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INVESTIGATING THE INFLUENCE OF NANO PARTICLE'S RADIUS ON THERMOPHYSICAL PROPERTIES OF AL_2O_3-WATER NANOFLUIDS UNDER BROWNIAN MOTION EFFECT

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ABSTRACT

In the past two decades, numerous studies and experiments have been conducted by several researchers around the world in the field of nanofluids. In most of these studies, CuO-water base, SiC-water base, and Al_2O_3-water base nanofluids have been utilized. As industry has shown a promising and increasing application of Al_2O_3-water nanofluids, a comparative numerical investigative study on the effect of nanoparticle's radius of Al_2O_3-water base nanofluid in a 2-D square shape enclosure is presented. This study has considered a Brownian motion effect in a single-phase flow regime. Saghir et al. [International Thermal Sciences, Vol. 100, 2016] have shown that single-phase approach predicts Nusselt number with a better accuracy when a range of Rayleigh numbers and particle concentrations is investigated. This study examined volumetric fraction of Al_2O_3 nanoparticles from 1vol% to 5vol% within a system in which input temperature variation is from $\Delta T=25°K$ to 75°K. It was revealed that thermal conductivity and dynamic viscosity are mostly influenced by the nanoparticle size (radius) among all the thermophysical properties of the nanofluid under this study. It was also shown that; as the radius of nanoparticles is increased the thermal conductivity and dynamic viscosity are decreased respectively. This reduction is more noticeable as the volumetric fraction of nanoparticles is increasing in the nanofluid.

INTRODUCTION

Nanofluids for the past two decades, from its inception by Choi [1], have been subject for numerous studies with regards to thermal conductivity and natural convection heat transfer [2-5]. Many of which are done by simulation and numerical analysis [2-5] while others done experimentally [6, 7]. Some studies have compared single-phase models with and without thermal dispersion effect, Eulerian-Eulerian and Eulerian-Mixture two-phase models [8] while others have investigated both single and two-phase numerically and made a comparison with experimental approaches [9]. Saghir et al. have mentioned that the Euler-Euler model is the most versatile disperse models, but with a high computational cost and up to 10% discrepancy when compared with Ho et al. [Int'l. Jour. of Thermal Sci., 2010, Vol. 49, pp. 1345-1353].

Although it has been shown that presence of nanoparticles in a fluid base may change the conductivity and viscosity of this class of fluids and cause an enhancement in heat absorption and heat transfer, but the discrepancy and contradictory results can be subjects of further studies to investigate the complex issues such as clustering and sedimentation of these particles in the base fluid. The concentration or volume fraction of nanoparticles is an integral parameter and plays a big role in nanofluids performance. Some studies have discussed the effect of nanoparticles mean diameter on mixed convection heat transfer of a nanofluid in a horizontal tube [10]. Others have shown Brownian motion effects on natural convection of nanofluids in a 2-D enclosure [11].

The model for a nanofluid concerning the effect of Brownian motion and thermophoresis was first presented by Boungiorno [12] and has been applied by Kuznetsov and Nield [13] to revisit the classical issue investigated by Kuiken and Bejan [14-16]. Utilising Al_2O_3 nanoarticles with mean diameter of 13 nm at 4.3% volume fraction increases the thermal conductivity by 30% as per Masuda et al. finding [17]. On the other hand, Lee et al. have shown that larger nanoparticles with an average diameter of 40 nm only increase not more than 10% [18]. It is inevitable that the heat transfer occurs on the particle surface, it is expected that the nanofluids show better thermal property in comparison with conventional heat transfer fluids and also other fluids which consist of macro-size particles. Li and Peterson [19] have shown this fact with their recent works.

They confirmed that the thermal conductivity enhancement of the two nanofluids demonstrated a nonlinear relationship with respect to temperature, nanoparticles volume fraction, and nanoparticles size on the effective thermal conductivity.

Convective heat transfer with nanofluids can also be modelled using the two-phase or single phase approach [9]. The first provides the possibility of understanding the function of both the fluid phase and the solid particles in the heat transfer process. The second assumes that the fluid phase and particles are in thermal and hydrodynamic equilibrium. This approach is simpler and requires less computational time [9, 10].

