The International Journal Of Engineering And Science (IJES)
|| Volume || 5 || Issue || 4 || Pages || PP -45-53|| 2016 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Thermophysical Property and Heat transfer Analysis of R245fa/Al_2O_3 Nanorefrigerant

[1]Asif Faizan, [2]Dong Han
[1]College of Thermal Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

ABSTRACT

Nanorefrigerants are special type of nanofluids that are synthesized by mixing or dispersing nanoparticles in refrigerants. They are relatively new with respect to other nanofluids and have broad range of application in refrigeration, air-conditioning systems and other heat transfer devices due to their enhanced heat transfer characteristics. In this paper thermophysical property of new type of nanorefrigerant, based on nanoparticles suspended in 1,1,1,3,3-pentafloropropane (R245fa) has been investigated. Models from existing studies have been used to determine thermophysical properties like thermal conduction, heat capacity, viscosity and density of R245fa nanorefrigerant. Nanoparticles of 1 to 5% volume fraction at temperature of 293 K have been used for the current study. Numerical study has been conducted using commercially available software FLUENT to investigate single phase heat transfer coefficient and Nusselt number of proposed nanorefrigerant at different nanoparticle concentration. Results from the current study shows that thermal conductivity increases and specific heat decreases with increase in particle concentration. In addition, viscosity and density shows increase with increase in volume fraction. Simulated results showed maximum increase of 70.2% and 48.9% in heat transfer coefficient and Nusselt number respectively compared to pure refrigerant at 5% volume fraction

Keywords: *Nanorefrigerant, R245fa, Thermophysical Properties, heat transfer*

Date of Submission: 29 March 2016 Date of Accepted: 09 April 2016

I. INTRODUCTION

Nanofluids are relatively recent approach to enhance thermal conductivity of conventional heat transfer fluids. The idea of nanofluids was first conceived by Stephen Choi [1] in 1995. Nanofluid is composed of nano size particles suspended in base fluid. Thermal conductivity of nanoparticles is much higher than that of the base fluid thus enhancing the overall thermal conductivity. Nanorefrigerant is a type of nanofluid which uses refrigerant as the base fluid. Recently Shengshan et al [2] showed that by using nanoparticles in refrigerants refrigeration system gives much better performance in respect of efficiency and energy saving.

Thermophysical properties of nanorefrigerant like thermal conductivity, viscosity, specific heat and density has significant effect on performance of system and its overall efficiency. Much work has been done regarding calculating thermophysical properties of conventionally used refrigerants such as R114b, R113, R134a, R600a, R12, R134a, R410a using different nanoparticles [3].

Recently with much increasing awareness of global warming and ozone depletion and its overall environmental effect, refrigerant are now being regulated. Ozone depletion potential (ODP) indicates the measure of ability of substance to destroy stratosphere and its reference is taken by refrigerant R11. Global warming potential (GWP) indicates property of substance to warm the planet by acting as greenhouse gas.

Table 1: Environmental effect of refrigerants

Refrigerant	**R134a**	**R113**	**R141b**	**R123**	**R12**	**R410a**	**R245fa**
ODP	0	1	0.12	0.02	1	0	0
GWP(100 years)	1430	6130	725	77	10900	2088	820

Table 1 gives the list of environmental data for refrigerants which has been commonly used as base fluid for nanorefrigerant. From Table 1 it can be seen that R245fa has less GWP and no ODP as compared to rest of the fluids thus exhibiting its potential environmental friendly refrigerant.

Jwo et al [4] investigated R12/Al_2O_3/MO nanorefrigerant in refrigerator using Al_2O_3 nanoparticles of volume fraction 0.05%, 0.1% and 0.2%. They compared R12 with R134a in same system which resulted in showing R12 has slow compression ratio than R134a. When R12 was replaced with R12/Al_2O_3 nanorefrigerant having 0.1 wt% of nanoparticles, the energy consumption reduced by 2.4%.

Kedzierki et al [5] investigated the kinematic viscosity and density of Al_2O_3 nanoparticles added to R134a using 10nm and 60nm size particles. Mahbubul et al[6] investigated the thermal conductivity and viscosity of Al_2O_3/R141b nanorefrigerant. They used volume fraction between 0.5 and 2%. Results showed that viscosity and thermal conductivity of nanorefrigerant increased by 179 and 1.62 times respectively at 2% volume fraction.

