Influence of Volume Concentration and Temperature on Viscosity and Thermal Conductivity of *Terminalia Superba* (Afara) Tree Bark Nanofluid

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Abstract: ***The influence of temperature and volume fraction on the thermal conductivity and viscosity of nanofluid produced from Terminalia Superba (Afara - EG) were investigated. An average particle size of 100nm was dispersed into pure ethylene glycol and magnetically stirred for 10 minutes for proper distribution and absorption before sonication. Volume fractions of 0.2%, 0.4%, 0.6%, 0.8% and 1.0% were produced by ultrasonication for an optimum sonication time of 30 minutes with amplitude of sonication as 80hz. Results of the thermophysical properties of Terminalia Superba tree bark nanofluid using ethylene glycol as base fluid are presented. As the temperature elevated from 20°C to 70°C, the viscosity decline. A rise in viscosity was recorded as volume fraction increased from 0.2% to 1.0%. The thermal conductivity increased with increase in temperature and volume fraction. Predicted values of thermal conductivity and viscosity for nanofluid produced from Terminalia Superba were found to be higher than the experimental values. Due to its low viscosity and thermal enhancement, it is suitable for application in cooling of electronics.***

Keywords: Viscosity, Thermal conductivity, *Terminalia Superba*, Ethylene Glycol, Temperature, Volume fraction

1. Introduction

The need for alternative, greener energy sources which improves the efficiency and effectiveness of heat exchange devices becomes imperative due to the current excessive consumption of fossil fuels. The conventional heat transfer fluid are water, ethylene glycol, glycerol and oil. These fluids are used for various applications like cooling by way of heat transfer and have shown a high level of ineffectiveness hence the need to improve on them by enhancing their heat transfer capacities. High performance of cooling and heating in industrial processes attributed to application of nanofluids has the potential of lowering production time, improves the thermal capacity, increase the life span of the equipment and may create a savings in energy. Blockage of channel and wearing out of tube materials was observed due to sedimentation which impedes smooth fluid flow when a two - phase suspensions of microparticles were tested. Nonetheless, suspensions with microparticles and single - phase pure fluids have more demerits when compared to nanofluids (Mohamoud et al.2016). Particle clogging of microchannels, wearing out of tube materials surfaces and sedimentation are issues when mitigated will ensure a well stable nanofluid. Long before now, the thermal fluids with high potential for heat transfer applications is in nanofluids. It is expected that the thermal conductivity of the base fluid should be lower than that of nanofluids. Because of ultrafine nature of the particles dispersed, there was a substantially increases in the thermal conductivity of the system which heightens its energy exchange capacity (Pastoriza - Gallego.2011; Chandrasekar et al.2010 and Niesen.1976). Then again, the characteristics of nanofluids that has to do with flow and deformation explains the proficient and active deployment of heat transfer systems which finds application in vehicle heat exchangers like the car radiator (Peyghambarzadeh et al.2011), heat pipes (Zamzamian et al.2011), and Heat, ventilation and air conditioning systems. A most significant properties of nanofluids which are crucial for the determining the coefficient of heat transfer is viscosity. This may be influenced by size of the nanoparticles, temperature and particle concentration in the nanofluid (Nguyen et al.2007). As temperature was varied from 10 to 70°C and solid concentrations ranged from 1% to 35%, the viscosity of TiO_2nanofluid was examined. Again Al_2O_3–water nanofluidwas prepared and its dynamic viscosity, was studied. The procedure was carried out with selected volume concentrations at room temperature with 43 nm nanoparticle diameter. Both results indicated thatas solid concentration increased, the dynamic viscosity increased significantly. (Fedele et al.2012; Chandrasekar et al.2010) Plant parts are being reduced into nanoscale and dispersed into base fluids that produced nanofluids with reasonable stability and enhanced thermo - physical properties (Gloria et al.2018). Nowack and Bucheli (Nowack and Bucheli.2007) reported a possibility of increase in toxicity due oxygen reactive species in oxides of metal nanoparticles. The dangerous condition posed by metals and oxides of nanofluidsto human and animal cells known as Cytotoxicity and genotoxicity leads to the death of cells. (Jamuna and Ravishankar, 2014). The viscosity, pH and electrical conductivity of Palm Kernel fibrenanofluid were examined as temperature and volume concentration were varied. The results showed increase in electrical conductivity and pH as solid concentration increased and temperature increased, while viscosity increased with increase in volume concentration but decreased with increase in temperature (Justin et al., 2018). Owing to the toxic effect of inogarnic nanomaterials, high cost, non - availability, it is essential to give more attention to the use of bio - synthesized, easily accessible, and inexpensive agricultural material such as Afara tree bark nanoparticle. In this paper, the behaviors of viscosity, and thermal conductivity of nanofluid prepared from Afara Tree Bark (ATB) using ethylene glycol as the base fluid were examined as temperature and volume concentrations were varied.