NOMENCLATURE

C_p	[J/kg.K]	Specific heat
k	[W/mK]	Thermal conductivity
ρ	[kg/m^3]	Density
R	[nm]	Nanoparticle radius
T	[K]	Temperature (Kelvin)

Special characters

$\emptyset$	[%]	Volume percentage (fraction)
κ	[J. K^{-1}]	Boltzmann constant
μ	[Ns m^{-2}]	Dynamic viscosity
ψ	[-]	Modelling function defined in Equations (2) & (4)

Subscripts

B	Brownian
C	Cold
f	fluid
nf	nanofluid
np	nanoparticle

THERMOPHYSICAL PROPERTIES OF NANOFLUID

1. Thermal Conductivity

The statics of effective thermal conductivity of nanofluid can be approximated by the Maxwell-Granet model [20] as shown in equation (1), and the dynamics of thermal conductivity when Brownian motion is concerned has been added by [11, 21] shown in equation (2).

$$k_{nf} = k_f \left[\frac{(k_{np}+2\,k_f)-2\emptyset(k_f-k_{np})}{(k_{np}+2\,k_f)+\emptyset(k_f-k_{np})}\right] \tag{1}$$

$$k_B = 5x10^4 \psi \emptyset \rho_f C_{p_f} \left(\sqrt{\frac{\kappa T}{2\rho_{np} R_{np}}}\right) f(T,\emptyset) \tag{2}$$

Where; $\kappa = 1.3807x\ 10^{-23}$, $\psi = 0.0011(100\phi)^{-0.7272}$,

and $f(T,\emptyset) = (-6.04\phi + 0.4705)T + (1722.3\phi - 134.63)$

and ψ, $f(T,\emptyset)$ are modelling functions.

2. Dynamic viscosity

In order to predict the nanofluid's viscosity, one can consider utilizing Brinkman model [Applied Sci. Res., t. A1, 1947, pp. 27-34], especially when dealing with low volume fraction of nanoparticles. Of course here again we should take Brownian motion into the consideration for modelling viscosity as done by [11, 21], therefore the viscosity is defined as follow:

$$\mu_{nf} = \left[\frac{\mu_f}{(1-\phi)^{2.5}}\right] \tag{3}$$

$$\mu_B = 5x10^4 \psi \emptyset \rho_f \left(\sqrt{\frac{\kappa T}{2\rho_{np} R_{np}}}\right) f(T,\emptyset) \tag{4}$$

Again here $\boldsymbol{\kappa}$, $\boldsymbol{\psi}$, $\boldsymbol{f}(\boldsymbol{T},\emptyset)$ are the same as above mentioned.

3. Specific heat

Specific heat in this study for the nanofluid can be written as follow [11]:

$$(C_p)_{nf} = \left[\frac{(1-\phi)(\rho C_p)_f + \emptyset\,(\rho C_p)_{np}}{\rho_{nf}}\right] \tag{5}$$

Here in Fig. 1 one can see that the specific heat of the nanofluid exponentially decreasing as the volume fraction of the nanoparticles is increasing in the mixture.

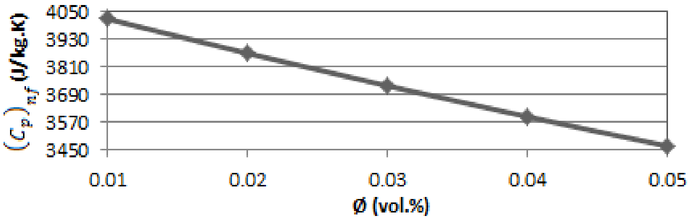

Figure 1 Specific heat vs. Ø vol. %

4. Density

Being a function of the nanoparticles density, fluid density along with the volume percentage of nanoparticles incorporated in the fluid mixture, the density of the nanofluid can be described as:

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_{np} \tag{6}$$

It is clearly shown in Fig. 2 that the density of nanofluid is directly increasing as volume fraction of nanoparticles increases.

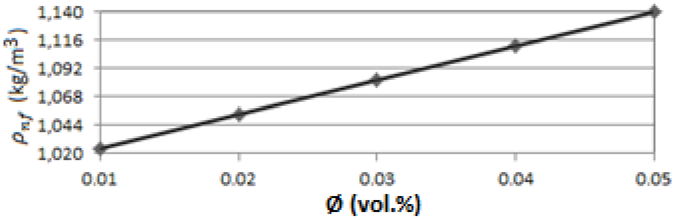

Figure 2 Nanofluid density vs. Ø vol. %

5. Coefficient of thermal expansion

Although temperature has a predominant role in thermal expansion as it has been mentioned in many literature, but it is worth mentioning that in mixed fluid under this study seems that volume fraction of the nanoparticle along with the nanoparticles diameter has some effect as can be seen in Table-1, below. These values are close to the work of Putra et al. [22] with a margin of approximately 2% of differences.

Table 1 Coefficient of thermal expansion values

T (°K)	Coefficient of thermal expansion, β (1/°K)
313	0.000377
338	0.000455
363	0.000561

METHOD

This work has utilized finite element numerical technique to simulate the governing equations (momentum, continuity, and energy) for single-phase model as used by [9].