Mahbubul et al [7] investigated viscosity of R123/TiO_2 experimentally by using 0.5%, 1%, 1.5% and 2% volume concentration of nanoparticles. Result showed that higher volume concentration results in higher viscosity. Mahbubul et al[8] further studied the effect heat transfer coefficient, viscosity, pressure drop and pumping power experimentally. Results showed increase in heat transfer coefficient, viscosity boiling heat transfer coefficient by increasing volume fraction of nanoparticles.

Many researchers also performed studies related to pool and flow boiling characteristics of nanorefrigerants. Trisaksri et al [9] investigated nucleate pool boiling of R141b/TiO_2 nanorefrigerant. They used TiO_2 nanoparticles of 0.01%, 0.03% and 0.05% of volume concentration. The results showed decrease in heat transfer coefficient with increase in volume fraction. Peng et al [10] shows the influence of CuO nanoparticles on heat transfer coefficient of R113 refrigerant experimentally. Characteristics of flow boiling has been investigated in an horizontal pipe by dispersing 0.1 wt% ,0.2 wt% and 0.5wt% of CuO nanoparticles in base fluid. Results showed enhancement in flow boiling heat transfer coefficient and maximum increase was seen at 29.7% . Tang et al [11] showed that by introducing Al_2O_3 nanoparticles in R141b refrigerant pool boiling heat transfer has improved as compared to pure R141b.

It can be seen that numerous studies has been performed on use of nanoparticles in refrigerants to improve thermophysical properties. This study aims to add an insight on newly proposed nanorefrigerant and to theoretically investigate its thermophysical properties and heat transfer characteristics. The objective is to investigate thermophysical properties such as thermal conductivity, viscosity, specific heat and density of new nanorefrigerant R245fa/Al_2O_3. To the best of author's knowledge no such study exists in current available literature.

II. METHODOLOGY

Al_2O_3 nanoparticles have been selected for the study of thermophysical properties of proposed refrigerant. Properties of Al_2O_3 nanoparticle and R245fa refrigerant are given in Table.2. The analysis was carried out with nanoparticles average size of 50 nm and volume concentration from 1% to 5%. All the properties of R245a/Al_2O_3 nanorefrigerant were calculated at temperature of 293 K using Microsoft Excel and existing correlations from literature.

Table 2: Properties of Al_2O_3 and R245fa

Properties	**R245fa**	**Al_2O_3**
Density ρ (kg/m3)	1339	3880
Dynamic Viscosity μ (Ns/m2)	0.402×10-3	-
Thermal Conductivity k (W/m.K)	0.081	40
Specific Heat capacity cp (kJ/kg.K)	1.36	0.729

2.1 Thermal Conductivity

Maxwell was first to propose model for conductivity of heterogeneous mixture. Thermal conductivity model is based on continues and discontinues phase. The effective thermal conductivity has been given by Maxwell [12] as

$$\frac{k_{eff}}{k_f} = \frac{k_s + 2k_f - 2\phi(k_f - k_p)}{k_s + 2k_f + \phi(k_f - k_p)} \qquad (1)$$

Where k_{eff} is the effective thermal conductivity of mixture and k_s and k_f are thermal conductivity of particle and base fluid respectively. ϕ is the volume fraction of particles in the base fluid.

Hamilton and Crosser [13] used Maxwell model to drive their own correlation of thermal conductivity. There model introduced non spherical shape nanoparticles. They used shape factor (n) which can be experimentally determined for different shapes n=3/Ψ where Ψ is the sphericity .

$$\frac{k_{eff}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)\phi(k_f - k_p)}{k_p + (n-1)k_f + \phi(k_f - k_p)} \qquad (2)$$

Note that for Ψ=1 the Hamilton and Crosser model reduce back to Maxwell model as given in equation (1)
Yu and Choi [14] introduced their model based on the assumption of layered structure formed by the base fluid around nanoparticle surface. The nanolayer enhances the thermal conductivity. Their model, which is modified Maxwell model, includes nanoparticle of radius (r) and nanolayer of thickness (h). The model takes following form

$$\frac{k_{eff}}{k_f} = \frac{k_p + 2k_f - 2\phi(k_f - k_p)(1+\eta)^3}{k_p + 2k_f + \phi(k_f - k_p)(1+\eta)^3} \qquad (3)$$

