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The Effect of Thermal Conductivity Enhancement for Brownian motion of Nanofluids

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Abstract

The Brownian dynamics simulations of the nanofluid system during which the inter-particle potential is decided supported Debye length and surface interaction of the fluid and also the solid. This increase is restricted by most concentration for each particle size and is below that expected by the speculation of effective medium. Now over the maximum limit, the particle aggregates begin to form. The Brownian motion contribution stays as the constant beyond a certain particle diameter. Here, we use a kinetic theory of gases based analysis of heat flow in fluid suspensions of solid nanoparticles i.e., nanofluids to indicate that the fluid mechanics results related to motion have solely the minor effect on the thermal conduction of the nanofluid. The results obtained by this analysis are same as that of the results of molecular dynamics simulations of the heat flow within the model nanofluid with well dispersed particles. This paper shows that the motion can increase the thermal conduction of the nanofluid by 6% primarily attributable to stochastic process motion and not solely through diffusion. The results analyzed within this paper are in keeping with the predictions of the effective medium theory additionally like recent experimental and theoretical results on the well spread metal nanoparticle suspensions.

Keywords: Brownian motion, Nanofluid, Thermal conductivity.

1. INTRODUCTION

According to the work of Einstein on the Brownian motion it's acknowledge that the mixture particles distributed within the fluid of smaller molecules behave as thermodynamic system. The structure and also the properties of this “macroparticle

system" are unremarkably determined by the forces of the interaction among macroparticles, the fluid or solvent enters within the variety of the thermal tub that providing mechanical energy for every degree of freedom of the macroparticles the acknowledge fluctuation dissipation theorem. The analysis and accuracy of the current description has been verified by experiments of Vrij et al., [1] who have determined the structure issue for the spherical mixture particles with size starting from twenty to two hundred nm. Within the real sense, the idealised onerous sphere fluid is realised abundant accurately and probed a lot of simply with colloids than with its atomic realization argon [2]. The 3-D Brownian motion is shown by the figure-1.

So that we've seen that the two particles fall quickly once falling near one alternative and on their line of centers. However, all the analysis has been administered ignoring Brownian effects. Once examining the dilute suspensions of mixture spheres in some liquid or water, we notice that every particle moves concerning with the continual however random zigzag motion. We are able to trust these particles as being perpetually bombarded by the random impacts of molecules of liquid. The ensuing motion of colloids is understood as Brownian movement [3], which sees them diffuse relative to each other. So in order to interpret this diffusive spreading, it can be much useful to model their behavior by using the random walks. This includes allowing each particle to take steps δx in any direction along each axis every time steps δt. The motions in every of those directions are statistically independent as colloids on colliding with water molecules can lose the initial rate. The particles can move severally from one another specified the walks are going to be unbiased.

The nanofluids would be ready by suspending solid particles with the dimensions of but a hundred nanometers within a basefluid. The terms synthesis and characterization are principally employed in the literature that describing the preparation section of the nanofluids. In general, it is same that the nanofluids contain millimicron sized solid fibers, particles, tubes or rods suspended in several basefluids [5]. By taking at the side of the basefluids and nanoparticles, some additives are utilised to extend stability of nanofluids and to boost the dispersion behavior of them. The nanoparticles of Al_2O_3 and basefluid water exploited in synthesis would be tabulated from completely different sources. [6]

2. LITERATURE REVIEW

All physical mechanisms have a crucial scale below that the properties of the fabric changes. Currently the trendy engineering science offers chemical and physical routes to organize nanostructured materials or nm sized particles designed on the molecular or atomic scales with increased thermo-physical properties compared to their several bulk forms.

Masuda et al., (1993), [7]; showed that the thermal conductivity and viscosity of the liquids are affected by dispersing the small tiny particles of c-aluminum oxide (Al_2O_3), silicon dioxide (SiO_2) and titanium dioxide (TiO_2).

Choi (1995), [8] presented a numerical analysis based on LBM to model convection heat transfer of the Carbon nanotube based nanofluids. The results show that adding of a low quantity of Carbon nanotube to the base fluid led to the significant enhancement of convection rate.

Lee et al., (1999), [9] have ascertained that it's attainable to interrupt the boundaries of the standard solid particle suspensions by considering the definition of nanoparticle fluid suspensions. These fluid suspensions of nanoparticle are said to be nanofluids, obtained by dispersing the nm sized particles within the typical base fluid like oil, antifreeze, water etc. The nanoparticles of materials like argentiferous oxides (CuO, Al2O3), compound ceramics (AlN, SiN), inorganic compound ceramics (TiC, SiC), metals (Ag, Cu, Au), semiconductors (SiC, TiO_2), single, double or multi walled carbon nanotubes (DWCNT, SWCNT, MWCNT), alloyed nanoparticles ($Al_{70}Cu_{30}$) etc. are used for preparation of the nanofluids.

