INVESTIGATION OF VISCOSITY OF R123-TiO2 NANOREFRIGERANT

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ABSTRACT

Nanorefrigerant is one kind of nanofluids. It is the mixture of nanoparticles 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 consideration as thermal conductivity. Pumping power and pressure drop depends on viscosity. In this paper, the volumetric and temperature effects over viscosity of R123-TiO2 nanorefrigerants have been studied for 5 to 20°C temperature and up to 2 vol. %. The effect of pressure drop with the increase of viscosity has also been investigated. Based on the analysis it is found that viscosity of nanorefrigerant increased accordingly with the increase of nanoparticle volume concentrations and decreases with the increment of temperature. Furthermore, pressure drop augmented significantly with the intensification of volume concentrations and vapor quality. Therefore, low volume concentrations of nanorefrigerant are suggested for better performance of a refrigeration system.

Keywords: Nanofluid, Pressure drop, Volume concentration, Temperature, Vapor quality.

1. INTRODUCTION

Nanofluids are new dimensional thermo fluids that have developed after the innovative research by Choi (1995). Nanofluid is a mixture of solid nanoparticles with thermofluid. Nanoparticles could be metal (e.g. Cu, Ni, Al, etc.), oxides (e.g. Al2O3, TiO2, CuO, SiO2, Fe2O3, Fe3O4, BaTiO3, etc.) and some other compounds (e.g. AlN, SiC, CaCO3, CNT, TNT, etc.) and base fluids are thermo fluids (e.g. Water, ethylene glycol, propylene glycol, engine oil, refrigerant, etc.). The nanorefrigerant could be said a particular type of nanofluid that has refrigerants as the base fluid (Wang et al., 2005). Conventional thermo fluids like: ethylene glycol, water, oil and refrigerant have poor heat transfer properties. However, considering their vast application in power generation, transportation, electronics, heating, cooling and chemical processes, it is necessary to re-engineering these thermo fluids for better heat transfer performances are important.

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.

Some researches have been done about the thermal conductivity of nanorefrigerants (Jiang et al., 2009). Furthermore, some review papers like: 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 is an important property, and it needs to be considered for heat transfer performance studies of a nanofluid (Eastman et al., 2004, Mahbubul et al., 2012). Viscosity is defined as the internal resistance of a fluid to flow and this property is important for all thermal applications those are involved with fluids (Nguyen et al., 2007). The pumping power is related with the viscosity of a fluid (Raja et al., 2012). Moreover, the pressure drop is directly proportional to the viscosity of a fluid specially in laminar flow. Furthermore, convective heat transfer coefficient is also influenced by viscosity.

The aim of this paper is to study the viscosity of R123-TiO2 refrigerant based nanofluid for different volume concentrations at different temperature. Pressure drop characteristics by using nanofluids in a simple system also have been investigated. The reasons for choosing TiO2 nanoparticles have been chosen because: (i) TiO2 has been considered as a safe material for human being and animals, (ii) TiO2 nanoparticles are produced in large industrial scale, (iii) TiO2 nanoparticles have been using in different application of nanotechnology including heat transfer properties, and (iv) metal oxides such as TiO2 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 measured moderately halogenated as it contains of methane or ethane in mixture with chlorine and fluorine. They have shorter
lifespan and are less vicious to the ozone layer related to CFCs. (http://www.airconditioning-systems.com/air-conditioner-refrigerant.html).

2. METHODOLOGY
Viscosity of nanofluid rises tremendously with the increase of nanoparticle volume concentrations. Therefore, in this paper a moderate concentration of nanoparticles up to 2 vol. % of viscosity of R123-TiO2 has been investigated. The viscosity of pure R123 refrigerant has been taken from RefProp. 7 database (Lemmon et al., 2002). The properties of TiO2 nanoparticles and R123 refrigerant have been presented in Table 1 and 2, respectively.

Table 1 Properties of TiO2 nanoparticle.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purities</td>
<td>%</td>
<td>≥99.5</td>
</tr>
<tr>
<td>Avg. particle diameter</td>
<td>nm</td>
<td>~21</td>
</tr>
<tr>
<td>Molecular mass</td>
<td>g/mol</td>
<td>79.87</td>
</tr>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>4260</td>
</tr>
</tbody>
</table>

Table 1 Properties of R123 refrigerant.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical formula</td>
<td></td>
<td>CHCl2CF3</td>
</tr>
<tr>
<td>Molecular mass (g/mol)</td>
<td></td>
<td>153</td>
</tr>
<tr>
<td>Normal boiling point (°C)</td>
<td></td>
<td>27.8</td>
</tr>
<tr>
<td>Freezing point (°C)</td>
<td></td>
<td>107</td>
</tr>
<tr>
<td>Critical temperature (°C)</td>
<td></td>
<td>184</td>
</tr>
<tr>
<td>Critical Pressure (MPa)</td>
<td></td>
<td>3.67</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td></td>
<td>1458.8</td>
</tr>
<tr>
<td>Thermal conductivity (W/m.K)</td>
<td></td>
<td>0.075862</td>
</tr>
<tr>
<td>Dynamic viscosity (mPas)</td>
<td></td>
<td>0.40805</td>
</tr>
<tr>
<td>Specific heat (J/kg.K)</td>
<td></td>
<td>1022</td>
</tr>
</tbody>
</table>

