EXPERIMENTAL STUDIES OF VISCOSITY AND STABILITY OF MANGO BARK 
(MANGIFERA INDICA) BASED NANOFLIUID

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Abstract

Preparation of nanofluid for industrial application has been faced with challenges of cost effectiveness, toxicity, eco-friendliness among others. The use of bio-inspired synthesis for the preparation of nanofluid has been investigated. Stability and viscosity of mango bark (Mangifera Indica) based nanofluid were studied. Sedimentation process, use of surfactants and Uv / vis spectra were used to determine the stability of the fluid. Viscosity of the fluid was investigated at varying temperature from 10°C to 60°C and Volume fraction of 0.1% to 4.0%. Result showed a good stability of the nanofluid without the use of surfactant. The viscosity of the nanofluid showed variation with the varying volume fractions, and working temperatures.

Keywords: Nanofluid, Bio-inspired synthesis, Mango bark, Surfactant, Viscosity, Volume fraction.

1. INTRODUCTION

The concept of nanofluids attracted lot of attention from the scientific world since its introduction by Choi et al (1995). Various researches are being conducted to shed light on thermo-physical properties such as thermal conductivity, viscosity, heat transfer coefficient, boiling heat transfer characteristics among others (Solangi, 2015).

Stability of nanofluid is the most important tool since nanofluid to be used for heat enhancement. Various methods have been used for the dispersion of nanofluid in basefluid. The aim is to overcome the various form of agglomeration of the nano particles due to physical structure of the nanoparticles (size, shape etc), the prevalent particle charge, the strength of Van der waals of attraction and repulsiveness strength. Agglomeration of the Nanoparticles results in settlement and clogging of micro channels and decrease in thermal conductivity of the Nanofluids. The use of ultrasonic vibration has been more popular for achieving uniform dispersion among the process of de-agglomeration. (Adio, 2015).

Several researches have characterised the stability of nanofluid based on sedimentation test, zeta potential value and Uv- Vis spectrometer (Hwang et al, 2006). Nanoparticle stability is affected by concentration, dispersant, viscosity and pH value of the base fluid. It is also dependent on the type of the Nanoparticles, size and shape and intensity of ultrasonic vibration used for the dispersion (Adio et al, 2015). Hwang et al (2006, 2007) studied the stability of Nanofluid with Uv – Vis spectrometer. They concluded that stability of nanofluids was strongly affected by the characteristics of the suspended particles and base fluids referred to as particle
morphology, chemical structure of particles and basefluid. They also stated that the addition of surfactant can improve the suspension stability. In a similar research on stability of nanofluid, Buxuan et al (2003) stated that the stability of nanofluid is affected by the diameter of nanoparticles and the viscosity of the nanofluid. Dean-Mo (2000) and Donsheng et al (2009) in their respective investigations concluded that mass fraction and pH values affect the stability of nanofluids.

Ibrahim et al (2013) investigated the Stability of glycol nanofluids. He investigated the effect of basefluid and the effect of day light on nanofluid stability. They concluded that the effects are a function of time. They also stated that the most simple, reliable and widely used techniques to evaluate the stability of nanofluid is the sedimentation method, also known as the settling bed as stated by witharana et al (2012) using nanofluid with and without surfactant.

Viscosity is an important parameter in heat transfer in fluids. It is a measure of the resistance of a fluid which is being deformed by either shear stress or extensional stress. It describes a fluid’s internal resistance to flow. Nanofluid research is mostly concentrated in heat transfer property of which viscosity is an important part. Viscosity has a significant role in heat transfer and fluid flow. Changes in viscosity properties influences the pumping power required as well as the convective heat transfer coefficients. Therefore, accurate information on the viscosity properties of nanofluids is essential (Yang et al, 2012).

Further research on the hydrodynamic properties of nanofluids resulted in concluding that they show abnormal increase in viscosity, which is an important parameter in determining the pumping power and other heat transfer characteristics such as convective heat transfer coefficient.