Wang et al., (1999) [10] have discussed the effective thermal conduction of mixtures of liquids and nanometer-size particles is measured by a steady-state parallel-plate technique. The tested liquids contain two kinds of nanoparticles, Al_2O_3 and CuO, spread in water, vacuum pump fluid, engine oil, and ethylene glycol. Their experimental results show that the thermal conductivities of nanoparticle–liquid mixtures are more than those of the base fluids. Exploitation theoretical models of effective thermal conductivity of a combination, they have incontestible that the expected thermal conductivities of nanoparticle–liquid mixtures are abundant under our measured information, indicating the defficiency within the existing models once used for nanoparticle–liquid mixtures.

These nanofluids are found to offer associate degree increased thermal conduction by, Eastman et al., (2001); [11] who showed that a "nanofluid" consisting of copper nanometer-sized particles distributed in glycol encompasses a abundant higher effective thermal conduction than either pure glycol or glycol containing identical volume fraction of distributed chemical compound nanoparticles. The effective thermal conduction of glycol is shown to be exaggerated by up to four-hundredth for a nanofluid consisting of glycol containing just about 0.3 vol % copper nanoparticles of mean diameter $\ll$10 nm. The results are abnormal supported previous theoretical calculations that had foreseen a robust result of particle form on effective nanofluid thermal conduction, however no result of either particle size or particle thermal conduction.

Choi et al., (2001); [12] analyzed that the measured thermal conductivity phenomenon is larger than the theoretical predictions and is nonlinear with fullerene loadings. This phenomena show the elemental limits of standard heat conductivity models for solid or liquid suspensions.

S. P. Jang et al., (2004) [13] have found that the movement of nanoparticles at the molecular and nanoscale level could be a key mechanism governing the thermal behavior of nanoparticle–fluid suspensions. They have devised a theoretical model that accounts for the basic role of dynamic nanoparticles in nanofluids. The model not solely captures the concentration and temperature-dependent conduction, however

conjointly predicts powerfully size-dependent conduction. Moreover, they have discovered a basic distinction between solid: solid composites and solid: liquid suspensions in size-dependent conduction. This understanding could lead on to style of nanoengineered next-generation coolants with industrial and medicine applications in high-heat-flux cooling.

A. K. Singh, (2008) [14] analyzes that most processes whose performance is altered by the heat generation could benefited from the nanofluid coolants. The nanofluids have big potential for the thermal management and control involved in various applications like as microelectro mechanical systems (MEMS), electronic cooling, spacecraft thermal management etc.

3. RESEARCH METHODOLOGY

In general, two production ways of preparation and dispersion, referred to as one-step method and two-step method occour. Moreover, the key to important increment of thermal conduction of nanofluids is synthesis, inside that non-agglomerated nanoparticle square measure suspended within the basefluid [6]. Within the single-step methodology, getting ready nanoparticles and dispersing within basefluid happens at the same time. In two-step method, nanoparticles are processed and created by some techniques initial and so spread them into the basefluid. Most nanofluids together with compound nanoparticles are generated by the means that of the two-step method, except for the metallike nanoparticles or particles with high thermal conduction one step method is employed ideally. For example, Fe or ethylene glycol nanofluid by taking advantage of the two-step method. During this case, the synthesis of Fe nanoparticles are performed by the chemical vapor condensation method and so, it had been spread within the basefluid.

The thermal properties of liquids play a very important decisive role in heating still as cooling applications within the industrial processes. The Thermal conduction of the liquid is a very important property that decides its heat transferring performance. The traditional heat transfer fluids have the poor thermal conduction that creates them inadequate for the immoderate high cooling applications. The various scientists have tried to reinforce the inherently poor thermal conduction of those heat transfer fluids by victimisation the solid additives following the classical effective medium theory given by Maxwell (1873) for effective properties of the mixtures. The fine calibration of dimensions of those solid suspensions to millimetre and micrometer ranges for recouping heat transfer performance have unsuccessful as a result of drawbacks like still particle geological phenomenon, low thermal conduction, particle impeding, corrosion of elements of machines, excessive pressure drop etc. The downscaling of particle sizes continued in rummage around for new sorts of fluid suspensions having increased thermal properties and additionally heat transfer performance.

