International Journal of Mechanical and Materials Engineering (IJMME), Vol. 7 (2012), No. 2, 146-151.

INVESTIGATION OF VISCOSITY OF R123-TIO$_2$ NANOREFRIGERANT

I.M. Mahbubul[1], R. Saidur[1,2] and M.A. Amalina[1]*
[1]Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2]UM Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4, Wisma R&D, University of Malaya, 59990 Kuala Lumpur, Malaysia
*Corresponding author's E-mail: mahbub_ipe@yahoo.com

Received 03 June 2012, Accepted 07 August 2012

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-TiO_2 nanorefrigerants have been studied for 5 to 20ºC 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 thermo fluid. Nanoparticles could be metal (e.g. Cu, Ni, Al, etc.), oxides (e.g. Al_2O_3, TiO_2, CuO, SiO_2, Fe_2O_3, Fe_3O_4, $BaTiO_3$, etc.) and some other compounds (e.g. AlN, SiC, $CaCO_3$, 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-TiO_2 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 TiO_2 nanoparticles have been chosen because: (i) TiO_2 has been considered as a safe material for human being and animals, (ii) TiO_2 nanoparticles are produced in large industrial scale, (iii) TiO_2 nanoparticles have been using in different application of nanotechnology including heat transfer properties, and (iv) 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 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-TiO_2 has been investigated. The viscosity of pure R123 refrigerant has been taken from RefProp. 7 database (Lemmon et al., 2002). The properties of TiO_2 nanoparticles and R123 refrigerant have been presented in Table 1 and 2, respectively.

Table 1 Properties of TiO_2 nanoparticle.

Property	Unit	Value
Purities	%	≥99.5
Avg. particle diameter	nm	~21
Molecular mass	g/mol	79.87
Density	kg/m^3	4260

Table 1 Properties of R123 refrigerant.

Property	R123
Chemical formula	$CHCl_2CF_3$
Molecular mass (g/mol)	153
Normal boiling point (^oC)	27.8
Freezing point (^oC)	107
Critical temperature (^oC)	184
Critical Pressure (MPa)	3.67
Density (kg/m^3)	1458.8
Thermal conductivity (W/m.K)	0.075862
Dynamic viscosity (mPas)	0.40805
Specific heat (J/kg.K)	1022

There are some theoretical formulae (model or correlations) available in literature to calculate the viscosity of nanofluids (in general these formulas 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:

$$\mu_{nf} = \mu_{bf}(1 + 2.5\phi) \tag{1}$$

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

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

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-TIO_2 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:

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

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.

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

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

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

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 ϕ:

$$\mu_{nf} = \mu_{bf}(1 + 2.5\emptyset + \frac{25}{4}\emptyset^2 + f(\emptyset^3)) \tag{6}$$

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

$$\mu_{nf} = \mu_{bf}(1 + 2.5\emptyset + 6.5\emptyset^2) \tag{7}$$

From the above two relations it is clear that, if second or higher orders of $\emptyset$ 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:

$$\varphi_n = \frac{m_n / \rho_n}{m_n / \rho_n + m_r / \rho_r} \tag{8}$$

Where, φ_n is the nanoparticle concentration; m_n and m_r are the mass of nanoparticle and refrigerant, respectively; and ρ_n and ρ_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:

$$\Delta P_{r,n,frict} = F_{PD} \cdot \Delta P_{r,frict} \qquad (9)$$

Where, F_{PD} is the nanoparticle impact factor and $\Delta P_{r,frict}$ 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,

$$F_{PD} = \exp\left\{\varnothing \times \left[2.19 \times 10^7 \times \frac{d_p}{D_i} + 37.26 \times \frac{\rho_p}{\rho_{l,r}} - 0.63 \times G - 217.73 \times x \times (1 - x)\right]\right\} \qquad (10)$$

Where, d_p is the nanoparticle average diameter; D_i is the tube internal diameter; ρ_p is the density of nanoparticle; $\rho_{l,r}$ 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 $0 \le x \le 1$.