Ojha et al (2010) studied the Stability, pH and Viscosity relationships in Zinc Oxide based nanofluids subject to heating and cooling cycles. ZnO nano-particles were dispersed into the base fluids by ultrasonic stirring. Sedimentation study of the various samples of ZnO nanofluids with different concentrations of ZnO nanoparticles, and surfactant (sodium hexametaphosphate (SHMP)) were observed. They stated that The ZnO nanoparticles sedimented within several minutes as zinc oxide is insoluble in water and also, the particles remained within the clusters without being dispersed. Enhanced stability of the ZnO nanofluids is observed with sodium hexametaphosphate as surfactant.

Namburu et al (2007) investigated experimentally the rheological properties of copper oxide nano particles suspended in 60:40 (by weight) ethylene glycol and water mixture. He worked within the range of 0% to 12% volume fraction and concluded that copper oxide nanofluids exhibit Newtonian behaviour in ethylene glycol and water mixture for concentrations varying from 0% to 6.12% with temperatures ranging from -35°C to 50°C. They also stated that the viscosity of nanofluid increases when the volume concentration of the nanoparticles increases and the viscosity decreases as the temperature increases. Pak and Cho, (1998) measured the variation of viscosity of nanofluids with nanoparticle size of γ-Al2O3 and TiO2 nanoparticles. They observed that the viscosity of the nanofluids decreased as the temperature increased and the rate of the decrease became larger with an increase in volume concentration. Nguyen et al (2007). experimental result on nanoparticles of γ-Al2O3 (with an average diameter of 36 and 47 nm) and CuO (with an average diameter of 29 nm) nanoparticles mixed in water at varying temperature up to 75 °C at
different volume concentrations from 1 to 9% showed that the nanoparticle size effect is more significantly for high volume concentrations.

In this work the researcher determine the stability of the bio-inspired synthesis nanofluid by considering the most factors that affect the stability of suspension as reported by Wang et al (2007). The factors include nanoparticles concentration, dispersant, and viscosity of basefluid. The researcher therefore focuses on the use of sedimentation method and UV-vis spectrometer for determining the stability of the nanofluid. It has been difficult to compare the stability of nanofluids reported by different researchers as there has been no uniform standard method at present for examining the stability of nanofluids.

2. PREPARATION OF NANOFLUID

The specimen used for the experiment is Mango bark (*Mangifera Indica*) fibres. The samples were collected washed with distilled water to remove impurities, cut into smaller sizes and sun dried to eliminate moisture. The dried specimen was charged into the 87002 LIMOGE-France milling machine at Federal Institute of Industrial research Oshodi Lagos, Nigeria for processing into nanoparticles. The processing time was 48hrs. Product was discharged and sieved with nanoparticle size sieve to obtain nanoparticles. The nanoparticle samples were both oven dried at temperature of 40 degrees for two hours to further remove moisture content of the sample. The two step method was used for the preparation of the nanofluid. Preparation of the nanofluid was done at the department of Mechanical and Aeronautic Engineering, University of Pretoria, South Africa. Different masses of the sample were measured using a digital highland HCB 1002 (Max:1000g and precision:0.01g) weighing balance for mass of sample and dispersed in the basefluid. Various volume fractions of the nanofluid ranging from 0.1% - 4.0% were prepared by dispersing the measured quantity of the nanoparticles in de-ionized water and sonicating the mixture for one hour using Hielscher ultrasonic processor (up200s). The purposes of the sonication are to breakdown or de-agglomerate clustered nanoparticles, to facilitate even particle distribution and to minimize nanoparticle sedimentation. The mass fraction of the nanoparticles for each volume fraction was determine using the equation stated by Eastman (1997)

\[
\phi = \frac{m_{np}/\rho_{np}}{m_{np}/\rho_{np} + m_{bf}/\rho_{bf}}
\]

Where,

\(\phi\) is the volume fraction; \(m_{np}\) is the mass of nanoparticle; \(\rho_{np}\) is the density of the nanoparticle; \(m_{bf}\) is the mass of the base fluid and \(\rho_{bf}\) is the density of the basefluid