Timofeeva [15] model is based on the theory of effective medium which is expressed as

$$\frac{k_{eff}}{k_f} = (1 + 3\phi) \qquad (4)$$

Sitprasert [16] model includes effect of nanoparticle concentration, size, and temperature dependent interfacial layer conductivity.

$$\frac{k_{eff}}{k_f} = \frac{(k_p - k_l)\phi k_l[2\beta_1^3 - \beta^3 + 1] + (k_p + 2k_l)\beta^3{}_1[\phi\beta^3(k_l - k_r) + k_r]}{\beta^3{}_1(k_p - 2k_l) - (k_p - k_l)\phi[\beta^3{}_1 + \beta^3 - 1]} \qquad (5)$$

where

$$\beta = 1 + \frac{t}{r_p}$$

$$\beta_1 = 1 + \frac{t}{2r_p}$$

The thickness and the thermal conductivity of interfacial layer are

$$t = 0.01(T - 273)r_p^{0.3}$$

$$k_l = C\frac{t}{r_p}k_r$$

Where r_p is the radius of nanoparticle and C is the unknown constant and can be determined by experiment. For Al_2O_3 the value of C is equal to 30.

2.2 Viscosity

Viscosity is an important parameter when dealing with nanofluid. It directly affects the pressure drop and pumping power of the system. Einstein [17] proposed the viscosity model which has been used by Brinkmann to calculate viscosity of particles suspended in fluid. Brinkmann model [18] includes the volume concentration of nanoparticles as shown in equation (6)

$$\frac{\mu_{eff}}{\mu_f} = \frac{1}{(1-\phi)^{2.5}} \qquad (6)$$

where μ_{eff} is the dynamic viscosity of nanofluid and μ_f is the dynamic of the basefluid. Wang etc al [19] model is given by

$$\frac{\mu_{eff}}{\mu_f} = (1 + 7.3\phi + 123\phi^2) \qquad (7)$$

Gherasim et al [20] proposed model for viscosity and it is given as equation(8)

$$\frac{\mu_{eff}}{\mu_f} = 0.904\, e^{14.8\phi} \qquad (8)$$

Pak and Cho[21] model is given by

$$\frac{\mu_{eff}}{\mu_f} = (1 + 39.11\phi + 533.9\phi^2) \qquad (9)$$

2.3 Specific Heat
Pak and Cho[13] has given the model to calculate the specific heat of nanofluids and is given as

$$C_{nf} = \phi C_p + (1+\phi)C_f \qquad (10)$$

where C_p and C_f are specific heat capacity of particle and base fluid respectively.

2.4 Density
Pak and Cho[13] used following equation for calculating density of nanofluids

$$\rho_{nf} = \phi\rho_p + (1+\phi)\rho_f \qquad (11)$$

where ρ_p and ρ_f are the density of particle and base fluid respectively

2.5 Heat Transfer
Enhancement of heat transfer characteristics in fluids is one of the key parameter for their utilization in industry. By adding nano-size particles in refrigerant, thermal conductivity can be increase which subsequently helps to enhance heat transfer rate. In this section numerical investigation of Al_2O_3/R245fa single phase convective heat transfer and Nusselt number has been conducted using commercially available software Ansys Fluent. The geometrical parameters used for study has been given in Fig 1. To study convective heat transfer study, the flow in taken to be fully turbulent.