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

Where, the factor G is:

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

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:

$$a = f_L \frac{2G^2}{D_i \rho_{r,L}} \qquad (13)$$

$$b = f_G \frac{2G^2}{D_i \rho_G} \qquad (14)$$

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

$$Re = \frac{GD_i}{\mu_r} \qquad (15)$$

Where μ_r is the viscosity of pure refrigerant.

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

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

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

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.

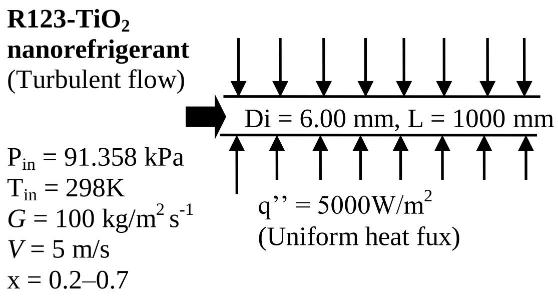

Figure 1 Test condition-Uniformly mass flow in a horizontal smooth tube.

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.

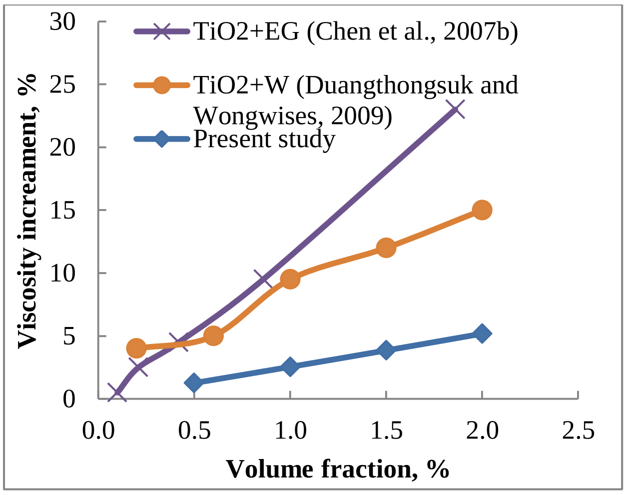

Figure 2 Viscosity increases with the increase of particle volume fractions.

Other two experimental works about viscosity of nanofluid have compared with this result. Duangthongsuk and Wongwises (2009) investigated the viscosity of nanofluid for TiO$_2$ with water. The authors found that viscosity of nanofluid increases with the increase of volume concentrations. The increment rate is linear but not fully straight line or constant rate. 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 accordingly with the 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 %.

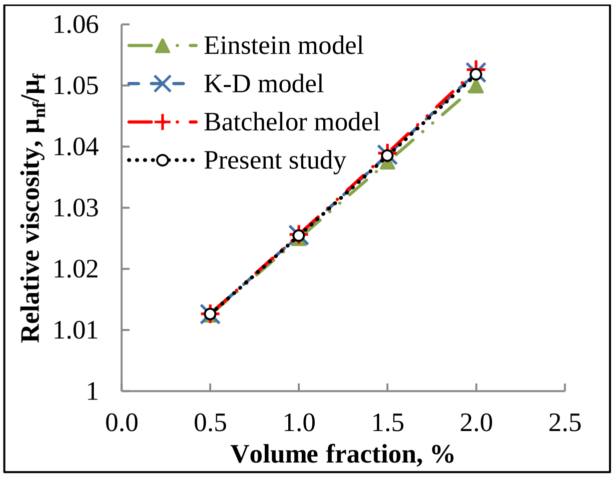

Figure 3 Comparison between experimental results with other model.

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.

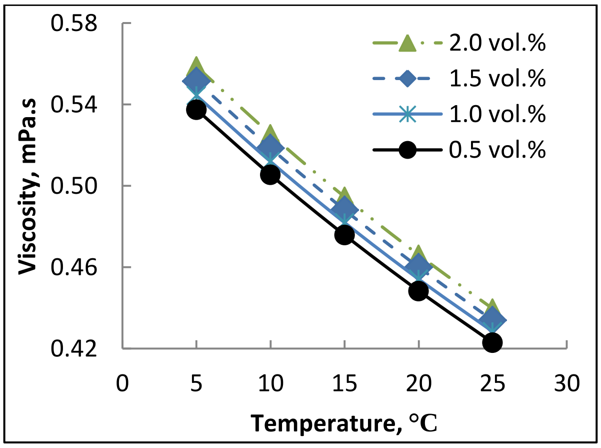

Figure 4 Effect of temperature over viscosity of nanorefrigerants.

