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INVESTIGATION OF VISCOSITY OF R123-TIO_2 NANOREFRIGERANT

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ABSTRACT

Nanorefrigerants are one kind of nanofluids. It is the mixture of nanoparticle with refrigerants. It has better heat transfer performance than traditional refrigerants. Recently, some researches have been done about nanorefrigerants. Most of them are related to thermal conductivity of these fluids. Viscosity also deserves as much attention as thermal conductivity. Pumping power and pressure drop depends on viscosity. In this paper, the volumetric effects over viscosity of R123-TiO_2 have been theoretically studied. Based on the analysis it is found that viscosity augmented accordingly with the increase of nanoparticle volume concentrations. Extreme percentage of nanoparticle can create clogging on the refrigeration system. Therefore, low volume concentrations of nanorefrigerant are suggested for better performance of a refrigeration system.

***Keywords**:* Viscosity, Nanorefrigerant, Volume concentration.

1. INTRODUCTION

Nanofluids are new dimensional thermo fluids that have emerged after the pioneering work by (Choi, 1995). Nanofluid is a solid-liquid mixture which consists of a nanoparticles and a base liquid. Nanoparticles are metal (Cu, Ni, Al, etc.), oxides (Al_2O_3, TiO_2, CuO, SiO_2, Fe_2O_3, Fe_3O_4, $BaTiO_3$, etc.) and some other compounds (AlN, SiC, $CaCO_3$, CNT, TNT, etc.) and base fluids are (Water, ethylene glycol, propylene glycol, engine oil, refrigerant, etc.). Due to very small sizes and large specific surface areas of the nanoparticles, nanofluids have superior properties like high thermal conductivity, minimal clogging in flow passages, long-term stability, and homogeneity (Chandrasekar et al., 2010). The nanorefrigerant is one kind of nanofluid, and its host fluid is refrigerant (Wang et al., 2005). Conventional thermo fluids like: ethylene glycol, water, oil and refrigerant have poor heat transfer properties. However, these have vast application in power generation, chemical processes, heating and cooling processes, transportation, electronics, automotive and other micro-sized applications. So, re-processing of these thermo fluids for good heat transfer properties is very essential.

Refrigerants are widely used in all types of the refrigeration system. Huge amount of energy is used by this equipment. Nanorefrigerants are potential to enhance heat transfer rate. It can make heat exchanger of air conditioning and refrigeration equipment more compact. This, consequently, will reduce energy consumption in these sectors. It also can reduce emissions, global warming potential and greenhouse-gas effect. However, for accurate and reliable performance (i.e. heat transfer, energy and lubricity) investigation, determination of fundamental properties such as thermal conductivity, viscosity, density, surface tensions and heat capacity of nanorefrigerant with varied concentrations needs to be carried out. There are some literatures on the pool boiling, nucleate boiling, and convective heat transfer, energy performance, lubricity, material compatibility of nanorefrigerant. Table 1 shows a list of literatures about the investigations of nanorefrigerants.

Table 1 List of literature about nanorefrgerants

Investigator	Nanofluid	Investigation
Shengshan and Lin (2007)	R134a - TiO_2	Energy savings 7.43%
Park and Jung (2007)	(R123, R134a)-CNT's	Heat transfer coefficient enhancement up to 36.6%
Bi et al. (2008)	Mineral Oil - TiO_2	26.1% less energy consumption
Trisaksri and Wongwises (2009)	R141b - TiO_2	Nucleate pool boiling heat transfer deteriorated with increasing particle concentrations
Peng et al. (2009)	R113-CuO	Maximum enhancement of heat transfer coefficient, 29.7%
Kedzierski et al. (2007)	R134a - CuO	Enhancement of heat transfer coefficient between 50% and 275% for 0.5% nanolubricant
Peng et al. (2010)	Diamond	Nucleate pool boiling heat transfer coefficient increased by 63.4%
Bi et al. (2011)	TiO_2	9.6% less energy used

Some researches have been done about the thermal conductivity of nanorefrigerants (Jiang et al., 2009). Furthermore, some review papers (Saidur et al., 2011) emphasized only about the thermal conductivity of nanorefrigerants. So far, our knowledge, no research has been performed on the viscosity of nanorefrigerants. However, viscosity seems to be a significant property, and it should be taken into consideration for heat transfer performance studies of a nanofluid (Eastman et al., 2004, Mahbubul et al., 2011).