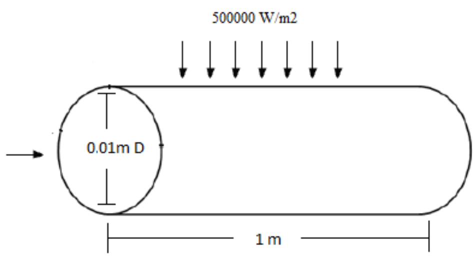

Fig 1. Computational domain dimensions

2.6 Governing Equations
Researchers have used various models for computation in field of nanofluids. This includes single phase approach, mixture model and Euler Lagrangian model .Use of mixture model shows better results than single phase approach, however single phase approach still give considerably accurate results [22]. At low concentration of Nanoparticles in base fluid single phase model can be used due to its simplicity and less computational time. Therefore single phase approach has been used to study the effect of heat transfer in nanorefrigerant. In this study it is assumed that

- Nanoparticles are spherical and uniform in size
- Nanoparticles and fluid flow with same uniform velocity
- Flow is incompressible and Newtonian

Based on above given assumptions, flow and heat transfer are considered by the continuity, momentum and energy equation as follows

Continuity equation:

$$(\nabla . V) = 0 \qquad (12)$$

Momentum Equation:

$$\rho(\nabla . V)V = -\nabla P + \mu\nabla^2 V \qquad (13)$$

Energy equation:

$$\rho C_p(\nabla . V)T = k\nabla^2 T \qquad (14)$$

For all the above mentioned equations (12-14) control volume approach using Ansys Fluent has been used. Both the momentum and energy equation has been discretized by second order upwind scheme. The coupling of pressure and velocity is dealt with the known semi implicit method for pressure linked equation (SIMPLE) algorithm.

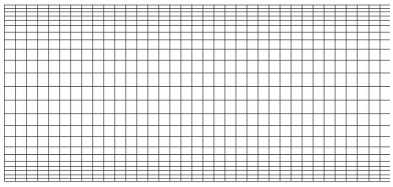

Fig.2. Generated structured mesh of computational domains

2.7 Boundary Conditions

The velocity at pipe inlet of nanorefrigerant has been calculated using Reynold number ranges from 20000 to 100000. Inlet temperature is set to be 293K with no slip boundary condition at the tube walls. Constant heat flux of 500000 W/m^2 has been considered for numerical analysis. Nanorefrigerant properties of thermal conductivity , density, specific heat, and viscosity has been calculated using equation 3,11,10 and 7 respectively because of their good agreement with experimental data as shown by Pantzali et al [23].

2.8. Data Reduction

The average convective heat transfer coefficient and average Nusselt number is calculated using equations (15) and (16) respectively.

$$\bar{h} = \frac{q''}{(\bar{T}w - \bar{T}f)} \qquad (15)$$

$$\overline{Nu} = \frac{\bar{h}d}{k} \qquad (16)$$

III. RESULTS AND DISCUSSION

3.1 Thermal Conductivity

Fig.1 shows the thermal conductivity of R245fa/Al_2O_3 nanorefrigerant with volume concentration from 1% to 5%. Different models were used to calculate the change in thermal conductivity with respect to change in volume concentration. Fig 1 shows that conductivity increases with increasing volume concentration. Maxwell[12] model shows lowest increase of 4.3 % as compared to rest of the models. Yu and Choi[14] model showed highest thermal conductivity of 16.5%.

Timofeeva[15], Hamilton [13] and Sitprasert [16] models almost showed same linear increase of thermal conductivity of about 12.4%. The results from current study were compared to other studies and showed same trend in thermal conductivity enhancement as of other nanorefrigerant. Increase in thermal conductivity of nanorefrigerant can be attributed to different mechanisms suggested by various authors. Keblinski et al [24] proposed four possible microscopic mechanisms for the increase in thermal conductivity: Brownian motion of nanoparticles, molecular level layering of the liquid-particle interface, ballistic rather than diffusive nature of heat conduction, and effect of nanoparticle clustering.

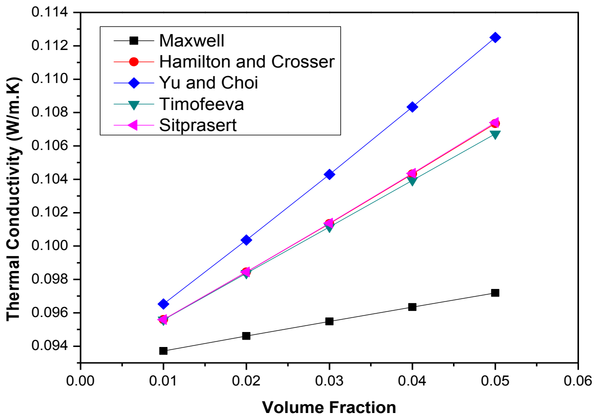

Fig.3. Effect of thermal conductivity with respect to volume fraction using different models