2. Experimental

2.1 Preparation and Characterisation of Afara Tree Bark (ATB) Nanoparticle

A 50 kg bag full of Afara tree bark was collected and sundried for about four weeks and then oven dried within temperature range of 40 to 50°C in order to ensure that all residue moisture is eliminated. The Afara tree bark was mechanically crushed by pounding to produce macrofibre particles. The fibres were introduced into the ball mill for further reduction. The charged milling machine was left to run for about 48hours nonstop. The particles were further ball milled for 24hours using a THYREC ball milling machine with sixty three steel balls of 14kg each and 66rpm speed. This gave an ultrafine, partially charred particles. The scanning electron microscopy (SEM) and transmission electron microscopy (TEM) images in Figure 1 and 2 showed an average particle size of 100nm and nearly even particle distribution though with clusters at some point. The density of Afara tree bark nanoparticle was 0.5192g/m^3 and the result of elemental analysis in Figure 3 showed traces of metallic elements which have records of thermal enhancement.

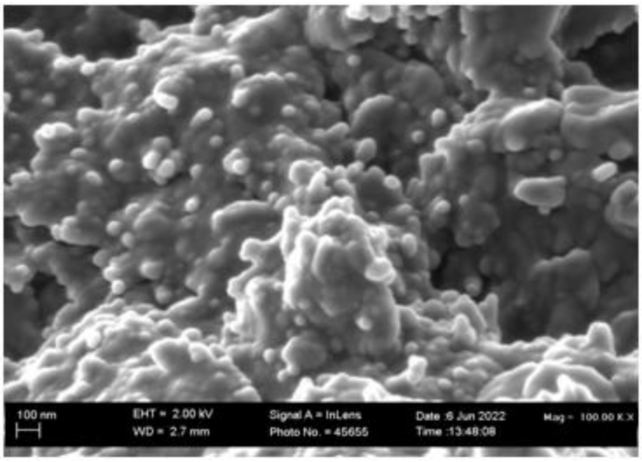

Figure 1: SEM Image of Afara Tree bark Nanoparticles

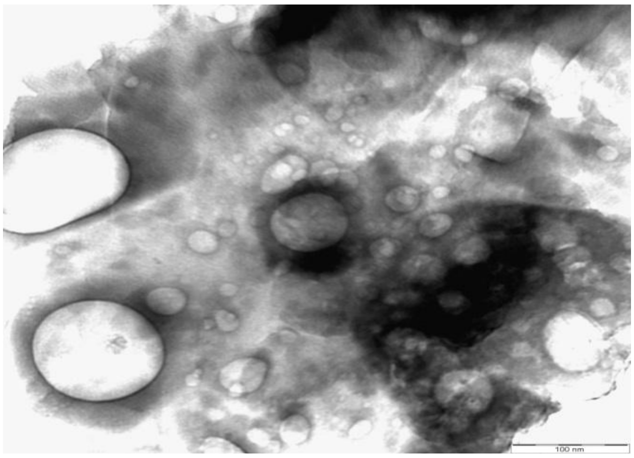

Figure 2: TEM Image of Afara Tree bark Nanoparticles

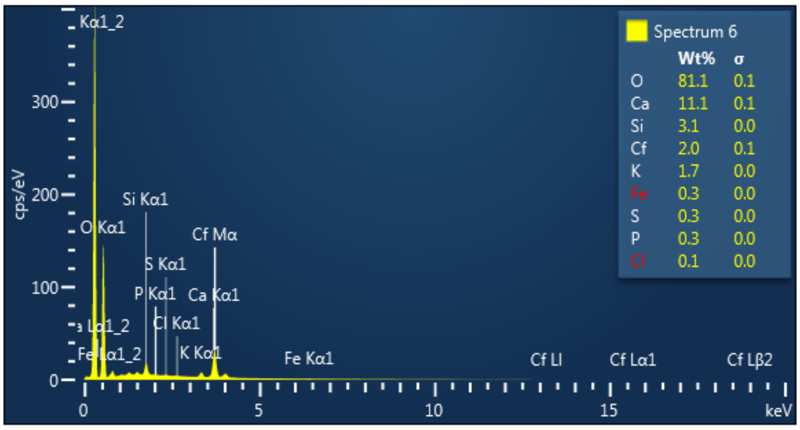

Figure 3: Results of Elemental Analysis of Afara Tree Bark Nanoparticles by EDX

2.2 Nanofluid preparation

Volume concentrations of 0.2, 0.4, 0.6, 0.8 and 1.0% were selected and calculated using equation 1 where $\emptyset$ is the volume fraction, Vnp and Vbf are volumes of the nanoparticle and base fluid, Mnp, Mbf, ρnp and ρbf are mass of the nanoparticles, mass of the base fluid, density of the nanoparticles and density of the base fluid respectively. The weight for the different volume fractions were measured using AS RADWAG 220 - R2 weighing machine of high sensitivity with minimum of and maximum capacity of 10mg and 220g, and 0.001g precision. The nanoparticles for the different volume concentrations were dispersed into 100ml Ethylene Glycol (base fluid). A cylindrical, ceramic magnetic stirrer was introduced into the mixture and the beaker was placed on the magnetic stirring machine and the speed was set at 6rpm. Stirring was carried out for 10 minutes to ensure proper magnetic force agitation, then the mixture was further subjected to intensive ultrasonic agitation, high - shear mixing and homogenizing using a QSonica LASEC Sonicator with a CL - 334 sonotrode with amplitude of 50. Each volume fraction in a beaker was partially immersed in LAUDA PROLINE RP1840 water thermal bath properly held in a stationary position by the jaws of a tripod stand with about 80% of the beaker (carrying the content) submerged in the bath and sonicated at a constant temperature of 20^{o}C.30 minutes optimal sonication time was selected after varying sonication time from 10 to 50 minutes for a 0.2% volume fraction of each sample in order to get the best sonication time with minimum sedimentation. Throughout the sonication period, pulse was made to be active for 5 seconds and idle for 2 seconds to get a homogenous, stable solution with minimum sedimentation after 48hours as shown in Figure 4.