The same trend for decrease of viscosity with the increase of temperature were found by some other researchers (e.g. Kulkarni et al., 2006; Namburu et al., 2007). High nanorefrigerant temperature intensifies the Brownian motion of nanoparticles and reduces the viscosity of nanorefrigerant. The highest viscosity observed at 5ºC and 2 volume concentration (%) of particles.

Figure 5 and 6 show the pressure drop characteristics of TiO_2/R123 nanorefrigerant as a function of nanoparticle volume concentration and vapor quality, respectively.

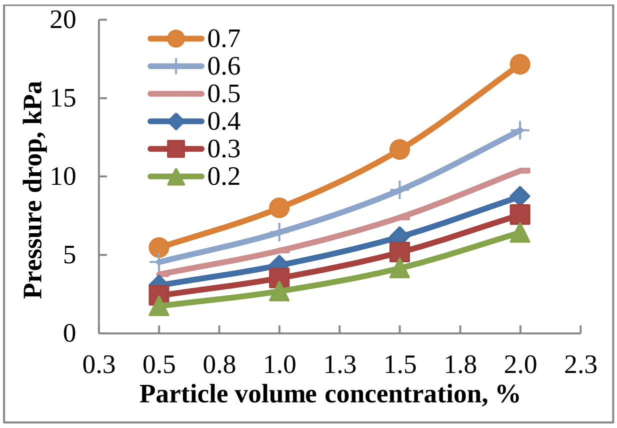

Figure 5 Frictional pressure drop versus particle volume concentration at G=100 $kgm^{-2}s^{-1}$ constant mass flux.

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.

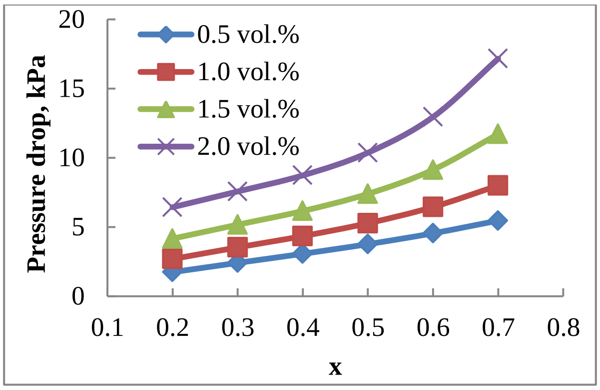

Figure 6 Frictional pressure drop versus local vapour quality at G=100 $kgm^{-2}s^{-1}$ constant mass flux.

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 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.

ACKNOWLEDGEMENT

The authors would like to acknowledge University of Malaya for financial support. This work was supported by the Fundamental Research Grant Scheme (FRGS) fund (Project no. FP017/2010B, FRGS) and Postgraduate Research Grant (PPP) (No. PV013/2011A).

REFERENCES

Batchelor, G. 1977. The effect of Brownian motion on the bulk stress in a suspension of spherical particles, Journal of Fluid Mechanics 83 (01): 97-117.

Brinkman, H. 1952. The viscosity of concentrated suspensions and solutions, The Journal of Chemical Physics 20: 571.

Chen, H., Ding, Y., He, Y. and Tan, C. 2007a. Rheological behaviour of ethylene glycol based titania nanofluids, Chemical Physics Letters 444 (4-6): 333-337.

Chen, H., Ding, Y. and Tan, C. 2007b. Rheological behaviour of nanofluids, New Journal of Physics 9 (10): 367-367.

Choi, S. 1995. Developments and applications of non-newtonian flows, American Society of Mechanical Engineering, New York 231: 99-105.

Duangthongsuk, W. and Wongwises, S. 2009. Measurement of temperature-dependent thermal conductivity and viscosity of TiO_2-water nanofluids, Experimental Thermal and Fluid Science 33 (4): 706-714.