3.2 Dynamic viscosity
Fig 2 shows the change in dynamic viscosity with respect to change in volume concentration. General trend shows that viscosity increases with the increase in volume concentration of nanoparticles. Brinkamnn model showed relatively much less increment in viscosity as compared to rest of the models in the study. Wang, Gherasim and Pak and Cho model showed increase of 54%, 80% and 197% respectively. As stated earlier, studies of viscosity of suspended particles in base fluid has been conducted by Einstein using spherical particles. Einstein model can only predict viscosity in very low volume fraction and not suitable to predict viscosity based on wide range of operating conditions. Pak and Cho [13] used empirical data to give correlation of viscosity of dispersed nanoparticles in base fluid. Brinkman model showed least increment in viscosity as compared with rest of the models.

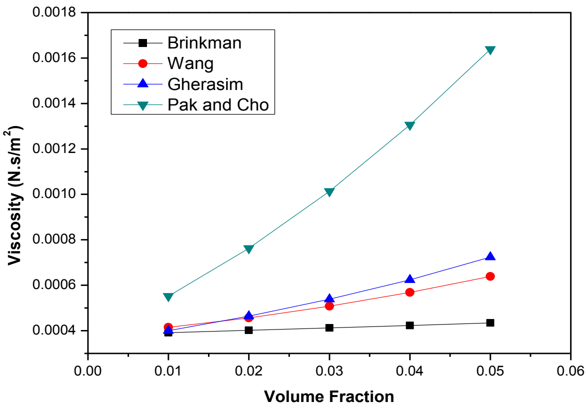

Fig.4. Effect of dynamics viscosity with respect to volume fraction using different models

3.3 Specific heat
The effect of volume concentration on specific heat of nanorefrigerant has been investigated. The specific heat was calculated using Eq(10).Fig 3 shows that by increasing the volume concentration of nanoparticles, specific heat capacity of nanorefrigerant decreases. The specific heat decreasing trend is similar to other nanorefrigerants as shown by Omer et al [25] . The decrease of nanorefrigerant specific heat compared with base fluid is due to lower specific heat capacity of added particles. Specific heat of nanorefrigerant has shown maximum decreased of 2.25% by addition of nanoparticle by 5% of volume fraction.

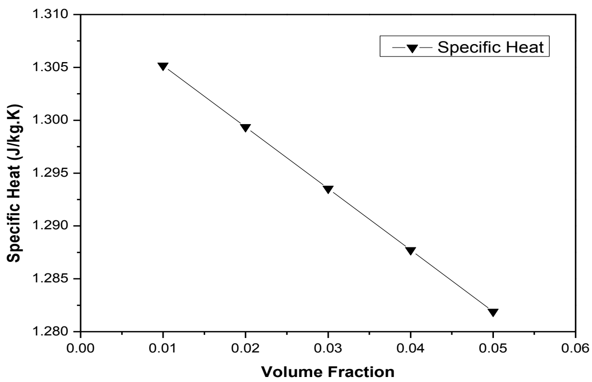

Fig.5. Effect of the specific heat of Al_2O_3/R245fa nanorefrigerant at different volume fraction

3.4 Density
The change in density of nanorefrigerant with respect to volume fraction has been shown in Fig.4. Eq (11) was used to calculate the density of nanorefrigerant. Density of nanoparticle is much higher compared with basefluid (Al_2O_3 and R245fa are about 3880 and 1339 kg/m^3, respectively) thus by addition of nanoparticles mixture of solid-liquid suspension shows much higher density. Most of the studies shows same trend of nanorefrigerant increasing density when compared with base fluid [25,26].