$$\emptyset = \frac{Vnp}{Vnp + Vbf} = \frac{Mnp/\rho np}{\frac{Mnp}{\rho np} + \frac{Mbf}{\rho bf}} \qquad (1)$$

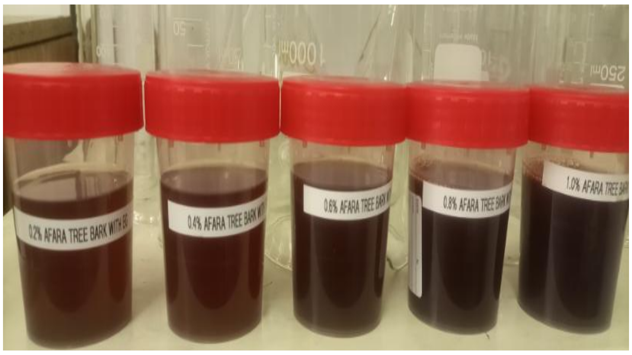

Figure 4: Images of Afara Tree Bark Nanofluids

2.3 Measurement of Thermal Conductivity

The transient hot - wire approach was used to measure the nanofluidrate of heat transfer. The KD2 Pro thermal property meter shown in Figure 5 is the setup for determining the thermal conductivity readings with measurement accuracy of ±5%. It consists of a sensor needle probe and handheld microcontroller. The heating element and a thermistor made up the components of KD2 sensor needle. A combination of the16 - bit microcontroller/AD converter, battery, controller module and power control circuitry is called the controller module. The sensitive needle probe, KS - 1 is made of stainless steel having a diameter of 1.3 mm and length of 60 mm and, and closely approaches the infinite line heat source which gives least disturbance to the sample during measurements. The sensor needle can be used for measuring thermal conductivity of fluids in the range of 0.2–2 W/mK. The rate at which heat is transferred (thermal conductivity) was quantified for the nanofluidand base fluid as volume concentrations and temperature of Afara tree bark nanofluid were varied. The probe was introduced uprightly through a port in the lid of the vessel into the sample.15cm^{3} of the sample was collected with its lead tightly covered in a thick cylindrical glass sample vial. A GRAND GD200 temperature controlled water bath was used with the sample almost fully immersed in the bath with a sealed vial left for 60 minutes to attain thermal stability to take place. Once the sample reaches the required temperature (lowest limit for measurement of thermal conductivity) in this case 20^{o}C. At each temperature readings were taken four times within intervals of 15minutes to ensure reproducibility. Thermal conductivity measurements were taken for base fluid and the volume concentrations of 0.2, 0.4, 0.6, 0.8 and 1.0% at a temperature range of 20 to 70^{o}C. The whole system was properly sealed and heated to a temperature slightly above the highest required limit for an hour and then switched off. The KD2 PRO was immediately connected and switched on while the thermal bath was slightly opened to so that there is a gradual drop in temperature as thermal conductivity readings were automatically taken at intervals of every 15minutes.