4. RESULTS AND DISCUSSION

In the present analysis, there's stress on the concentration of the stationary fluids. Then to produce estimate for contribution of the Brownian motion induced nanoscale fluid flow to the thermal conduction phenomenon, allow us to assume that the complete volume of the fluid diffuses along with nanoparticles which the rate of fluid is that the same as that of the rate of the particles. On considering these assumptions, that overestimate the particular magnitude of fluid rate field, a standard kinetic theory of gases formula offers Brownian motion iatrogenic contribution to thermal conduction phenomenon, κ_B, as given:

$$\kappa_B = D_B c_p, \tag{1}$$

Where c_p is the heat capability of the fluid per unit volume at the constant pressure, and D_B is that the diffusivity of the nanoparticles. One ought to note that owing to a lot of higher volume of the fluid at the low particle volume fraction, the particles themselves carry a lot of less heat than the fluid moving at the side of the particles. So, we are able to neglect the direct contribution of particle movement to the thermal transport. The thermal conduction of base fluid, κ_F will be conjointly written within the style of relative atomic mass (1) as:

$$\kappa_F = D_T c_p, \tag{2}$$

Where D_T is the thermal diffusivity of the fluid defined as:

$$D_T = \kappa_F / c_p.$$

The ratio of κ_B to κ_F can be evaluated by combining the equations (1) and (2), as follows:

$$\kappa_B / \kappa_F = D_B / D_T, \tag{3}$$

i.e., the quantitative relation of the motion contribution to thermal conductivity to the thermal conductivity of the base fluid is given by the quantitative relation of nanoparticle diffusivity to the fluid thermal diffusivity. Wide ranges of the experimental and theoretical analysis were conducted in literature to model thermal conduction phenomenon of the nanofluids. The prevailing results were unremarkably supported the conception of the effective thermal physical phenomenon of a two part mixture. The Maxwell (1881) model was the primary models that projected for solid and liquid mixture with comparatively massive particles. It absolutely was supported resolution of thermal conductivity equation through a stationary random suspension of spheres. The effective thermal physical phenomenon is given by the equation as follows: [15]

$$k_{eff} = \{k_p + 2k_{bf} + 2\phi(k_p - k_{bf})\}\, k_{bf} / \{k_p + 2k_{bf} - \phi(k_p - k_{bf})\} \tag{4}$$

Where k_p is that the thermal conduction of the particles, k_{eff} is that the effective thermal conduction of the nanofluid, k_{bf} is base fluid thermal conduction, and ϕ is volume fraction of the suspended particles. The appropriate trend within the experimental studies is that the thermal conduction of nanofluids will increase with decreasing the particle size. This trend is on paper supported by two mechanisms of

the thermal conduction enhancement; the Brownian motion of nanoparticles and liquid layering around nanoparticles. However, there's additionally an appropriate quantity of contradictory information in some analyses that indicate decreasing thermal conduction with decreasing the particle size. The various results illustrated neither agreement regarding mechanisms for thermal transfer improvement nor a unified attainable rationalization associated with the massive discrepancies within the results even for same base fluid and nanoparticles size. There are numerous models out there thus for in context to the activity of the effective thermal conduction of nanofluids (Wang and Mujumdar, 2007) [16] however there exists an oversized range of deviations between them. Within the present, there aren't any experimental or theoretical results during this context to relinquish and predicts accurately regarding the thermal conduction of the nanofluids [17]. Some Nanofluids with their thermal conduction increase in nanofluid thermal conduction over base fluid thermal conduction and synthesis procedure used as reported in some analyses are shown in the table-1. [18]

Table -1.

Particle Type	Base Fluid	Particle Volume Fraction (%)	Particle Size (nm)	Maximum Enhancement (%)	Temp.	Reference
Al_2O_3	Water	1.30-4.30	13	32.4	≥31.85ºC	Masuda et al. [7]
Al_2O_3	Water	1.00-4.30	38.4	10	Room temp.	Lee et al. [9]
Al_2O_3	Water	1.00-5.00	38.4	18	Room temp.	Lee et al. [9]
Al_2O_3	Water	3.00-5.50	28	16	Room temp.	Wang et al. [10]
Al_2O_3	Water	5.00	60.4	23	Room temp.	Xie et al. [19]
Al_2O_3	Water	1.00-4.00	38.4	24	Room temp.	Das et al. [20]
Al_2O_3	Water	2.00-10.00	36	29	27.5ºC-34.7ºC	Li et al. [21]

5. CONCLUSION

We have analyze a kinetic theory argument and additionally the results of molecular dynamics simulations, each resulting in the conclusion that the thermal conduction phenomenon of a nanofluid with well spread nanoparticles is well delineate by the effective medium theory and doesn't show any vital enhancements attributable to their effects related to Brownian motion induced hydrodynamic effects. Our conclusions are in agreement with results of various experiments on thermal coduction phenomenon of suspension of well spread metal nanoparticles, and recommend that alternative effects, like particle clustering, are responsible for giant thermal conduction phenomenon will increase ascertained in some “experiments”.

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