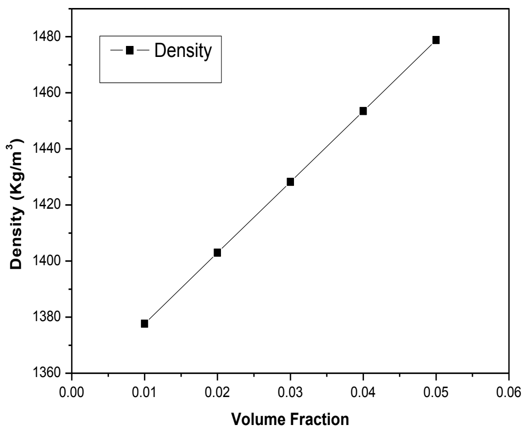

Fig.6. Effect of the density of Al_2O_3/R245fa nanorefrigerant at different volume fraction

3.5 Numerical Method and Validation

The computational fluid dynamic code FLUENT has been used to solve the present problem. The governing equations (12) to (14) were solved by control volume approach. This method is based on the spatial integration of the conserved equations over finite control volumes, converting the governing equation to a set of algebraic equations. The algebraic discretized equations were solved throughout the physical domain under consideration. The computer model was simulated using pure refrigerant initially without any addition of nanoparticles. Simulation results compared with Gnielinksi correlation [27] shows that uniform grid of size 24 × 1000 is adequate to ensure satisfactory results. Maximum error is 6.6%.

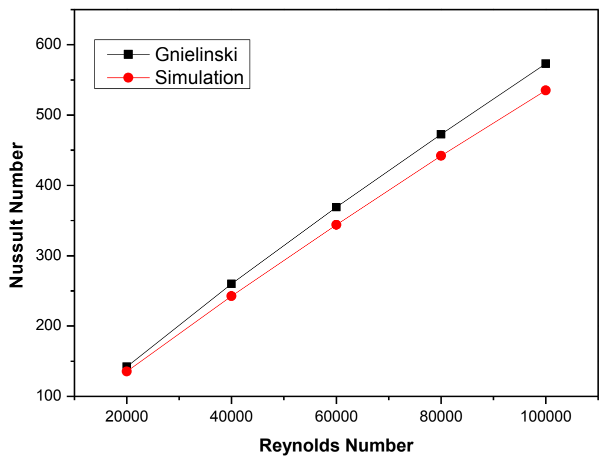

Fig 7. Grid validation by using correlation by Gnielinski [27]

3.6 Convective heat transfer coefficient

Fig 8 shows the evolution of heat transfer coefficient with increasing volume fraction over the Reynolds number that ranges from 2000 to 10000. With the increase of nanoparticle volume fraction heat transfer coefficient shows rise in its value. The maximum increase can be seen at Re of 10000 and volume fraction of 5% of about 70.2%. This increase of heat transfer coefficient can be explained by improvement in thermophysical properties of base fluid. Due to higher thermal conductivity of nanoparticles compared with that of base fluid, heat transfer coefficient tends to increase. Moreover, the product between specific heat and density also increases, therefore more energy is required to increase the bulk temperature with respect to the base fluid. The increase in heat transfer coefficient is of particular interest to the researchers due to its advantage while choosing nanorefrigerant over conventional refrigerants.

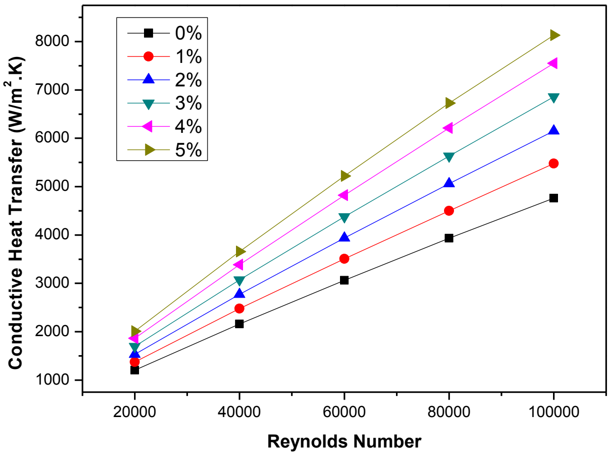

Fig 8. Comparison of average heat transfer coefficient at different Reynolds number with changing volume fraction

3.7 Nusselt Number

Fig 9 shows comparative analysis between base fluid and nanorefrigerant at different volume concentration for Reynolds number ranging between 20000 and 100000. Nusselt number increases with the increase in volume concentration. The trend of Nusselt number argumentation for different concentration of nano-particle is almost similar by variation of Reynolds number. However the increase in heat transfer due to increasing Reynolds number is due to thinner sub laminar layer. Maximum increase in Nusselt number for this study can be seen at Re 100000 of 48.9% for volume fraction of 5%. The overall increase in Nusselt number of nanorefrigerant has a clear advantage over base fluid when used in devices like heat exchangers, refrigeration systems and heat pumps.