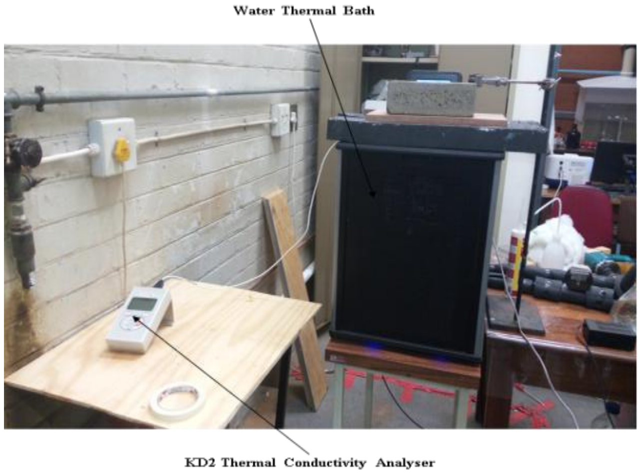

Figure 5: Setup for Thermal Conductivity Measurement

2.4 Viscosity measurement

A sine - wave viscometer (Vibro SV–10) with viscosity limits in magnitude of 0.3–10, 000 mPas was used to measure viscosity of the nanofluid. The apparatus measuring cup was equipped with a jacket of water is connected to an efficient temperature controlled, programmable thermal bath. The viscosity of fluid samples were determined using a viscometer with tuning - fork vibration method at a constant resonating frequency of 30 Hz and resonating frequency was maintains based on power differentials. Uniform temperature at the sampling site was obtained through the use of a temperature monitoring with a temperature sensor fixed between the vibrating forks. The viscosity and temperature of the sample were precisely registered within immediate seconds using the online windows communication device at second. The viscometer was calibrated at 25^{o}C using one - point calibration for Flamboyant tree bark and ethylene glycol by extrapolation of standard viscosity of ethylene glycol (gotten from online engineering toolbox). After calibration, the viscosity data were measured for volume fractions of 0.2, 0.4, 0.6, 0.8 and 1.0% for each of the samples in the temperature range of 20 - 70 ^{o}C.