There are some theoretical formulae (model or correlations) available in literature to calculate the viscosity of nanofluids (in general these formulae are for particle suspension viscosity). Among these theories, Einstein (1906) is the pioneer and some other researchers derived relations basically from this equation. The assumptions made for this theory is linearly viscous fluid having dilute, suspended, and spherical particles for a low particle volume concentrations ($\phi < 0.02$). The model is stated as:

$$\mu_{af} = \mu_{bf} \left(1 + 2.5\phi \right)$$  \hspace{1cm} (1)

In 1952, Brinkman (1952) has modified Einstein’s model to be useful for reasonable particle volume concentrations, as:

$$\mu_{af} = \mu_{bf} \left(1 - \phi \right)^{2.5}$$  \hspace{1cm} (2)

Peng et al. (2009a) suggested Brinkman equation to calculate the viscosity of refrigerant based nanofluid. In this analysis Eq. (2) was used to predict viscosity of R123-TiO2 nanorefrigerant.

Some other models were used to compare the value of this analysis. Krieger (1959) derived a semi-empirical relation for the shear viscosity that covered the full range of particle volume concentration, known as K-D model:

$$\mu_{af} = \mu_{bf} \left(1 - (\phi / \phi_m) \right)^{-[n]_{\phi_m}}$$  \hspace{1cm} (3)

Where $\phi_m$ 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.

Later on Chen et al. (2007b) has modified this equation and termed as Modified Krieger and Dougherty (K-D) model as:

$$\mu_{af} = \mu_{bf} \left(1 - (\phi / \phi_m) \right)^{-2.5\phi_m}$$  \hspace{1cm} (4)

$$\phi_a = \phi \left(a_a / a \right)^{2-D}$$  \hspace{1cm} (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.

Lundgren (1972) proposed the following correlation to predict the suspension viscosity under the form of a Taylor series in terms of $\phi$:

$$\mu_{af} = \mu_{bf} \left(1 + 2.5 \phi + \frac{25}{4} \phi^2 + f(\phi^3) \right)$$  \hspace{1cm} (6)

Considering the effect of Brownian motion of particles on suspension of rigid and spherical particles; Batchelor (1977) proposed the following formula:

$$\mu_{af} = \mu_{bf} \left(1 + 2.5 \phi + 6.5 \phi^2 \right)$$  \hspace{1cm} (7)

From the above two relations it is clear that, if second or higher orders of $\phi$ are ignored, and then these models will be the same as Einstein’s model.

The equation has been used to calculate the volume fraction of nanorefrigerants is:

$$\phi_n = \frac{m_n / \rho_n}{m_n / \rho_n + m_r / \rho_r}$$  \hspace{1cm} (8)

Where, $\phi_n$ is the nanoparticle concentration; $m_n$ and $m_r$ are the mass of nanoparticle and refrigerant, respectively; and $\rho_n$ and $\rho_r$ are the density of nanoparticle and liquid phase density of refrigerant, respectively.
The pressure drop can be calculated from friction factor, density, mass flux, vapor quality, tube length and diameter. A correlation proposed by Peng et al. (2009b) has been used to investigate the effect of nanoparticles on frictional pressure drop of nanorefrigerant flow boiling inside a horizontal smooth tube, and the formula is:

$$\Delta P_{r,frict} = F_{PBD} \cdot \Delta P_{frict} \quad (9)$$

Where, $F_{PBD}$ is the nanoparticle impact factor and $\Delta P_{frict}$ is the frictional pressure drop of pure refrigerant. The nanoparticle impact factor is important to correct the frictional pressure drop of pure refrigerant due to nanoparticles suspension. The nanoparticle impact factor can be determined by:

$$F_{PBD} = \exp \left\{ \phi \times \left[ 2.19 \times 10^7 \times \frac{d_p}{D_t} + 37.26 \times \frac{\rho_p}{\rho_{lr}} - 0.63 \times G - 217.73 \times x \times (1 - x) \right] \right\} \quad (10)$$

Where, $d_p$ is the nanoparticle average diameter; $D_t$ is the tube internal diameter; $\rho_p$ is the density of nanoparticle; $\rho_{lr}$ is the liquid-phase density of pure refrigerant; $G$ is the mass flux and $x$ is the vapor quality. A correlation proposed by Müller-Steinhagen and Heck (1986) was used to determine the frictional pressure drop of pure refrigerant (Ould Didi et al., 2002). The model is proposed for two-phase flow with the acceptable vapor quality in range of $0 \leq x \leq 1$.