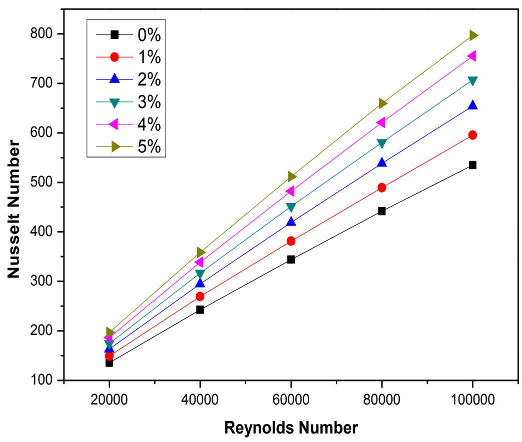

Fig 9. Comparison of average heat transfer coefficient at different Reynolds number with changing volume fraction

IV. Conclusion

In this study thermal conductivity, dynamic viscosity, specific heat and density of new nanorefrigerant R245fa/Al_2O_3 has been analyzed. It has been seen from the study that thermal conductivity increase with increase of nanoparticle volume fraction in base refrigerant R245fa with maximum to 16.5% at 5% volume fraction. Thermal conductivity of nanorefrigerant increases with increase in temperature. Dynamic viscosity increases with the increase in volume fraction of nanoparticle and decreases with the increase in temperature.

Specific heat capacity increases with increase in temperature and density decreases with increase in temperature. Increase in thermal conductivity is a promising characteristic of R245fa/Al_2O_3 nanorefrigerant with respect to its applications in industry as a refrigerant where high heat transfer property is required, but it comes with the penalty of increase in viscosity, so optimized solution is required to select the volume fraction of nanoparticles in the base fluid for optimum performance.

Simulation results from current study shows an increase of heat transfer coefficient with increase of volume fraction in nanorefrigerant at any given Reynolds number. Nusselt number shows same increasing trend with increase in volume fraction. The maximum increase has been seen at Reynolds number 100000 of 70.2% and 48.9% for heat transfer coefficient and Nusselt number respectively.

This study investigated effect of adding nanoparticles in refrigerant and significant increase in nanorefrigerant thermal properties has been pointed out. More study and specially experiment are required to investigate more into improving thermophysical and heat transfer properties of newly proposed Al_2O_3/R245fa nanorefrigerant

REFERENCES

[1]. S. Choi, Enhancing thermal conductivity of fluids with nanoparticles, in: D.A. Siginer, H.P. Wang (Eds.), developments applications of non-newtonian flows, ASME, New York, 1995, pp. 99–105. FED-vol 231/MD-vol.

[2]. Shenshan Bi,Kai Guo etc al. Performance of domestic refrigerator using TiO2-600a nano-refrigerant as working fluid, Energy Conservation and Management, 2010, pp 733-737

[3]. Celen, A., Çebi, A., Aktas, M., Mahian, O., Dalkilic, A. S., & Wongwises, S. (2014). A review of nanorefrigerants: Flow characteristics and applications. *International Journal of Refrigeration*, *44*, 125-140..

[4]. Jwo, Ching-Song, et al. "Effects of nanolubricant on performance of hydrocarbon refrigerant system." *Journal of Vacuum Science & Technology B*27.3 (2009): 1473-1477.

[5]. Kedzierski, Mark A. "Viscosity and density of aluminum oxide nanolubricant."*international journal of refrigeration* 36.4 (2013): 1333-1340.

[6]. Mahbubul, I. M., R. Saidur, and M. A. Amalina. "Influence of particle concentration and temperature on thermal conductivity and viscosity of Al 2 O 3/R141b nanorefrigerant." *International Communications in Heat and Mass Transfer* 43 (2013): 100-104.

[7]. Mahbubul, I. M., R. Saidur, and M. A. Amalina. "Investigation of viscosity of R123-TiO2 nanorefrigerant." *Proceedings of Regional Tribology Conference 2011: RTC2011*. Malaysian Tribology Society, 2011.