3. Results and Discussion

3.1Viscosity of Afara - EG Nanofluids

The impact of volume fraction and temperature on viscosity of afara tree bark (ATB) nanofluids with ethylene glycol as base fluid are shown in Figures 6. This shows how volume fraction and temperature affects viscosities of ATB - EG nanofluids**.** . This indicates that the viscosity decreased with increase in temperature and as the volume fraction increased, the viscosity increased.1.0% volume fraction had the highest viscosity of 27.91mPaS at 20^{O}C and 0.2% had the lowest viscosity of 3.99mPaS at 70^{O}C. Ethylene Glycol Base ATB nanofluid fluid which showed a decrease in viscosity with temperature also gave a trend indicating that the viscosity values of the nanofluids were above that of the base fluid. The trend also reveals that the viscosity increased with increase in particle loading (increase in volume fraction). Average relative viscosities for all volume fractions were calculated and presented in Figures 7. These represents the viscosity enhancement of the nanofluid when there is a rise in volume concentration increased. A highest enhancement of relative viscosity of 1.23 and lowest value of 1.03 were recorded for ATB nanofluid 1.0 and 0.2% volume concentrations respectively. In comparing experimental and predicted values of viscosity, there was significant difference in their mean values. Einstein, Bachelor and Brinkman models in Figure 8 were used to predict the theoretical values of relative viscosity of ATB - EG nanofluids. The result showed that the experimental relative viscosity values under predicted the Einstein's, Bachelor's and Brinkman's models which implies that the models could not predict the nanofluid viscosity. In the evaluation of heat transfer coefficient viscosity is a very significant property of nanofluids and may vary with size of the nanoparticles, temperature and volume fraction of the nanofluid (Nguyen et al.2007). The viscosity of ethylene glycol - SiO$_2$nanofluids greatly diminishes when impacted by temperature. As widely published in literature, this is typical of nanofluid and the trend here is in conforms with present work (Numburu et al.2007). Theoretical prediction SiO$_2$ - Ethylene glycol nanofluid was done using Einstein model and the result underpredicted the relative viscosity of the nanofluid (Mohsen et al.2016). A similar result was presented in this work. (Justin et al.2018) reported that the viscosity of palm kernel fibre (PKF - EG/water) nanofluid reduced significantly with an rise in the working temperature. The viscosity of coconut fibre - carbon nanofluid with water and ethylene glycol as base fluid was measured. The Viscosities of four different weight fractions (0.04 wt%, 0.08 wt%, 0.5 wt% and 1 wt%) at various temperatures were measured from 15 ^{O}C to 60 ^{O}C and the results showed that an increase or decrease in temperature has a significant impact on the viscosity value since the viscosity was seen to decrease as the temperature increased (Gloria et al.2018). This effect has been accredited to a decrease in intermolecular forces arising from micro - convection. In practice, the trade - off between the heat transfer capabilities and viscosity of the heat transfer fluid is required. Low viscosity under operating conditions improves the medium's ability to exchange heat, thereby reducing the amount of power consumption by recirculating pumps and enabling systems to achieve lower minimum operating temperatures which improves efficiency of operation and extends the life span of the system.

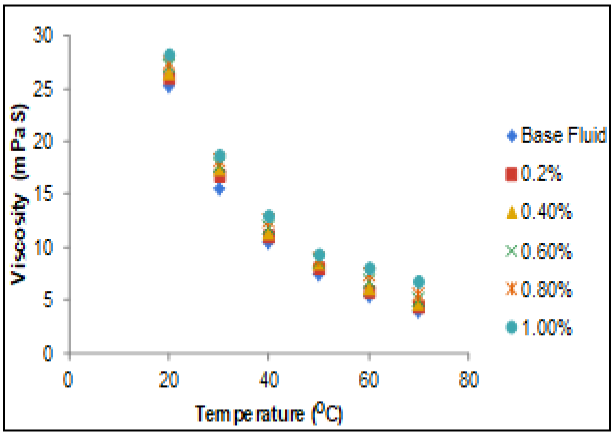

Figure 6: Effect of Temperature and Volume fraction on the viscosity of ATB - EG Nanofluid

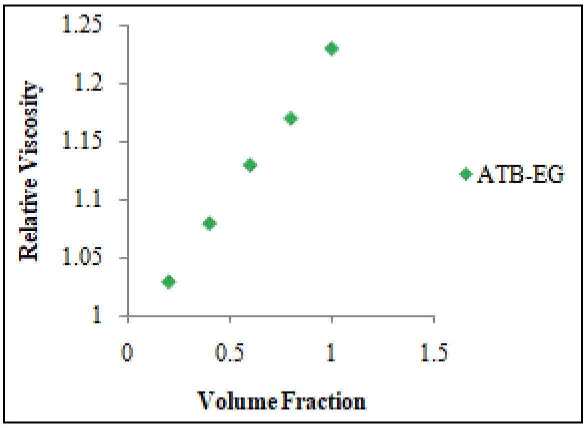

Figure 7: Viscosity Enhancement of Afara Tree Bark Nanofluid with Ethylene Glycol as Base Fluid.

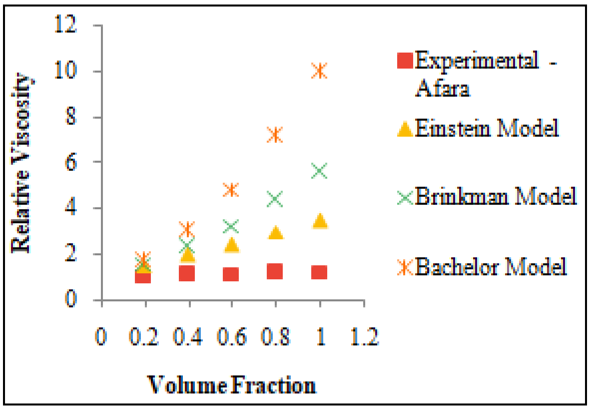

Figure 8: Comparison of Experimental Values with Einstein, Brinkman and Bachelors Prediction of Relative Viscosity