The objective of this paper is to investigate the viscosity of a refrigerant based nanofluid for different volume concentrations. In the subsequent sections theoretical models (including conventional model of viscosity for suspensions) and correlations for volume concentration's effect over viscosity and experimental results concerning volume fraction effects on viscosity, have been described consecutively.

2. METHODOLOGY

Viscosity describes the internal resistance of a fluid to flow and it is an important property for all thermal applications involving fluids (Nguyen et al., 2007). The pumping power is related with the viscosity of a fluid. In laminar flow, the pressure drop is directly proportional to the viscosity. Furthermore, convective heat transfer coefficient is influenced by viscosity. . First, (Masuda et al., 1993) measured the viscosity of some water-based nanofluids for Al_2O_3, SiO_2 and TiO_2. Then (Pak and Cho, 1998) presented some additional data for Al_2O_3/water nanofluid. Some parameters like, temperature, particle size & shape, and volume concentrations have shown to have a great effect over viscosity of nanofluid.

In this paper, viscosity of R123-TiO_2 has been investigated for 1–5 volumes %. The reasons for choosing TiO_2 nanoparticles are that (i) TiO_2 is currently regarded as a safe material for human being and animals, (ii) TiO_2 nanoparticles are produced in large industrial scale, and (iii) metal oxides such as TiO_2 are chemically more stable than their metallic counterparts (Chen et al., 2007a). The reasons of choosing refrigerant R123 is: it is a low-pressure fluid, and this air conditioner refrigerant is considered partially halogenated as they consist of methane or ethane in combination with chlorine and fluorine. They are shorter lifespan and are less destructive to the ozone layer compared to CFCs. (http://www.airconditioning-systems.com/air-conditioner-refrigerant.html). The viscosity of pure R123 refrigerant has been taken from (Lemmon et al., 2002) for 27^{o}C.

There are some existing theoretical formulae to estimate the particle suspension viscosities. Among them, equation suggested by (Einstein, 1906) could be labeled the pioneer one and most of the other derivations have been basically established from this relation. His assumptions are based on linear viscous fluid containing to dilute, suspended, spherical particles and low particle volume fractions ($\emptyset < 0.02$). The suggested formula is as follows:

$$\mu_{nf} = \mu_{bf}(1 + 2.5\emptyset) \quad (1)$$

Here, μ_{nf} is the viscosity of suspension; μ_{bf} is the viscosity of base fluid, and $\emptyset$ is the volume fraction of particle in base fluid.

Brinkman (1952) extended Einstein's formula to be used with moderate particle concentrations, as follows:

$$\mu_{nf} = \mu_{bf}/(1 - \emptyset)^{2.5} \quad (2)$$

Peng et al. (2009) suggested Brinkman equation to calculate the viscosity of refrigerant based nanofluid. And we have applied this Eq. (2) to get experimental data about viscosity of nanorefrigerant.

Krieger (1959) derived a semi-empirical relation for the shear viscosity covering the full range of particle volume fraction:

$$\mu_{nf} = \mu_{bf}\left(1 - (\emptyset/\emptyset_m)\right)^{-[\eta]\emptyset_m} \quad (3)$$

Where $\emptyset_m$ is the maximum particle packing fraction, which varies from 0.495 to 0.54 under quiescent conditions, and is approximately 0.605 at high shear rates.

This equation has been modified by (Chen et al., 2007b) and termed Modified Krieger and Dougherty equation as:

$$\mu_{nf} = \mu_{bf}\left(1 - (\emptyset_a/\emptyset_m)\right)^{-2.5\emptyset_m} \quad (4)$$

$$\emptyset_a = \emptyset(a_a/a)^{3-D} \quad (5)$$

Where, a_a and a, are the radii of aggregates and primary particles, respectively. D is the fractal index having a typical value of 1.8 for nanofluids.

Frankel and Acrivos (1967) presented a correlation:

$$\mu_{nf} = \mu_{bf}\frac{9}{8}\left[\frac{(\emptyset/\emptyset_m)^{\frac{1}{3}}}{1-(\emptyset/\emptyset_m)^{\frac{1}{3}}}\right] \quad (6)$$

Where, $\emptyset_m$ is the maximum particle volume fraction as determined experimentally.

