Investigation on stability and density of methanol based TiO$_2$ nanofluids

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Abstract. This work has investigated the enhancement of heat transfer considering the density of methanol based nanofluids with TiO$_2$ nanoparticles at various volume fractions and temperatures. Nanoparticles are suspended into methanol base fluid at four different concentrations which are 0.01, 0.05, 0.10 and 0.15 vol% and the nanofluids preparation were completed through sonication using ultrasonic homogenizer. The density of prepared nanofluids was measured by KEM-DA 130N density meter at four different temperatures (5, 10, 15 and 20 °C). The results show that the density increases with increase of volume concentrations while the density decreases with increasing temperature and the increment is observed about 2.2% over the base fluid at 0.15 vol% and 20 °C temperature.

1. Introduction:

Nanofluid is a fluid suspension containing metallic or non-metallic nanoparticles with a typical size of (1-100 nm) dispersed into the base fluid. The concept of nanofluids was first introduced by Choi, in 1995 [1]. It is a new class of heat transfer fluids due to its attractive enhancements on thermo–physical properties and heat transfer. For heating and cooling process, cooling is an essential part of multitudinous industrial and civil application such as power generation, chemical process, microelectronics, transportation, air condition and micro–sized application etc. [2, 3]. 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 [4, 5].

Density of fluid is an important thermo–physical property. Like viscosity, density of any fluid also has direct impact over pressure drop and pumping power and it also affects on Reynolds number, Nusselt number, thermal diffusivity as well as heat transfer coefficient of a heat transfer fluid. However, only a limited number of studies have been conducted on density of nanofluids. Sommers et al. [6] observed a linear relationship between density and particle concentration for Al$_2$O$_3$–propanol nanofluid. Correspondingly, Teng et al. [7] found that the density of Al$_2$O$_3$–water nanofluid increased with the increase of volume concentrations (0.5–1.5 wt %) and decreased with increase in temperature (10–40 °C).

In a temperature range of 200–500 K methanol was used as a working fluid of a different heat pipe [8]. Different type of heat pipes like conventional, vapor–dynamic thermosyphons, sorption and micro-miniature heat pipe have recently been used for heat transfer applications [9]. The methanol based
nanofluids were also used as a working fluids in HVAC systems [10]. However, there is no such study done about density measurement of methanol based nanofluids. Only few literature focuses on thermal conductivity measurement and rheology behavior of methanol based nanofluids [11-13]. Therefore, the objective of this study is to investigate the stability and density of TiO_2 nanoparticles suspended in methanol at different volume fraction of nanoparticles with different temperatures. This study will help the researchers to get the idea about the effect of nanoparticles on the density of methanol nanofluids which will encourage the researchers to apply nanoparticles in different kind of heat pipes and thermosypons heat exchangers in HVAC system.

2. Experimental process

2.1 Materials and preparation of nanofluids

The nanoparticles, TiO_2 were purchased from Sigma-Aldrich, Malaysia. 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 (a), where the actual dimensions of the nanoparticles can be determined to be ~21 nm. The base fluid, methanol was purchased from R&M Chemicals (Malaysia).

Then the two-step method was applied to prepare methanol based nanofluids at different volume concentrations. The nanoparticles were suspended into the base fluid (methanol) followed by shaking in the incubator for 30 min at 150 rpm. The suspension was mixed using ultra-sonication homogenizer. The details of experiment conditions are summarized in table 1. Figure 1(b) shows the TEM images of nanoparticles mixed in methanol which was obtained using Libra 120 transmission electron microscope. The images obtained show that the particles are indeed very small, whereas some of the particles match the manufacturer’s specified size, while some exceed the specified size.

| Table 1: Experimental conditions |
|----------------------------------|
| **Base fluid**                   | Methanol                  |
| **Nanoparticle**                 | TiO_2                     |
| **Nanoparticle type**            | Spherical                 |
| **Nanoparticle size (nm)**       | 21 nm                     |
| **Volume concentration (vol%)**  | 0.01, 0.05, 0.10 and 0.15 |
| **Ultra-sonicator**              | Time [min] 120            |
|                                  | Power [W] 500             |
|                                  | Frequency [kHz] 20        |
|                                  | Pulse [s] 2               |
|                                  | Term [s] 2                |
2.2 Stability characterization of nanofluids

In this investigation, the UV–Vis. spectrophotometer, Lambda 35 model, Perkin Elemer make, absorption range of 190 nm to 1100nm was used to study the stability of nanofluid. The inspection range is from 200nm to 800nm. The U-V vis. spectrometer works under the principal of Beer–Lamberts law. Beer–Lamberts law relates that an absorbance of light and proportion of material through is passing. The lesser the suspended particles in the solution makes the light absorption lesser.