3.2 Thermal Conductivity

The influence of volume concentration and temperature on the thermal conductivity of afara tree bark (ATB) nanofluids with ethylene glycol as base fluid are shown in Figures 9. Here it was observed that thermal conductivity of the nanofluids increased with increase in temperature. This increase was above that of the base fluid. It was observed that ATB nanofluids with ethylene glycol base fluid had higher thermal conductivity for all volume fractions with the highest value of 0.343W/mK for volume fraction 0.8% and at 70^{o}C which is higher than that of the base fluid which had a highest value of 0.294W/mK at 70^{O}C. This could be due to traces of metallic materials found in the results of elemental analysis of the nanoparticles. ATB nanofluid recorded high thermal conductivity enhancement as volume fraction increased though with some level of agglomeration setting in at 0.8% volume fraction which saw a sudden decline as presented in Figure 10. A highest enhancement of 12.1% at 1.0% volume concentration was achieved with lowest enhancement of 6.7% at 0.2% volume fraction. This shows clearly that thermal conductivity is a strong function of the particle volume concentration and temperature. Figure 11 showed a comparison of predicted values of relative thermal conductivity and the experimental values. The theoretical thermal conductivity of ATB - EG were determined using heat transfer predicting models like Wasp, Maxwell and Hamilton and Crosser. The predicted values were found to be lower than the values of experimental work which means that the theoretical models under projected the thermal conductivity of afara tree bark. (Dahai *et al*.2018). The effective thermal conductivity of ATB against the volume concentration showed a linear variation. The current experimental data agree well with the measured data (Das et al.2003) where temperature was varied in the range of 21 to 51 °C demonstrating an enhancement of 2 to 10 % for the particle load of 2.0 vol%. It was shown (Haoran et al.2015) that the effect of volume fraction of ethylene glycol on the thermal conductivity for 75EG/25WT, 85EG/15WT and 95EG/5WT (volume ratios of ethylene glycol and water) based ZnO nanofluid were experimentally investigated and ZnO - 75EG/25WT gave higher thermal conductivity values than ZnO - 85EG/15WT and ZnO - 95EG/5WT. This result agrees with that of ATB nanofluid. The mechanism behind the thermal conductivity enhancement such as Brownian motion and micro convection, explain the conductivity enhancement. Brownian or random motion increases with increase in temperature that is why the thermal conductivity increases with temperature. This was because higher particle surface to volume ratio is due to more particles loading. Particle to particle interactions, nanoparticle cluster and Brownian motion may be the possible reasons for this enhancement. From the reported results it is clear that nanofluids exhibit much higher thermal conductivities than their base fluids even when the concentrations of suspended nanoparticles are very low and they increase significantly with nanoparticle volume fraction

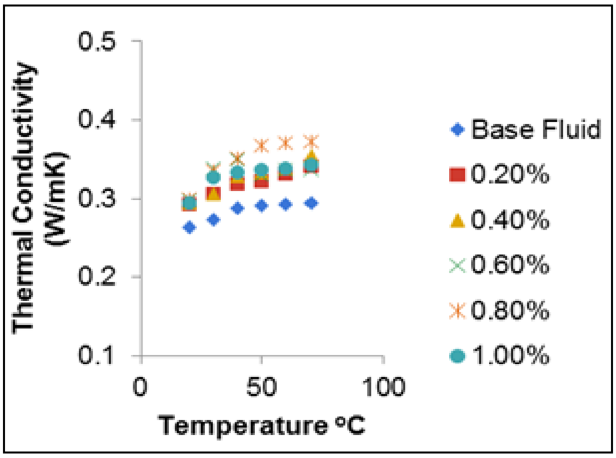

Figure 9: Effect of Temperature and Volume Fraction on Thermal Conductivity of Afara Tree Bark Nanofluid