TRENDS AND RESULTS

As it has been presented by other researcher such as Pak and Cho [23] their empirical equation for thermal conductivity does not show the effect of temperature, it only shows the effect of volume fraction of nanoparticles. Teng et al. [24] has evaluated the result of [23] with their experimental work and have shown variations, however when considering results of [19] in which they incorporated the effect of temperature, they have reached within ± 2% with their own results. Fig. 3 shows the result of thermal conductivity for 3 different temperature input in this investigation. It is clear that the thermal conductivity is a function of both temperature and volume fractions of particles as used in equation (1) above.

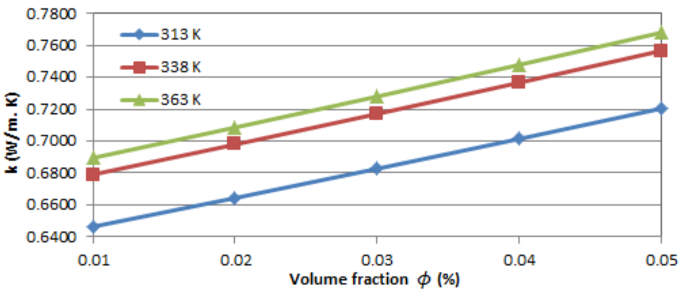

Figure 3 Thermal conductivity vs. Ø vol. %

However if we consider equation (2) which considers Brownian motion effect, the results can be read in Fig. 4. As:

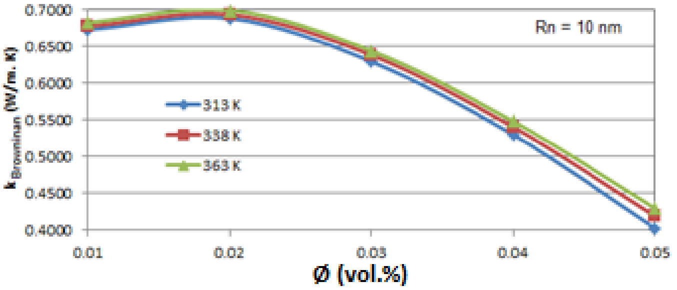

Figure 4 Thermal conductivity vs. Ø vol. %, R_n = 10 nm.

As shown in Fig. 4, thermal conductivity is increasing as temperature is increasing from 313K to 363K; however as volume fraction is increasing there is a drop in thermal conductivity except at 2%. This of course needs further study. On the other hand when just 2% is plotted against temperature increase as shown in Fig. 5, thermal conductivity is proportionally increasing as temperature is increased.

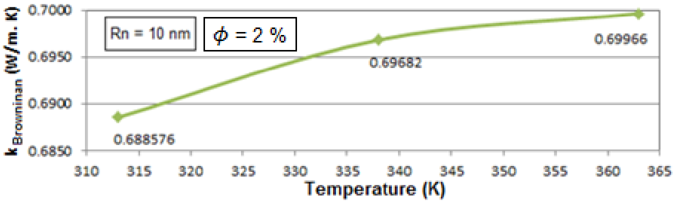

Figure 5 Thermal conductivity vs. input temperature with R_n = 10 nm.

The following figures (Fig. 6 to Fig. 9) will depict the results for other nanoparticles radii (R_n).

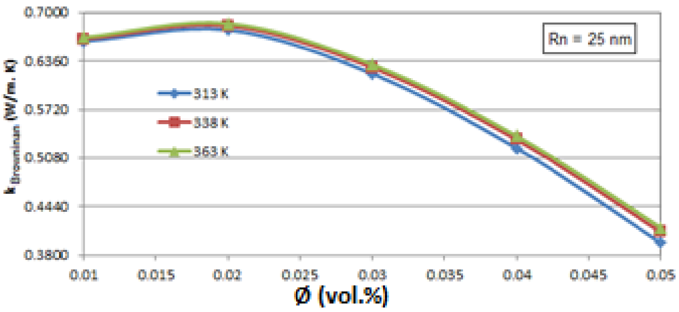

Figure 6 Thermal conductivity vs. Ø vol. %, R_n = 25 nm.

Figure 7 reveals the increased of thermal conductivities as a result of temperature increase for 2 percent volume fraction, however are lower compared with R_n = 10 nm. And this trend can be seen in Fig. 8 and Fig. 9 as well.

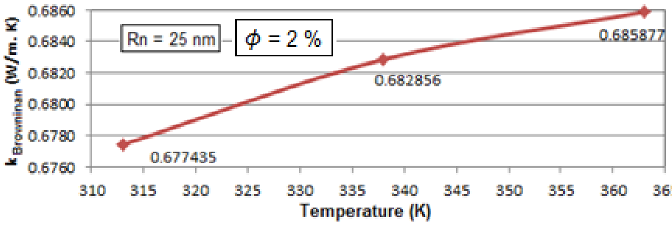

Figure 7 Thermal conductivity vs. input temperature. With R_n = 25 nm.

