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Sensitivity of thermal conductivity for Al_2O_3 nanofluids

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ABSTRACT

Present work deals with synthesis, characterization and the sensitivity study of thermal conductivity of Al_2O_3 nanofluids in different base fluids with change in concentration and temperature. In this work, the solution combustion synthesis method was used for synthesis and samples were combusted at three different temperatures. It was observed that increase in combustion temperature leads to the increase in particle size. Al_2O_3 nanoparticles combusted at 1000 °C, having average particle size 53 nm, were used for preparation of nanofluids in distilled water and ethylene glycol base fluids using two step approach. For change in temperature from 10 to 70 °C and concentration variation from 0 to 2 vol%; 30 and 31% increase in thermal conductivity was observed for distilled water and ethylene glycol based Al_2O_3 nanofluids, respectively. Finally, sensitivity analysis for thermal conductivity was also performed. Results of sensitivity analysis revealed that change in thermal conductivity is more sensitive to increase in volume percent at higher concentration.

1. Introduction

Nanofluids are fluids containing nanoparticles with size generally less than 100 nm. Nanofluids have attracted considerable attention recently because of their potential as high performance heat transfer fluids in automotive and electronic cooling [1], and in microchannel heat sinks [2]. Al_2O_3 nanofluids have emerged as a potential agent in heat transfer applications. In particular, $A1_2O_3$ nanoparticles have excellent dispersion properties in water and ethylene glycol and form stable suspensions [3]. In general, alumina has many interesting properties such as high hardness, high stability, high insulation and transparency [4].

Al_2O_3 nanoparticles can be synthesized by many techniques including sol-gel [5], pyrolysis [6], hydrothermal [7], laser ablation [8], solution combustion [9], plasma [10], freeze drying of sulphate solutions [11], controlled hydrolysis of metal alkoxide [12], and aerosol methods [13]. It is also reported that for obtaining dense nanocrystalline Al_2O_3 products, either phase transformation from γ to α has to be arrested or nanocrystalline α-Al_2O_3 powders have to be used [14–16]. Fatemeh et al. [17] explored the effect of stirring time on synthesis of nano-α-Alumina particles. Alumina nanoparticles were synthesized through alkoxide route using a sol-gel method and concluded that the introduction of different stirring times affected particle size. Crystalline α-Al_2O_3 can be synthesized through the use of the solution combustion method [18]. Generally, combustion synthesis is an excellent technique for preparing high temperature materials because of its low cost, high yield and ability to achieve high purity single or multi-phase complex oxide powders in as-synthesized state.

Kole and Dey [19] prepared various suspensions containing Al_2O_3 nanoparticles (<50 nm) in car engine coolant. Thermal conductivity of nanofluids has been investigated both as a function of concentration of Al_2O_3 nanoparticles as well as temperature between 10 and 80 °C. Zamzamian et al. [20] has illustrated the enhanced heat transfer characteristics of Al_2O_3/EG nanofluids. Xie et al. observed an increase followed by a decrease in the thermal conductivity with particle size for alumina nanoparticles in ethylene glycol, as well as in pump oil for nanofluids containing five different sizes of alumina nanoparticles [21]. Patel et al. performed an experimental investigation on thermal conductivity enhancement of oxide nanofluids [22]. They observed that the thermal conductivity of a nanoparticle suspension is relatively higher at lower volume fractions, thereby giving a non-linear dependence on particle volume fraction.

Thermal conductivity of Al_2O_3/water (29 nm) nanofluids of volume concentration up to 9% in the temperature range from 20 °C to 40 °C was measured by Mintsa et al. and observed that the thermal conductivity increased with the increase of volume concentration and with the decrease of particle size [23]. They also provided

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Nomenclature

DW	distilled water
hν	energy (eV)
α, γ	different phases of Al_2O_3 nanoparticles
UV–Vis	UV visible spectroscopy
EG	ethylene glycol
DLS	dynamic light scattering
TEM	transmission electron microscopy
XRD	X-ray diffraction

new thermal conductivity expressions for Al_2O_3-water nanofluids with particle sizes of 47, 36, and 29 nm by curve fitting their in-house experimental data. Sundar et al. estimated thermal conductivity of ethylene glycol and water mixture based Al_2O_3 nanofluids for particle concentration up to 0.8% and temperature range from 15 °C to 50 °C [24]. A new correlation was also developed by them based on the experimental data for the estimation of thermal conductivity of nanofluids. Beck et al. studied thermal conductivity of alumina nanoparticles dispersed in ethylene glycol and illustrated that the effect of mass or volume fraction of nanoparticles on the thermal conductivity of nanofluids can be correlated using the Hamilton and Crosser or Yu and Choi models [25]. Sridhara et al. prepared review by collecting results of various studies on Al_2O_3 nanofluids [26]. Table 1 summarizes results of some experimental studies on thermal conductivity enhancement using Al_2O_3 nanofluids.