[8]. Mahbubul, I. M., R. Saidur, and M. A. Amalina. "Heat transfer and pressure drop characteristics of Al 2 O 3-R141b nanorefrigerant in horizontal smooth circular tube." *Procedia Engineering* 56 (2013): 323-329.

[9]. Trisaksri, Visinee, and Somchai Wongwises. "Nucleate pool boiling heat transfer of TiO 2–R141b nanofluids." *International Journal of Heat and Mass Transfer* 52.5 (2009): 1582-1588.

[10]. Peng, Hao, et al. "Measurement and correlation of frictional pressure drop of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube. "*international journal of refrigeration* 32.7 (2009): 1756-1764.

[11]. Tang, Xiao, Yao-Hua Zhao, and Yan-hua Diao. "Experimental investigation of the nucleate pool boiling heat transfer characteristics of δ-Al 2 O 3-R141b nanofluids on a horizontal plate." *Experimental Thermal and Fluid Science* 52 (2014): 88-96.

[12]. James Clark Maxwell, A Treatise on Electricity and Magnetism, Unabridged, Dover,1954.

[13]. R.L. Hamilton, O.K. Crosser, Thermal conductivity of heterogeneous two-component systems, Ind. Eng. Chem. Fundam. 1.3 (1962) 187–191.

[14]. W. Yu, S.U.S. Choi, The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Maxwellmodel, J. Nanoparticle Res. 5.1-2 (2003) 167–171.

[15]. E.V. Timofeeva, A.N. Gavrilov, J.M. McCloskey, Y.V. Tolmachev, "Thermal conductivity and particle agglomeration in alumina nanofluids": experiment and theory, Phys. Rev. 76 (6) (2007) 061203

[16]. C. Sitprasert, P. Dechaumphai, V. Juntasaro, A thermal conductivity model for nanofluids including effect of the temperature-dependent interfacial layer, J.Nanopart. Res. 11 (6) (2009) 1465–1476.

[17]. Albert Einstein, A new determination of molecular dimensions, Ann. Phys. 19.2 (1906) 289–306

[18]. H.C. Brinkman, The viscosity of concentrated suspensions and solutions, J. Chem.Phys. 20 (4) (2004) 571-571

[19]. Xinwei Wang, Xianfan Xu, Stephen U.S. Choi, Thermal conductivity of nanoparticle–fluid mixture, J. Thermophys. Heat Transf. 13.4 (1999) 474–480

[20]. Gherasim Iulian, Gilles Roy, Cong Tam Nguyen, Vo-Ngoc Dinh, Experimental investigation of nanofluids in confined laminar radial flows, Int. J. Therm. Sci. 48 (8)(2009) 1486–1493

[21]. Pak Bock Choon, Young I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Exp. Heat Transf. Int. J. 11 (2) (1998) 151–170

[22]. Kamyar, A., R. Saidur, and M. Hasanuzzaman. "Application of computational fluid dynamics (CFD) for nanofluids." *International Journal of Heat and Mass Transfer* 55.15 (2012): 4104-4115.

[23]. Pantzali, M. N., A. A. Mouza, and S. V. Paras. "Investigating the efficacy of nanofluids as coolants in plate heat exchangers (PHE)." *Chemical Engineering Science* 64.14 (2009): 3290-3300.

[24]. Keblinski, Phillbot, et al. "Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids)." *International journal of heat and mass transfer*45.4 (2002): 855-863.

[25]. Alawi, Omer A., and Nor Azwadi Che Sidik. "Influence of particle concentration and temperature on the Thermophysical properties of CuO/R134a nanorefrigerant." International Communications in Heat and Mass Transfer 58 (2014): 79-84.

[26]. Mahbubul, I. M., et al. "Thermophysical properties and heat transfer performance of Al $_2$ O $_3$/R-134a nanorefrigerants." *International Journal of Heat and Mass Transfer* 57.1 (2013): 100-108.

[27]. Bergman, Theodore L., Frank P. Incropera, and Adrienne S. Lavine. *Fundamentals of heat and mass transfer*. John Wiley & Sons, 2011.