$$\Delta P_{r,frict} = G(1 - x)^{1/3} + bx^3 \quad (11)$$

Where, the factor $G$ is:

$$G = a + 2(b - a)x \quad (12)$$

In equation (12), $a$ and $b$ are frictional pressure gradients for entire flow liquid and the entire flow vapor in the tube which can be determined from:

$$a = f_L \frac{2G^2}{D_l \rho_{lr}} \quad (13)$$

$$b = f_G \frac{2G^2}{D_l \rho_{G}} \quad (14)$$

Where, $f_L$ and $f_G$ are the friction factor which depend on Reynolds number; $\rho_{G}$ is density of vapor refrigerant. The Reynolds number can be calculated from equation (15):

$$Re = \frac{GD_l}{\mu_r} \quad (15)$$

Where $\mu_r$ is the viscosity of pure refrigerant.

The friction factor can be obtained either from equation (16) or (17):

$$f = \frac{16}{Re} \quad \text{for } Re < 2000 \quad \text{(laminar flow)} \quad (16)$$

$$f = \frac{0.079}{Re^{0.25}} \quad \text{for } Re \geq 2000 \quad \text{(turbulent flow)} \quad (17)$$

Experimental condition to measure the pressure drop characteristics of nanorefrigerants was used as same as used by Mahbubul et al. (2011). Some constant parameters of nanorefrigerant flows inside a horizontal smooth tube can be observed in Figure 1 that has been used for this analysis.

**R123-TiO$_2$ nanorefrigerant**

(Turbulent flow)

- $P_{in} = 91.358$ kPa
- $T_{in} = 298K$
- $G = 100 \text{ kg/m}^2 \text{s}^{-1}$
- $V = 5 \text{ m/s}$
- $x = 0.2$–$0.7$
- $q''' = 5000 \text{W/m}^2$
- $\text{Uniform heat flux}$

![Figure 1 Test condition-Uniformly mass flow in a horizontal smooth tube.](image)

**3. RESULT AND DISCUSSION**

The increase of viscosity for TiO$_2$-R123 nanorefrigerants in respect of volume concentrations have been plotted in Figure 2. It shows viscosity increases with the increase of volume fractions.

![Figure 2 Viscosity increases with the increase of particle volume fractions.](image)
intensification of volume fractions. However, in their studies, the increment rate is very high and almost linear trend. The authors reported large agglomeration of nanoparticles on the suspensions.

Figure 3 shows a comparison among present study with some other models. The result of the present study is almost similar to K-D and Batchelor models where the result of Einstein's model is quite low, especially for the high-volume percentage. All of these four results are nearly same up to one volume concentrations (%). However, Einstein’s model is suggested for the low-volume fraction like, less than 2 %.

Figure 3 Comparison between experimental results with other model.

Figure 4 shows the effect of temperature over viscosity of nanorefrigerants. Normally viscosity of thermo fluid decreases accordingly with the increase of temperature. In this study it has been seen that also viscosity of nanorefrigerant decreased accordingly with the intensification of temperature.

Figure 4 Effect of temperature over viscosity of nanorefrigerants.

The highest frictional pressure drop occurred at vapor quality of 0.7 where the value was 17.16 kPa with 2 vol. % of particle concentration. Pressure drop of pure refrigerant with same vapor quality was only 3.72 kPa. The lowest pressure drop was found 1.74 kPa at vapor quality of 0.2 with 0.5 vol. % of particle concentration. However, pressure drop was 1.12 kPa for pure refrigerant with the same condition. Even with only 0.5 vol. % of nanoparticles concentration, the pressure drop enhancement was 55 % relative to pure R123 refrigerant.

Figure 5 Frictional pressure drop versus particle volume concentration at G=100 kgm$^{-2}$s$^{-1}$ constant mass flux.

Suspending nanoparticles into the refrigerant generally increase the pressure drop even though the mass flow rate of the refrigerant was considered to be constant in this study. When the particle volume fraction is suspended more than 1.5 vol. %, the enhancements of
pressure drop for all vapor qualities were found to be increased rapidly. By increasing the nanoparticles concentration, more collision between the nanoparticles and wall interaction could be occurred and higher pressure drop compared to pure refrigerant was observed for the nanorefrigerant.

4. CONCLUSION

In this study, attempt has been made to investigate the viscosity of nanorefrigerants for TiO$_2$ nanoparticles with R123 refrigerant. Through this study, it is found that volume fractions and temperature have significant effects over viscosity of nanofluids. Results indicate that viscosity increases with the increase of the particle volume fractions. However, it decreases with the increase of temperature. Furthermore, viscosity is directly related to pressure drop characteristics. Pressure drop increases with the increase of volume concentrations and vapor quality.

At the moment, scientists used mathematical relationship/model to analyze thermophysical properties (e.g. 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 be 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. Particle size and shape have also effect over viscosity of nanofluids. Therefore, the effect of particle size and shape need to be identified.

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