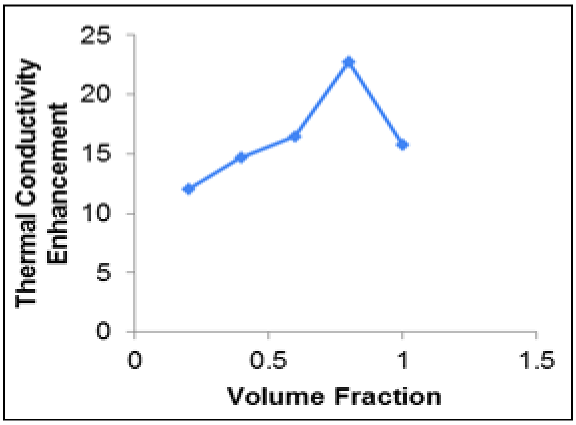

Figure 10: Enhancement of Thermal Conductivity of Afara Tree Bark Nanofluid with Ethylene Glycol as Base Fluid**.**

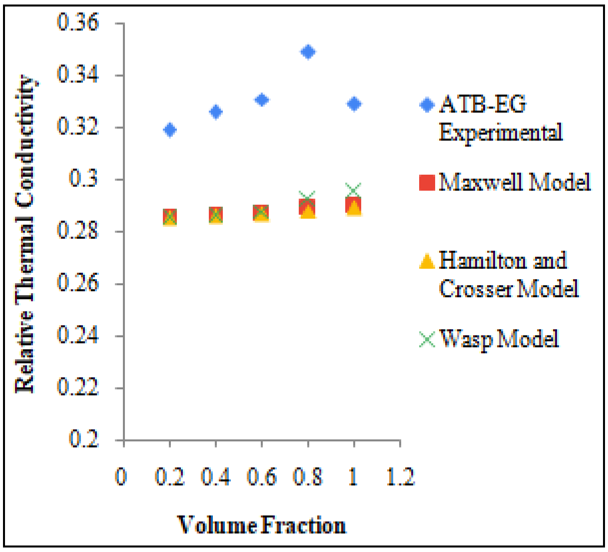

Figure 11: Experimental and Predicted Values of Relative Thermal Conductivities of Afara Tree Bark Nanofluid

4. Conclusion

Stable nanofluid of ATB - EG of varying volume fractions (0.2 – 1.0 %) were formulated through the optimization of the parameters (dispersion fraction, sonication time and amplitude) related to the formulation of stable nanofluids. The stability of ATB - EG nanofluids were verified using UV visible spectrophotometry and visual inspection techniques with both ATB - EG appearing more stable though with little traces of sediments four weeks after preparation. TEM characterization of samples of nanofluids with the highest volume concentration values revealed good suspension of the respective nanoparticles into the base fluids. TEM images also showed both spherical and rod shapes of ATB with particles size of 100nm. Results of elemental analysis showed traces of metallic materials like Iron and Silicon. Investigation of the effect of volume fraction and temperature on the viscosity and thermal conductivity of Afara tree bark (ATB) nanofluid with ethylene glycol as base fluid was carried out. It was observed that viscosity increased with increase in volume fraction and decreased with increase in temperature.1.0% volume fraction had the highest viscosity of 27.91mPaS at 20^{O}C and 0.2% had the lowest viscosity of 3.99mPaS at

$70^{O}C$. Ethylene Glycol Base fluid which also showed a decrease in viscosity with temperature also gave a trend which indicates that the viscosity value of the nanofluids are above the values of the base fluid. ATB - EG nanofluid had highest viscosity enhancement of 1.23 and lowest value of 1.03. Einstein, Bachelor and Brinkman models were drafted for forecasting the theoretical values of relative viscosity of both ATB - EG nanofluids. The result shows that the experimental relative viscosity values were less than Einstein's, Bachelor's and Brinkman's predicted values which implies that the models could not predict the viscosity of both nanofluids. The impact of volume concentration and temperature on the thermal conductivity of ATB - EG was examined. The thermal conductivity of ATB - EG nanofluid increased with increase in temperature and volume fraction. This increase is above that of the base fluid. It was observed that the nanofluids with ethylene glycol base fluid had higher thermal conductivity for all volume fractions of ATB with the highest value of 0.343W/mK for 0.8% volume fraction for ATB at $70^{o}C$ which had a sudden decline at 1.0% due to agglomeration. ATB - EG had highest thermal conductivity enhancement of 12.6% at 0.8% and lowest enhancement of 6.7% at 0.2% volume fraction. Wasp, Hamilton and Crosser and Maxwell, models under - predicted the thermal conductivity of ATB - EG. In general, ATB - EG nanofluid showed appreciable improvement in thermal conductivity as compared to the base fluid and the viscosity enhancement is quite minimal which is suitable for applications in areas with low thermal conductivity and viscosity like cooling in electronics.