3. CHECKING STABILITY

In order to select the most stabilized nanofluid for the study, the researcher studied the stability of various nanofluids with various concentrations by mass of the nanoparticles sonicated with and without surfactants. The surfactants used during the experimentation to enhance stability were Hexadecyltri methyl ammonia bromide \((C_{19}H_{42}B_{r}N)\), sodium dodecylsulfate \((C_{12}H_{25}N_{a}O_{4}S)\)
and lauric acid. 10% surfactant of the mass fraction of the nanoparticle of the volume fraction was added to the respective volume fraction and its stability observed. The various volume fractions were ultrasonicated at various energy levels ranging from 211,923J to 417,232J for sonication time of one hour to overcome the aggregation of particles resulting from effective Vander Waals forces (Cheng et al, 2010). The sedimentation and reaction of each sample was observed. Wang et al (2007) determine the stability of nano-particle suspension using a similar approach and concluded that the stability depends on the diameter of nanoparticles, dynamic viscosity of nanofluid, pH value of nanofluids and mass fraction of dispersant.

The Table 1 below shows the volume fractions and sedimentation rate for mango bark nanoparticles with and without surfactants.

**Table 1: Volume Fractions, and Sedimentation Rate for Mango Bark Fibres with and without Surfactants**

<table>
<thead>
<tr>
<th>S/No</th>
<th>Name of specimen</th>
<th>Volume fraction</th>
<th>Name of surfactant</th>
<th>Duration</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M.B + DI – Water</td>
<td>0.1 – 4.0%</td>
<td>-</td>
<td>Ohrs to 2wks</td>
<td>No settlement of particles was observed.</td>
</tr>
<tr>
<td>2</td>
<td>M.B + DI – Water</td>
<td>0.1 – 4.0%</td>
<td>H.A.B</td>
<td>Ohrs to 2wks</td>
<td>No settlement of particles was observed.</td>
</tr>
<tr>
<td>3</td>
<td>M.B + DI – Water</td>
<td>0.1 – 4.0%</td>
<td>S.D.S</td>
<td>Ohrs to 1wk</td>
<td>No settlement of particles observed. Settlement of some particles was observed.</td>
</tr>
<tr>
<td>4</td>
<td>M.B + DI – Water</td>
<td>0.1 – 4.0%</td>
<td>Lauric Acid</td>
<td>Ohrs 1-2hrs</td>
<td>No reaction observed. Particles reacted forming colloidal solution.</td>
</tr>
</tbody>
</table>
Fig. 1: (a) Mango bark without surfactant 2 weeks after sonication for volume fractions (b) Mango bark without surfactant 2 hours after sonication for volume fractions (c) and (d) mango bark + surfactant 2 weeks after sonication (e) Mango bark + surfactant, 2 hours after sonication

4. Uv-Vis spectrometer:

The Jenway 24VDC Uv-visible spectrometer with frequency rating of 50/60Hz was used for the spectrum and photometric study. Diluted 15ml of each suspension was poured into test tubes and inserted in the spectrometer. The absorbency of the respective nano-suspensions was measured. The suspensions were allowed to sediment and experiment was repeated on the sample after 1 hour and 24 hours respectively.

5. Particle characterization

The mass fraction for each volume fraction was determined using Eastman et al (1997) formulae in equation 1. The weight of the nanoparticle and base fluid was measured using RADWAG precision balance (As 220.02) and sonicated for one hour using Q700 ultrasonicator (Qsonica, USA) for each volume fraction to enable dispersion of the nanoparticles in the basefluid. The Transmission Electron Microscope (TEM) was used to determine the size and morphology characterization.

6. Viscosity measurement

The viscosity of the fluid was measure using AND vibro viscometer (up 200S) with measuring range of 0.3 – 1000 Mpa.s. The figure 2 below shows the experimental set up.
Plate 2: (a) Hielscher ultrasonic processor (up200s) (b) The AND Vibro Viscometer

The Sv-10 vibro-viscometer was connected to a temperature regulatory water bath through which the temperature in the measuring cup of the vibro-viscometer was regulated via the water inlet and outlet hoses. The vibro-viscometer was also connected to a mini display and control pad and a desktop computer for measuring the viscosity. The apparatus was calibrated using distilled water known viscosity of 0.89 mps at 20°C.