Eastman, J.A., Phillpot, S., Choi, S. and Keblinski, P. 2004. Thermal transport in nanofluids 1, Annu. Rev. Mater. Res. 34: 219-246.

Einstein, A. 1906. Eine neue bestimmung der moleküldimensionen, Annalen der Physik 324 (2): 289-306.

Http://Www.Airconditioning-Systems.Com/Air-Conditioner-Refrigerant.Html. Accesed on 19/07/2011.

Jiang, W., Ding, G. and Peng, H. 2009. Measurement and model on thermal conductivities of carbon nanotube nanorefrigerants, International Journal of Thermal Sciences 48 (6): 1108-1115.

Krieger, I.M. 1959. A mechanism for non Newtonian flow in suspensions of rigid spheres, Trans. Soc. Rheol. 3: 137-152.

Kulkarni, D.P., Das, D.K. and Chukwu, G.A. 2006. Temperature dependent rheological property of copper oxide nanoparticles suspension (nanofluid), Journal of Nanoscience and Nanotechnology 6 (4): 1150-1154.

Lemmon, E.W., Mclinden, M.O. and Huber, M.L. 2002. NIST Reference Fluid Thermodynamic and Transport Properties—Refprop 7.0, NIST Std. Database. Boulder.

Lundgren, T.S. 1972. Slow flow through stationary random beds and suspensions of spheres, Journal of Fluid Mechanics 51 (02): 273-299.

Mahbubul, I.M., Saidur, R. and Amalina, M.A. 2012. Latest developments on the viscosity of nanofluids, International Journal of Heat and Mass Transfer 55 (4): 877-888.

Mahbubul, I.M., Saidur, R. and Amalina, M.A. 2011. Pressure drop characteristics of TiO_2–R123 nanorefrigerant in a circular tube, Engineering e-Transaction 6 (2): 131-138.

Müller-Steinhagen, H. and Heck, K. 1986. A simple friction pressure drop correlation for two-phase flow in pipes, Chemical Engineering and Processing 20 (6): 297-308.

Namburu, P., Kulkarni, D., Misra, D. and Das, D. 2007. Viscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture, Experimental Thermal and Fluid Science 32 (2): 397-402.

Nguyen, C., Desgranges, F., Roy, G., Galanis, N., Mare, T., Boucher, S. and Anguemintsa, H. 2007. Temperature and particle-size dependent viscosity data for water-based nanofluids – Hysteresis phenomenon, International Journal of Heat and Fluid Flow 28 (6): 1492-1506.

Ould Didi, M., Kattan, N. and Thome, J. 2002. Prediction of two-phase pressure gradients of refrigerants in horizontal tubes, International Journal of Refrigeration 25 (7): 935-947.

Peng, H., Ding, G., Hu, H., Jiang, W., Zhuang, D. and Wang, K. 2010. Nucleate pool boiling heat transfer characteristics of refrigerant/oil mixture with diamond nanoparticles, International Journal of Refrigeration 33 (2): 347-358.

Peng, H., Ding, G., Jiang, W., Hu, H. and Gao, Y. 2009a. Heat transfer characteristics of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube, International Journal of Refrigeration 32 (6): 1259-1270.

Peng, H., Ding, G., Jiang, W., Hu, H. and Gao, Y. 2009b. Measurement and correlation of frictional pressure drop of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube, International Journal of Refrigeration 32 (7): 1756-1764.

Raja, M., Arunachalam, R.M. and Suresh, S. 2012. Experimental studies on heat transfer of alumina/water nanofluid in a shell and tube heat exchanger with wire coil insert, International Journal of Mechanical and Materials Engineering 7 (1): 16-23.

Saidur, R., Kazi, S.N., Hossain, M.S., Rahman, M.M. and Mohammed, H.A. 2011. A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems, Renewable and Sustainable Energy Reviews 15 (1): 310-323.

Wang, K., Ding, G. and Jiang, W. 2005. Development of nanorefrigerant and its rudiment property. In: 8th International Symposium on Fluid Control, Measurement and Visualization, Chengdu, China. pp. 13-13.