Lundgren (1972) proposed the following equation under the form of a Taylor series in $\emptyset$:

$$\mu_{nf} = \mu_{bf}\left(1 + 2.5\emptyset + \frac{25}{4}\emptyset^2 + f(\emptyset^3)\right) \quad (7)$$

Considering the effect due to the Brownian motion of particles on the bulk stress of an approximately isotropic suspension of rigid and spherical particles; (Batchelor, 1977) proposed the following formula in 1977:

$$\mu_{nf} = \mu_{bf}(1 + 2.5\emptyset + 6.5\emptyset^2) \quad (8)$$

It is clear from the above two relations that, if second or higher orders of $\emptyset$ are ignored, then these formulas will be the same as Einstein's formula.

There are some correlations available for the temperature and/or particle size effect over viscosity of nanofluids most of which are not versatile enough.

3. RESULT AND DISCUSSION

The increase of viscosity for TiO_2-R113 in respect of volume concentrations have been plotted in Figure 1. It shows viscosity increases with the increase of volume fractions.

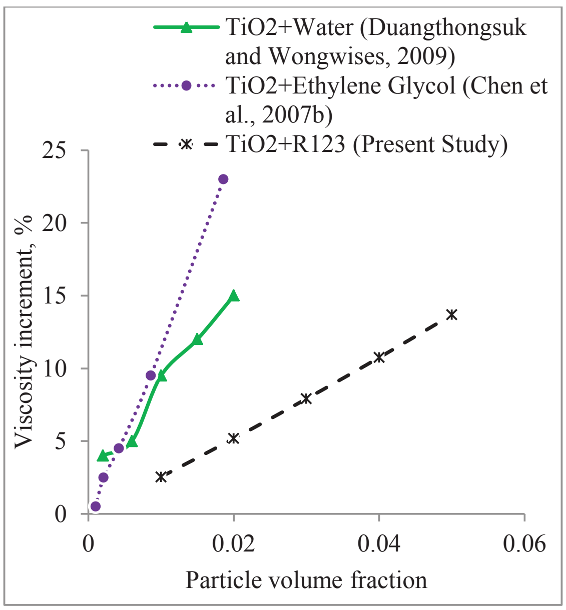

Figure 1 Viscosity increases with the increase of particle volume fractions.

Other two experimental works about viscosity of nanofluid have compared with this result. Duangthongsuk and Wongwises (2009) investigate the viscosity of nanofluid for TiO_2 with water. They found viscosity of nanofluid increases with the increase of volume concentrations, but the increment is not fully linear. It may have happened because of the experimental setup, mixture/stability of nanofluid and also particle size, shape or agglomeration. Chen et al. (2007b) studied the viscosity of nanofluid for TiO_2 with Ethylene glycol and found viscosity increases with the increase of volume fractions. But in their case, the increment is almost linear and increment rate is very high. Because in their study, the nanoparticles were spherical shape, and large agglomeration had occurred. Figure 2 shows a comparison between present studies with some other models. The result of the present study is almost similar to Batchelor model where the result of Einstein's model is quite low, especially for the high-volume percentage. And up to two volumes % all the three results are nearly same. However, Einstein's model is suggested for the low-volume fraction like, less than 2 %.

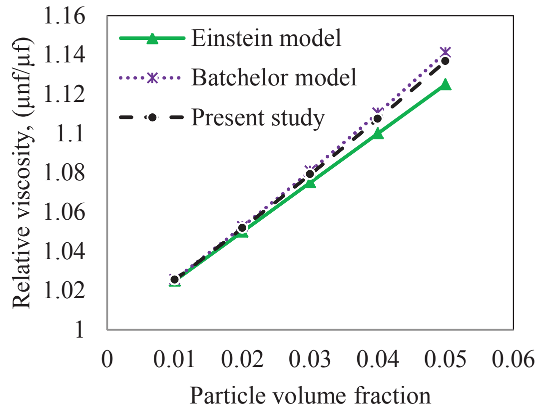

Figure 2 Comparison between experimental results with other model.

4. CONCLUSION

In this study, attempt has been made to investigate the viscosity of nanorefrigerants as TiO_2 with R123. Through this study, it is found that volume fractions have significant effects over viscosity of nanofluids. Results indicate that viscosity increases with the increase of the particle volume fractions.

At the moment, scientists used mathematical relationship/model (thermal conductivity, viscosity, density, surface tensions and specific heat) of other fluids and applying in nanorefrigerant. As different fluids have different fundamental properties, the model used may not a correct one. It is expected that if experimental values of nanorefrigerant are obtained, it would be more appropriate for better analysis of heat transfer, energy performance, and lubricity and so on.

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