After the calibration, De-ionised water (basefluid) was poured in the measuring cup and the measuring sensor of the vibro-viscometer was lowered to come in contact with the surface of the basefluid. The temperature of the basefluid at the measuring cup was controlled by employing a water jacket connected to the programmable thermal bath. The two vibrating forks keep the temperature of the measurement site uniform and this was monitored with temperature probe affixed equidistance in between the two forks. The temperature of the measurement site was controlled between 10°C and 60°C. The water bath temperature was lowered to 8°C and allows the set up temperature to normalize before measurement was started. Increment of the temperature was done at 10°C up to 60°C.

The computer automatically records the data. The data collection was done by the software wingatherR (Brookfield, 1999) which collected the viscosity, temperature and time. All the viscosity measurements were recorded at steady condition.

The experiment was repeated with mango bark based nanofluid for volume fractions of 0.1%, 0.5%, 1%, 2%, 3%, 4%, respectively.
7. RESULTS AND DISCUSSIONS

7.1 The Transmission Electron Micrograph (TEM)

The result of fig.3(a) shows TEM view for primary particle size of 200nm, and (b) SEM view for 200nm respectively for mango bark nanoparticles and are spherical in shape. Particles with much smaller dimensions can also be seen. The result also shows that clustering of the nanoparticles occurred.

Fig.3: (a) TEM View for 200nm (b) SEM View for 200nm for Mango Bark Nanoparticles

7.2 Checking of Stability

Fig. 4 (i), (ii), (iii) show that the peak absorbance of mango bark nanofluid for 0.1%, 0.2%’ 0.3 appears at 290nm, 290nm and 309nm respectively. The nanofluid sample showed a symmetrical peak at 290nm for 0.1% volume fraction. This peak typically represents the formation of small nanoparticles in solution. The trend of the graphs a, b, and c for 0.1% volume fraction show similar peak for interval of 0hrs, 24hrs and two weeks.

A broad peak is observed for 0.2% and 0.3% volume fraction at 290nm and 309nm respectively. This can be attributed to more concentration of the nanoparticles in solution. Graphs a, b, and c of volume fractions 0.2% and 0.3% have the same trends of broad peaks for intervals of 0hrs, 24hrs and two weeks.
Fig. 4: Uv – Vis Spectrum of Mango Bark based Nanofluid
Result shows that at the time of completion of sonication for each volume fraction, no sedimentation of the nanoparticle was observed either nanofluids (nanofluid with surfactant or without surfactants). After 2hrs of observation, the nanofluid with lauric acid as surfactant reacted rapidly forming sludge in the solution. Sedimentation of particles was observed for nanofluid with sodium dodecylsulfate (C\(_{12}\)H\(_{25}\)N\(_{a}\)O\(_4\)S) as surfactant after one week of observation. Nanofluid with Hexadecyltri methyl ammonia bromide (C\(_{19}\)H\(_{42}\)Br\(_N\)), as surfactant and that without surfactant showed no settlement of particles after 2 weeks of observation.

7.3 Variation of Viscosity with Temperature

Fig.5 shows the variation of viscosity with temperature for mango bark nanofluid at volume fractions of 0% to 4.0%.

For 0% volume fraction the viscosity is of de-ionized water at varying temperature between 10\(^\circ\)C to 60\(^\circ\)C. The results show a higher viscosity of 1.25 at 10\(^\circ\)C and decreases to 0.55 at 60\(^\circ\)C. For 0.1% volume fraction, the viscosity of the nanofluid is lower than that of basefluid at 10\(^\circ\)C and the viscosity decreases as the temperature increases. For 0.5% volume fractions the viscosity increases as the volume fractions increases and decreases as the temperature increases. A similar trend is observed for all other volume fractions as shown in table 2.