Figure 2. UV–Vis spectrum of TiO$_2$–methanol nanofluids
Figure 2 shows the stability of TiO$_2$–methanol nanofluids after ultrasonic agitation. It also shows that the peak absorbance of TiO$_2$ nanoparticle suspension in methanol occurred at 226 nm. The absorption range of the nanofluid was 1.62. The UV–visibility was measured after seven days and there was no distinguished difference between the density of freshly prepared nanofluids and the old one of seven days.

2.3 Measurement of density
The density of methanol based nanofluids was measured by using a density meter, KEM-DA 130N (Kyoto, Japan). This device measures a density range of 0 to 2000 kg/m$^3$. The accuracy of the equipment is ± 0.001% kg/m$^3$. The density was measured at different temperatures and volume concentrations in this study. All data were recorded for three times and the corresponding average values were plotted. since, there is no existing literature related to density of methanol based nanofluids, the experimental values were then compare with that obtained from the most used Pak and Choi [14] model, which is as follows:

$$\rho_{nf} = (1 - \phi)\rho_{bf} + \rho_{np}\phi$$  \hspace{2cm} (1)

where $\rho$ is the density, $\phi$ is the volume fraction and subscript nf–nanofluid, bf–base fluid and np–nanoparticle.

3. Result and discussion

3.1 Visualization effect
Figure 3 shows the photos of TiO$_2$–methanol nanofluids for four volume fractions by shaking with an orbital incubator shaker and sonication. Photos of TiO$_2$–methanol nanofluids were taken just after preparation and after one week. Figure 3 (b) shows that the sedimentation starting rate was very slow. Generally, the sedimentation of mixtures is measured from the bottom of the specimen. It could be possible when there are slurries obvious at the bottom of the sample. This happened especially for the low concentration in the suspension.

![Figure 3](image)

Figure 3: Photos of visualization (a) just after preparation and (b) one week later for TiO$_2$–methanol nanofluids

3.2 Density
Figure 4 shows the comparison between the experimental values obtained from the current study with the existing literature data [15]. The results show relatively acceptable consensus with the existing data. The uncertainties in the measurements of density are approximately 1.2% for pure methanol.
The density of TiO$_2$–methanol nanofluids, as a function of different temperatures and volume concentrations is shown in Figure 5. The results shows that the density of methanol based nanofluids increases with volume concentration but decreases with temperature. Besides, the density of nanofluids was higher than the base fluids. For example, at 5 °C, the density was 811.83 kg/m$^3$ for 0.01 vol% and 818.74 kg/m$^3$ for 0.15 vol%. At volume concentration of 0.15 vol%, the density was 809.13 kg/m$^3$ at 20 °C and 818.74 kg/m$^3$ at 5 °C. The highest increment was observed for 0.15 vol% and 5 °C. Similarly, the same result was found for all volume concentration in this experiment. This was due to dispersion of high density nanoparticles in the base fluids.

Figure 4. Density comparison with measured and reference data
Figure 5. Density of TiO$_2$–methanol as a function of temperature and volume fraction

The experimental value of density of methanol based nanofluids at 20 °C was compared with the model given by Pak and Choi [14] shown in Figure 6. The experimental value was slightly higher than the existing correlation. The highest deviation was observed about 1.5% from the existing correlation. This was due to the difference in the density of the base fluids and water based nanofluids whereas Pak and Cho model was proposed latter.

Figure 6. Comparison of measured density with the values obtained from existing correlations
4. Conclusion

In this study, density of TiO$_2$–methanol nanofluids is investigated at different volume concentrations and temperatures. The experimental results are then compared with existing correlations. The findings of this study are summarized as follows:

(a) Density increases with the increase of volume concentrations and decreases with the increase of temperatures.
(b) Density increases about 2.2% with nanoparticle volume concentration 0.15 vol% and at 20 °C temperature.
(c) The existing correlations for predicting the density of methanol base nanofluids gave lower values than the experimental values.

Therefore, the density and stability of the above mentioned nanofluids will be further investigated with different surfactants such as, PEG, HTAB, SDS and PEG.

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