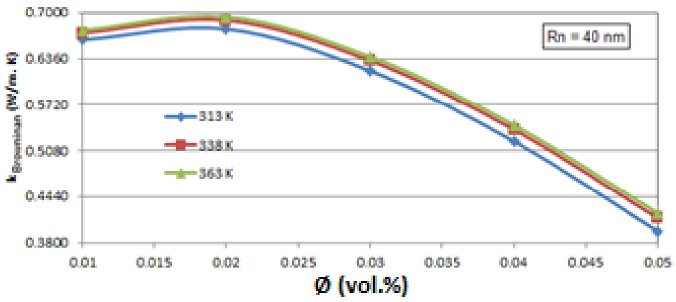

Figure 8 Thermal conductivity vs. Ø vol. %, R_n = 40 nm.

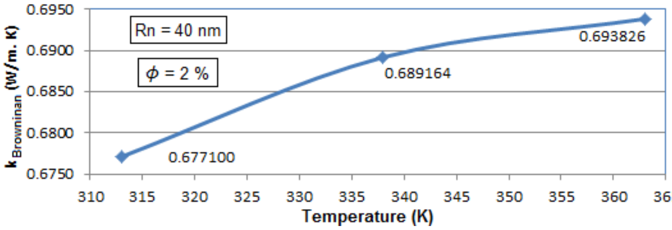

Figure 9 Thermal conductivity vs. input temperature. With R_n = 40 nm.

CONCLUSION

As investigative numerical results have shown, one can conclude, in spite of the slight variation and at times contradictories but with more adjustments in the empirical formulas as presented in the recent literature, that for application of nanofluids in general and alumina/water base in particular as shown in this investigation, can improve thermal conductivity. Influence of nanoparticles volume fractions and the radius of nanoparticles on thermophysical properties of nanofluids are worth mentioning and more noticeably on thermal conductivity and dynamic viscosity.

Table -2 will sum up the findings with respect to some of the published results such as [11]. It should be mentioned that the author of this work will be conducting a modelling and simulation to coin the results furthermore.

As can be read from Table -1, there are some deviations abot 2.8% in the results in compare to other researcher work such as thermal conductivity at 1% volume fraction, and or 2.6% at 4% volume fraction of nanoparticles in the nanofluid.

Table 1 Thermophysical Properties of Alumina/Water nanofluids.

Fluid	Tavg (K)		Density (kg/m3)		Specific heat (J/kg. K)		Thermal Conductivity (W/m. K)		Dynamic Viscosity (Pa. s)	
Properties	Ref. [11]	This work	Ref. [11]	This work	Ref. [11]	This work	Ref. [11]	This work	Ref. [11]	This work
Pure water	298	300	997.13	997.73	4180	4179.56	0.613	0.613	0.000891	0.0008941
	307	313	994.43	995.71	4178	4176.89	0.613	0.613	0.000734	0.0008592
	315	325	991.46	994.16	4179	4174.23	0.613	0.613	0.000629	0.0007017
Alumina			3970	3880	7650	880	40	25		
Nanofluid with Ø = 1%	298	300	1026.9	1025.27	4047.97	4018.75	0.628	0.6464	0.0009136	0.0009167
	307	313	1024.2	1024.54	4045.71	4019.81	0.628	0.6464	0.0007526	0.0008809
	315	325	1021.3	1022.38	4046.28	4021.15	0.628	0.6464	0.0006450	0.0007195
Nanofluid with Ø = 2%	298	300		1054.63		3869.34		0.6644		0.0009286
	307	313		1053.54		3870.28		0.6644		0.0009035
	315	325		1051.82		3871.55		0.6644		0.0008876
Nanofluid with Ø = 3%	298	300		1083.65		3727.62		0.6827		0.0009413
	307	313		1082.23		3728.73		0.6827		0.0009270
	315	325		1079.47		3730.14		0.6827		0.0009012
Nanofluid with Ø = 4%	298	300	1116.04	1112.32	3694.08	3593.18	0.683	0.7014	0.0009867	0.0009825
	307	313	1113.45	1111.07	3691.24	3594.52	0.683	0.7014	0.0008128	0.0009013
	315	325	1110.60	1109.73	3690.84	3595.36	0.683	0.7014	0.0006965	0.0008064
Nanofluid with Ø = 5%	298	300		1140.15		3466.95		0.7205		0.0009963
	307	313		1139.92		3467.10		0.7205		0.0009765
	315	325		1137.64		3468.37		0.7205		0.0008736

Furthermore, the dynamic viscosity is within 1% deviation at 1% volume fraction and 0.5% at 4% volume fraction which are in a good agreement. Finally one can see that the thermal conductivity has been enhanced by 11.4% with comparison by pure water as far as [11] and in this investigation by 13.2% when 2% volume fraction and nanoparticle with 80 nm diameter is used.

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