<table>
<thead>
<tr>
<th>TEMP (^\circ)C</th>
<th>DI-WATER</th>
<th>(\phi = 0.1)%</th>
<th>(\phi = 0.5)%</th>
<th>(\phi = 1.0)%</th>
<th>(\phi = 2.0)%</th>
<th>(\phi = 3.0)%</th>
<th>(\phi = 4.0)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.25</td>
<td>1.13</td>
<td>1.29</td>
<td>1.35</td>
<td>1.62</td>
<td>2.25</td>
<td>2.88</td>
</tr>
<tr>
<td>15</td>
<td>1.19</td>
<td>1.02</td>
<td>1.12</td>
<td>1.18</td>
<td>1.4</td>
<td>1.93</td>
<td>2.44</td>
</tr>
<tr>
<td>20</td>
<td>1.06</td>
<td>0.98</td>
<td>1</td>
<td>1.05</td>
<td>1.25</td>
<td>1.68</td>
<td>2.19</td>
</tr>
<tr>
<td>25</td>
<td>0.96</td>
<td>0.88</td>
<td>0.9</td>
<td>0.95</td>
<td>1.12</td>
<td>1.47</td>
<td>2.06</td>
</tr>
<tr>
<td>30</td>
<td>0.87</td>
<td>0.79</td>
<td>0.82</td>
<td>0.87</td>
<td>1.02</td>
<td>1.31</td>
<td>1.84</td>
</tr>
<tr>
<td>35</td>
<td>0.8</td>
<td>0.73</td>
<td>0.76</td>
<td>0.8</td>
<td>0.93</td>
<td>1.16</td>
<td>1.66</td>
</tr>
<tr>
<td>40</td>
<td>0.73</td>
<td>0.66</td>
<td>0.73</td>
<td>0.74</td>
<td>0.87</td>
<td>1.04</td>
<td>1.52</td>
</tr>
<tr>
<td>45</td>
<td>0.68</td>
<td>0.61</td>
<td>0.69</td>
<td>0.69</td>
<td>0.8</td>
<td>0.94</td>
<td>1.37</td>
</tr>
<tr>
<td>50</td>
<td>0.63</td>
<td>0.57</td>
<td>0.68</td>
<td>0.66</td>
<td>0.72</td>
<td>0.84</td>
<td>1.18</td>
</tr>
<tr>
<td>55</td>
<td>0.59</td>
<td>0.5</td>
<td>0.64</td>
<td>0.63</td>
<td>0.64</td>
<td>0.71</td>
<td>1.01</td>
</tr>
<tr>
<td>60</td>
<td>0.55</td>
<td>0.43</td>
<td>0.63</td>
<td>0.62</td>
<td>0.57</td>
<td>0.65</td>
<td>0.97</td>
</tr>
</tbody>
</table>

The result of this work is in agreement with reports in various literatures. Yang et al (2012), Nguyen et al (2007), Namburet al (2007) reported the same trend of increased effective viscosity with increase concentration of nanoparticles in basefluid irrespective of the basefluid.
Fig. 5: Variation of Temperature with Viscosity for 0.1% - 4.0% Volume Fraction for Mango Bark Nanofluid.

The result also agrees with the report of Pak and Cho(1998)Chen et al (2011),Duan et al (2011), Adio et al (2015), They respectively investigated the variation of viscosity using metallic based nanofluid and reported that viscosity obeys the same trend of increasing with increase in concentration and decreasing as temperature increases.

8. Conclusion

The parameters considered in this work were limited to particle volume concentration, temperature, nanoparticle and base fluid. The stability of nanofluids was found to be high for nanofluids without surfactants and that with Hexadecyltri methyl ammonia bromide (C_{19}H_{42}BrN), as surfactant. The choice of nanofluid without the use of surfactant for mango bark fibres was considered for cost effectiveness as it shows no settlement of particles after 2 weeks of observation.

A trend of variation of viscosity with temperature was observed for all volume fractions. Viscosity increases as the volume fractions increases and decreases as the temperature increases. This trend is in agreement with works reported in literature for metallic and non metallic oxide based nanofluids.

Considering the present work it can be stated that mango bark based nanofluid is a good substitute for metallic and non metallic oxide nanofluids for heat enhancement. However, it has been clearly shown by the available results in literature that the heat transfer behavior of nanofluids is very complex and many other important factors influence on the heat transfer performance of the nanofluids. So, further works will include experimental research investigations.
or the parametric study to understand the heat transfer characteristics of the nanofluid and identify areas of applications for better conclusion

REFERENCES