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References

[1] Chandrasekar M., Suresh S., and Chandra B.2010. Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/ water nanofluid, Exp. Therm. Fluid Sci.34 (2) 210–216.

[2] Dahai Z., Lingling W., Wei Y., and Huaqing X.2018. Intriguingly high thermal conductivity increment for CuO nanowires contained nanofluids with low viscosity. Scientific Reports PMC5869596.

[3] Das, S. K., Putra, N., Thiesen, P. and Roetzel, W.2003. "Temperature Dependence of Thermal Conductivity Enhancement for Nanofluids, " J. Heat Transfer, 125 (4), pp.567 - 574.

[4] Fedele L., Colla L., Bobbo S.2012. Viscosity and thermal conductivity measurements of water - based nanofluids containing titanium oxide nanoparticles, Int. J. Refrig.35 (8//) 1359–1366.

[5] Gloria A. A., Freddie I., Mohsen S., Josua P. M.2018. Investigation of the Viscosity and Stability of Green Nanofluids from Coconut Fibre Carbon Nanoparticles: Effect of Temperature and Mass Fraction International Journal of Applied Engineering Research ISSN 0973 - 4562 Volume 13, Number 10 pp.8336 - 8342.

[6] Haoran, L., Yurong, H., Yanwei, H., Baocheng, J., Yimin, H.2015. Thermophysical and Natural Convection Characteristics of Ethylene Glycol and Water Mixture Based ZnO Nanofluid., *International Journal of heat and Mass Transfer* 91, 385 – 389.

[7] Jamuna B. A., Ravishankar R. V.2014. "Environmental Risk, Human Health, and Toxic Effects of Nanoparticles, " in *Nanomaterials for Environmental Protection*: John Wiley & Sons, Inc,, pp.523 - 535.

[8] Justin T. A., Jacob S. I., Saheed A. A., Mehdi M., Mohsen S., Josua P. M.2018. Experimental investigations into viscosity, pH and electrical conductivity of nanofluid prepared from palm kernel fibre and mixture of water and ethylene glycol.

[9] Mohamoud J., Tejvir S., Seifelislam M., Gamaleldin M. K., Ayman S., Rima J. I., and Muataz A.2016. Atieh College of Science and Engineering, Hamad Bin Khalifa University (HBKU), Qatar Critical Review on Nanofluids: Preparation, Characterization, and ApplicationsHindawi Publishing Corporation Journal of Nanomaterials Volume, Article ID 6717624, 22 pageshttp: //dx. doi. org/10.1155/2016/6717624

[10] Mohsen S., Saboura Y., Josua P. M.2016. A new model for density of nanofluids including nanolayer International Communications in Heat and Mass Transfer 78 (2016) 168–174

[11] Nguyen, C. Desgranges F., Roy G., Galanis N., Mare T., Boucher S., Anguemintsa H.2007. Temperature and particle - size dependent viscosity data forwater - based nanofluids – hysteresis phenomenon, Int. J. Heat Fluid Flow 28 (6) 1492–1506.

[12] Niesen L. E.1970. "Generalized equation for the elastic moduli of composite materials", *Journal Apply. Physics*, vol.41, pp.4626 - 4627.

[13] Nowack B., Bucheli T. D., 2007. "Occurrence, behavior and effects of nanoparticles in the environment, " *Environmental pollution*, vol.150, no.1, pp.5 - 22.

[14] Numburu P. K., Kulkarni, D. P., Dandekar, A. and Das, D. K.2007. Experimental investigation of viscosity and specific heat of silicon dioxide nanofluids. Micro Nano Lett; 2: 67 - 71.

[15] Pastoriza - Gallego M. J., Lugo L and Legido J. L.2011. Thermal conductivity and viscosity measurements of ethylene glycol - based Al2O3 nanofluids. Nanoscale Res Lett.6: 221_231.

[16] Peyghambarzadeh S. M., Hashemabadi S. H., Jamnani M. S. and Hoseini S. M.2011. Improving the cooling performance of automobile radiator with Al_2O_3/water nanofluid, *Applied Thermal Engineering 31* 1833–1838.

[17] Zamzamian A., Oskouie S. N., Doosthoseini A., Joneidi A., Pazouki M.2011. Experimental investigation of forced convective heat transfer coefficient in nanofluids of Al_2O_3/EG and CuO/EG in a double pipe and plate heat exchangers under turbulent flow, *Experimental Thermal and Fluid Science 35* 495–502.