Experimental investigation on the stability and density of TiO$_2$, Al$_2$O$_3$, SiO$_2$ and TiSiO$_4$

Z Said$^{a,b,*}$, M Sajid H$^a$, A Kamyar$^a$ and R Saidur$^{a,b}$

$^a$ Department of Mechanical Engineering
Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

$^b$ UM Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4, Wisma R & D, University of Malaya, 50603 Kuala Lumpur, Malaysia

Email: zafar@siswa.um.edu.my / zaffar_14@yahoo.com

Abstract. At present, literature data on density of nanofluids are still scarce and controversial. In this paper, density data for nanofluids formed by water, as a base fluid, and solid nanoparticles of two different materials are presented. Density was measured by using a Density Meter DA-130N from Kyoto Electronics. The obtain result is compared with previous models and found incompatible for temperature variations.

1. Introduction

Researchers have always been thoroughly looking for ways to optimize the energy use in various devices. This is achievable through different tools. Nanofluids, defined as the mixture of a base fluid and nano-sized (1-100 nm) solid particles, have been recently introduced as one of the novel solutions in this issue. Because of their enhanced capability in terms of heat transfer, these fluids could be implemented as cooling media in different applications. However, existence of solid particles leads to interesting characteristics in the fundamental thermo-physical properties of nanofluids. Thermal conductivity, viscosity, density and stability have been investigated throughout the recent years by many researchers. For the first time, Masuda et al. [1] reported a nearly 30% increase in the thermal conductivity of Al$_2$O$_3$/water nanofluids. In other early studies different increment in the thermal conductivity were reported like 40% increase [2] for copper and 15% increment [3] for alumina nanoparticles. The mechanism of thermal conductivity enhancement has been discussed by some studies like [4-6]. Brownian motion and thermophoresis have been stated to be the main factors behind the heat transfer behavior of nanofluids.

Viscosity of nanofluids has become of importance since it can majorly affect the performance of the system. Rheological behavior of nanofluid flow has been studied recently by many researchers. Reports indicate that viscosity generally increases due to the existence of nanoparticles [7, 8]. Effective parameters on the viscosity like temperature, particle size and volumetric concentration have been investigated by some researchers [9-11]. Nevertheless, study on the density of nanofluids still seems to be confined to few researches. Sommers and Yerkes [12] investigated the density of alumina propanol nanofluid. Density characterization in this study was done by two different methods.
Nanofluids with oxide nanoparticles are interesting because they can be produced more easily than metallic or carbon nanotubes nanoparticles, and they are relatively cheap. In this study, four different types of water based nanofluids such as, TiO$_2$, SiO$_2$, Al$_2$O$_3$ and TiSiO$_4$ has been characterized.

2. Experimental Investigation

2.1. Materials

Some Deionised water was used as a base fluid. The nanoparticles (TiO$_2$, P25 ≥ 99.5% trace metals basis), (SiO$_2$, 99.5% trace metals basis), (TiSiO$_4$, 99.8%) and (Al$_2$O$_3$, 99.8% trace metals basis) were purchased from Sigma-Aldrich. Field emission scanning electron microscope (FE-SEM) was used to obtain the morphological characterization of the nanoparticles with SIGMA Zeiss instrument (Carl Zeiss SMT Ltd., UK). SEM pictures of the respective nanoparticles are shown in figure 1, where the actual dimensions of the nanoparticles can be determined to be 20-40nm, 20-30nm, and 12-120nm respectively. Clear images of Al$_2$O$_3$ and SiO$_2$ could not be obtained by SEM.

![Figure 1. SEM (scanning electron microscope) images of (a) TiO$_2$ (b) Al$_2$O$_3$ (c) SiO$_2$ and (d) TiSiO$_4$ nanoparticles.](image)

Figure 1 given below shows the images of nanoparticles mixed in deionized water, which was obtained using Libra 120 transmission electron microscope at University Malaya. The images obtained show that the particles are indeed very small, whereas some of the particles match the manufacturer’s specified size, while some exceeds the specified size (shown in the title boxes).

2.2. Nanofluid preparation

For this investigation, Nanofluids were prepared by dispersing nanoparticles in distilled water using two step method. Nanoparticles were dispersed into the base fluid using ultra sonic agitation. We used 30 mins of sonication time for preparing the samples. Different volume concentrations of nanoparticles (0.05%, 0.5%, 1%, 3% and 5%) were used to prepare distilled water based nanofluids mechanically. The density and stability of the above mentioned nanofluids will be further investigated with different surfactants such as, PEG, HTAB, SDS and PEG.

2.3. Stability characterization of nanofluids

A Zetasizer 3000HSa (Malvern), based on the Dynamic Light Scattering (DLS), was used to analyses the average dimension of the nanoparticles in solution. The Zeta potential of nanoparticles was measured by the Zetasizer 3000 HSA (Malvern).
2.4. Density of nanofluids

Density is a very important property of a fluid and it affects the friction factor, pump loss, Reynolds number, etc. Pak and Chao [14] considered only the concentration variation at constant temperature (298K) and proposed a formula to measure density of nanofluids. Vajjah et al.[15] has also investigated on density of Al$_2$O$_3$, ZnO$_2$ and Sb$_2$O$_3$:SnO$_2$ EG-W based nanofluids. They compared their result with the proposed formula of Pak and Chao [14] and proposed a correction factor for the relation for their investigated nanofluids. The proposed correction factor also does not reflect the temperature affect. Khanafer and Vafai [16] determined the density of the nanofluids at various temperatures and reported a correlation counting both concentration and temperature. But the correlation is proposed only for the Al$_2$O$_3$ water based nanofluid. As the scope of this investigation is mainly to find out the temperature effect on the nanofluids of different concentrations the proposed correlation of Khanafer and Vafai [16] as represented as Equation (1) is used for our work. The Density Meter DA-130N from Kyoto Electronics was used to measure the density of the nanofluids.

\[ \rho_{\text{eff}} = 1001.064 + 2738.6191\varphi_p - 0.2095T \]  

where, \( 0 \leq \varphi_p \leq 0.04,5 \left( \leq T(\degree C) \leq 40 \right) \)

\( (1) \)

3. Results and Discussion

Equation (1 was compared with our experimental result and represented in the Figure 1. It is clearly visible from the figure that the equation is only valid for up to 1%vol. Since the above mentioned equation was reported for only Al$_2$O$_3$ other nanofluids’ results cannot be compared.

Density variation with concentration at constant temperature (25\degree C) is analysed for the validation of experimental procedure and similar result obtained as claimed by the model shown in Figure 2.

4. Conclusion

Thermo-physical property of nanofluids was evaluated in this work. The physical properties at varying temperatures are significant for engineering calculations. The present model of density doesn’t satisfy the experimental results. The model was claimed valid for Al$_2$O$_3$ for up to 4% vol. concentration but it failed when temperature variation is considered. However, the Pak and Chow model shows an excellent agreement with our experimental value at 25\degree C. Density variations with
temperature at lower concentration (< 1%) are noticeable and significant, thus further investigation should be carried out. New model to meet the experimental results is under study.

Figure 1. Density vs. Temperature Graph for Al₂O₃ Water based nanofluid at different temperature.

Figure 2. Density vs. Concentration graph for the water based nanofluids

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