Table 1
Summary of work showing applications of Al_2O_3 nanofluids in thermal conductivity enhancement.

Objective	Results	Ref.
To study the effect of particle size on the thermal conductivity of alumina nanofluids	Thermal conductivity enhancement decreases as particle size decreases below about 50 nm	[27]
Alteration of thermal conductivity of liquid by dispersing ultra-fine particles	Nanofluids generates thermal conductivity increase of up to 30% at volume fractions of less than 4.3%	[28]
Measuring thermal conductivity of fluids containing oxide nanoparticles	20% thermal conductivity increase for Al_2O_3-water/ethylene glycol nanofluids at a volume fraction of 4%	[29]
Thermal conductivity of nanoparticle-fluid mixture	12% increase in thermal conductivity for 28-nm diameter Al_2O_3-water nanofluids with 3% volume fraction	[30]
Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions	Provided thermal conductivity expressions in terms of temperature and volume fraction for Al_2O_3-water nanofluids	[31]
A combined model for the effective thermal conductivity of nanofluids	20% increase in thermal conductivity for 4% Al_2O_3-water nanofluids	[32]
Experimental investigations on thermal conductivity of water and Al_2O_3 nanofluids at low concentrations	Enhancement of thermal conductivity at low concentrations	[33]
Investigations on Al_2O_3-based nanofluids with 43 nm diameter of particle at different volume concentrations	Found a linear increase in conductivity with increase in volume concentration	[34]
Temperature dependence of thermal conductivity enhancement for nanofluids	Dramatic increase in the enhancement of conductivity takes place with temperature	[35]

Nnanna studied heat transfer behaviour of buoyancy-driven nanofluids and observed that the presence of nanoparticles in buoyancy-driven flows affects the thermophysical properties of the fluid and consequently alters the rate of heat transfer [36]. Garoosi et al. investigated the natural convection of nanofluids using Buongiorno model [37]. They investigated the effect of volume fraction, size and type of nanoparticles and nanofluid average temperature on heat transfer rate. It was observed that by reducing the diameter of nanoparticles and increasing the average fluid temperature, the heat transfer rate increases. Transient magneto-hydrodynamic laminar free convection flow of nanofluid past a vertical surface has also been investigated [38]. The results concluded that by reducing the nanoparticle volume fraction, the skin friction coefficient enhances. Beg et al. conducted computational fluid dynamics simulation of laminar convection of Al_2O_3–water bio-nanofluids [39] and found that the heat transfer coefficient distinctly increases with increasing nanofluid particle concentration. De Risi et al. investigated the application of Al_2O_3 nanofluids in cooling system for wind turbines [40]. Sidik et al. undertook a state of art review on the application of nanofluids in vehicle engine cooling systems [41].

Although Al_2O_3 nanofluids have been investigated extensively but still it lacks comprehensive study [42]. In most investigations on Al_2O_3 nanofluids, researchers have used the commercially available Al_2O_3 nanoparticles which are cost ineffective. In this work self-synthesized Al_2O_3 nanoparticles have been used for preparation of nanofluids that makes it cost effective for the application of real world problems. Size controlled synthesis of Al_2O_3 nanoparticles by changing the combustion temperature has also been performed in this study. This gives a novel insight to obtain the range of thermal conductivity just through the use of different sized nanoparticles for the same base fluid as reported in literature heat transfer characteristics alter significantly in correlation to the size of the particles, especially in the nano regime. Although existing research has already outlined studies on these nanofluids, combined studies in single work are scarce [43]. A comprehensive review literature is available which combines the results of previous work, yet it is not ideal to compare results from different experiments. The reason being is that different experiments have varying environmental conditions that may lead to incorrect or biased results.

Lomascolo et al. performed a review on heat transfer using nanofluids and concluded that there are large discrepancies in reported results which indicates the requirement of consistent studies [44]. Existing reported data of Al_2O_3 nanofluids require the systematic study for exploring the effect of concentration of nanoparticles, temperature of nanofluids and different base fluids on thermal conductivity of nanofluids. The work outlined in this paper is conducted within controlled environmental conditions, as to provide a better insight towards the actual performance of different fluids. Al_2O_3 nanofluids have been explored for optimal operating temperature range for real world applications and also at low volume concentration as compared to others [45]. The reason being that while exploring the potential of nanotechnology, it should always be from minimal quantity. Sensitivity analysis for