci.* 2009, 33, 706-714.
8. Suganthi, K.S.; Leela Vinodhan, V.; Rajan, K.S. Heat transfer performance and transport properties of ZnO–ethylene glycol and ZnO–ethylene glycol–water nanofluid coolants. *App. Energy*. **2014**, 135, 548-559.
9. Colla, L.; Fedele, L.; Scattolini, M.; Bobbo, S. Water-Based Fe_2O_3 Nanofluid Characterization: Thermal Conductivity and Viscosity Measurements and Correlation. *Adv. Mech. Eng.* 2012, 674947.
10. Sunil, J.; Maheswaran, R.; Vettumperumal, R.; Kishor Kumar, S. Experimental Investigation on the Thermal Properties of NiO-Nanofluids. *J. Nanofluids.* **2019**, 8, 1577-1582.
11. Minakov, A.V.; Rudyak, V.Y.; Pryazhnikov, M.I. Systematic Experimental Study of the Viscosity of Nanofluids. *Heat Transfer Eng.* **2021**, 42, 1024-1040.
12. LI Xinfang.; Dongsheng, Z.; Xianju, W. Experimental investigation on viscosity of Cu-H_2O nanofluids. *J. Wuhan Univ. Tech. Mater. Sci.* **2009**, 24, 48-52.
13. Godson, L.; Raja, B.; Mohan Lal, D.; Wongwises, S. Experimental Investigation on the Thermal Conductivity and Viscosity of Silver-Deionized Water Nanofluid. *Exp. Heat Transfer: A Journal of Thermal Energy Generation, Transport, Storage, and Conversion.* **2010**, 23, 317-332.
14. Sharma, S.; Tiwari, A.K.; Tiwari, S.; Prakash, R. Viscosity of hybrid nanofluids: Measurement and comparison. *J. Mech. Eng. Sci.* **2018**, 12, 3614-3623.
15. Huminic, G.; Vardaru, A.; Huminic, A.; Fleaca, C.; Dumitrache, F.; Morjan, I. Water-based graphene oxide–silicon hybrid nanofluids-experimental and theoretical approach. *Int. J. Mol. Sci.* **2022**, 23, 3056.
16. Garg, P.; Alvarado, J.L.; Marsh, C.; Carlson, T.A.; Kessler, D.A.; Annamalai, K. An experimental study on the effect of ultrasonication on viscosity and heat transfer performance of multi-wall carbon nanotube-based aqueous nanofluids. *Int. J. Heat Mass Transfer.* **2009**, 52, 5090-5101.
17. Avsec, J.; Oblak, M. The calculation of thermal conductivity, viscosity and thermodynamic properties for nanofluids on the basis of statistical nanomechanics. *Int. J. Heat Mass Transfer.* **2007**, 50, 4331-4341.

18. Nguyen, C.T.; Desgranges, F.; Roy, G.; Galanis, N.; Mare, T.; Boucher, S.; Minsta, H.A. Temperature and particle-size dependent viscosity data for water based nanofluids – hysteresis phenomenon. *Int. J. Heat Fluid Flow.* **2007**, 28, 1492-1506.
19. Abu-Nada, E. Effects of variable viscosity and thermal conductivity of Al_2O_3–water nanofluid on heat transfer enhancement in natural convection. *Int. J. Heat Fluid Flow.* **2009**, 30, 679-690.
20. Chandrasekar, M.; Suresh, S.; Chandra Bose, A. Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/water nanofluid. *Exp. Therm. Fluid Sci.* **2010**, 34, 210-216.
21. Etaig, S.; Hasan, R.; Perera, N. Investigation of a new effective viscosity model for nanofluids. *Procedia Eng.* **2016**, 157, 404-413.
22. Udawattha, D.D.; Narayana, M.; Wijayarathne, U.P.L. Predicting the effective viscosity of nanofluids based on the rheology of suspensions of solid particles. *J. King Saud Univ. – Sci.* **2019**, 31, 412-426.
23. Demirpolat, A.B.; Das, M. Prediction of viscosity values of nanofluids at different pH values by alternating decision tree and multilayer perceptron methods. *Appl. Sci.* **2019**, 9, 1288.
24. Dhahri, M.; Aouinet, H.; Sammouda, H. A new empirical correlating equation for calculating effective viscosity of nanofluids. *Heat Transfer-Asian Res.* **2019**, 48, 1547-1562.
25. Klazly, M.; Bognar, G. A novel empirical equation for the effective viscosity of nanofluids based on theoretical and empirical results. *Int. Commun. Heat Mass Transf.* **2022**, 135, 106054.
26. Mishra, P.C.; Mukherjee, S.; Nayak, SK.; Panda, A. A brief review on viscosity of nanofluids. *Int. Nano. Lett.* **2014**, 4, 109-120.
27. Meyer, J.P.; Adio, S.A.; Sharifpur, M.; Nwosu, P.N. The viscosity of nanofluids: A review of the theoretical, empirical, and numerical models. *Heat Transfer Eng.* **2016**, 37, 387-421.
28. Bashirnezhad, K.; Bazri, S.; Safaei, M.R.; Goodarzi, M.; Dahari, M.; Mahian, O.; Dalkılıça, A.S.; Wongwises, S. Viscosity of nanofluids: A review of recent experimental studies. *Int. Comm. Heat Mass Transfer.* **2016**, 73, 114-123.
29. Koca, H.D.; Doganay, S.; Turgut, A.; Tavman, I.H.; Saidur, R.; Mahbubul, I.M. Effect of particle size on the viscosity of nanofluids: A review. *Renew. Sust. Energy Rev.* **2018**, 82, 1664-1674.
30. Ezekwem, C. A recent review of viscosity models for nanofluids. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects.* **2022**, 44, 1250-1315.
31. Iyahraja, S.; Selwin Rajadurai, J. Study of thermal conductivity enhancement of aqueous suspensions containing silver nanoparticles. *AIP Adv.* **2015**, 5, 057103.
32. Iyahraja, S.; Selwin Rajadurai, J. Stability of aqueous nanofluids containing PVP-coated silver nanoparticles. *Arabian J. Sci. Eng.* **2016**, 41, 653-660.
33. Batchelor, G. K. The effect of Brownian motion on the bulk stress in a suspension of spherical particles. *J. Fluid Mech.* **1977**, 83, 97-117.
34. Wang, W.; Xu, X.; Choi, S.U.S. Thermal conductivity of nanoparticle – fluid mixture. *J. Thermophys. Heat Transfer.* **1999**, 13, 474-480.