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Sensitivity of thermal conductivity for Al_2O_3 nanofluids

Ravi Agarwal [a,*], Kamalesh Verma [b], Narendra Kumar Agrawal [c], Ramvir Singh [b]

[a] Centre for Converging Technologies, University of Rajasthan, Jaipur 302004, India
[b] Department of Physics, University of Rajasthan, Jaipur 302004, India
[c] Department of Physics, Malaviya National Institute of Technology, Jaipur 302017, India

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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

* Corresponding author.
E-mail address: agarwal.ravi.cct@gmail.com (R. Agarwal).

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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

Al_2O_3 nanofluids with respect to change in volume percent has also been reported in this work. As far as the authors are aware, there are no previous studies on sensitivity analysis performed on Al_2O_3 nanofluids.

In this work, aluminum oxide nanoparticles have been synthesized by solution combustion synthesis method and characterized using UV–Vis, DLS, TEM and XRD. Synthesized nanoparticles were heat treated at 850, 1000 and 1150 °C to evaluate the effect of combustion temperature on properties of synthesized nanoparticles. Nanofluids were prepared using a two-step approach by dispersing synthesized Al_2O_3 nanoparticles in distilled water and ethylene glycol at different concentrations. Prepared nanofluids were investigated for the enhancement in thermal conductivity at different temperatures. Sensitivity analysis for thermal conductivity was also performed. Motivation behind the study was to establish the concise effect of temperature, concentration and base fluid on the thermal conductivity of Al_2O_3 nanofluids. The effect of combustion temperature was also evaluated on the properties of synthesized nanoparticles.

2. Synthesis of Al_2O_3 nanoparticles

The solution combustion synthesis method was applied to synthesize Al_2O_3 nanoparticles. Aluminum nitrate and urea used were of analytical reagent grade. To synthesize aluminum oxide nanoparticles, stoichiometric amount of urea was added in aqueous solution of aluminum nitrate through vigorous stirring. The solution obtained was placed on preheated hot plate for boiling, foaming and flaming that produced transparent stick gel. This gel was dehydrated at 100 °C for 2 h and dried gel was combusted in air furnace to improve purity. To observe effect of combustion temperature, obtained Al_2O_3 nanoparticles were divided into three parts and combusted at 850, 1000 and 1150 °C for 2 h. Combusted powders were crushed using mortar and pestle.

3. Characterization of Al_2O_3 nanoparticles

3.1. UV–Vis

Fig. 1 illustrates the absorption spectra of synthesized Al_2O_3 nanoparticles recorded by UV–Vis Spectrophotometer (Shimadzu; UV-1800). Three different graphs corresponded to Al_2O_3 nanoparticles combusted at three different combustion temperatures. Nanoparticles combusted at 850 °C, 1000 °C and 1150 °C exhibited respective absorption maximum at 215 nm, 218 nm and 227 nm which corresponded to inter band transition from deep level electrons of valance band. Results revealed that an increase in annealing temperature leads to red shift in absorption peak wavelength. This confirmed that the shifting of energy levels corresponds to size difference among the synthesized nanoparticles at three different temperatures.

Calculated band gap energy using the Tauc relation plot (Fig. 2) are 4.20, 4.15 and 4.09 eV for samples annealed at 850 °C, 1000 °C and 1150 °C, respectively. In general, band gap decreases with increasing particle size which indicates that size of Al_2O_3 nanoparticles increases with increase in annealing temperature.

3.2. DLS

DLS provides clear insights and precise information about particle size. Fig. 3 illustrates the result of size measurement performed using DLS (Malvern; Nano-ZS). Particle size analysis (Fig. 3) exhibits the weighted average particle size as 38, 53 and 70 nm for samples combusted at 850, 1000 and 1150 °C respectively that confirmed the synthesis of nano sized particles.

3.3. TEM

In this work, the aim was to enhance the thermal conductivity of nanofluids for which nanoparticles size and phase are going to be important factors. Transmission Electron Microscopy (TEM) provides high resolution images of samples that give better view of particle size, size distribution, phase and morphology. The information provided by TEM together with findings of the literature review can directly be used for determining which Al_2O_3 nanoparticles are most suitable for problem under consideration. Fig. 4 shows images of three samples at different magnifications along with Selected Area Electron Diffraction (SAED) pattern recorded using TEM (Tecnai; FEI G2 S-Twin). Narrow particle size distribution of Al_2O_3 nanoparticles can be observed from images with different particle size for samples combusted at different temperatures. SAED pattern helps identify the nature of samples corresponding to information of different planes of material under investigation. Small and bright spots forming rings in SAED pattern are attributed to the Bragg's reflection which confirms that synthesized nanoparticles are poly-nanocrystalline in nature.

Fig. 4(a) indicates the average particle size 37 nm (standard deviation of 3 nm) for synthesized Al_2O_3 nanoparticles combusted at 850 °C. Three different rings of bright spots represent the Bragg's reflection from three different planes characteristics of γ-Al_2O_3

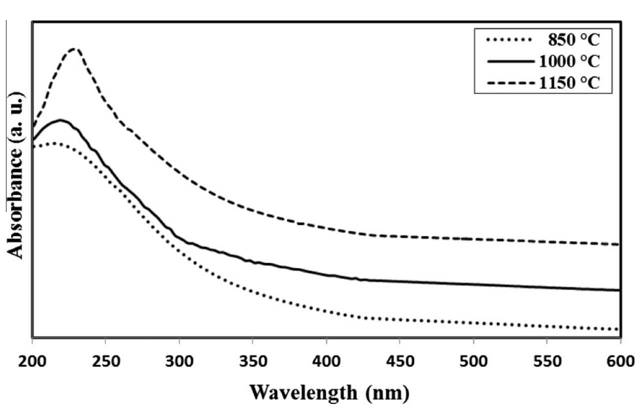

Fig. 1. UV–Vis absorption spectra of synthesized Al_2O_3 NPs.

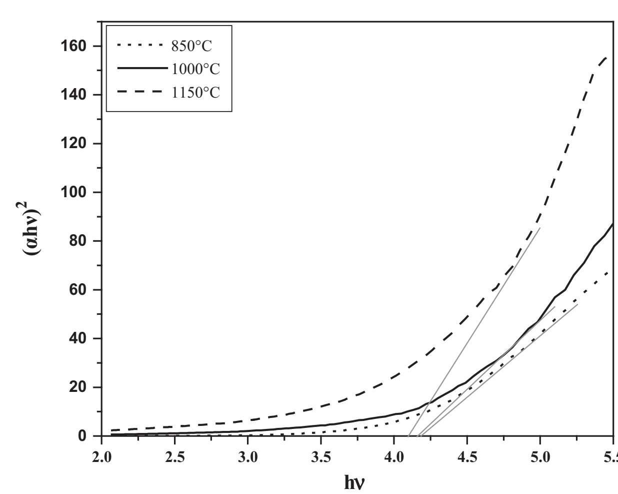

Fig. 2. Direct band gap Tauc relation plot of synthesized Al_2O_3 NPs.

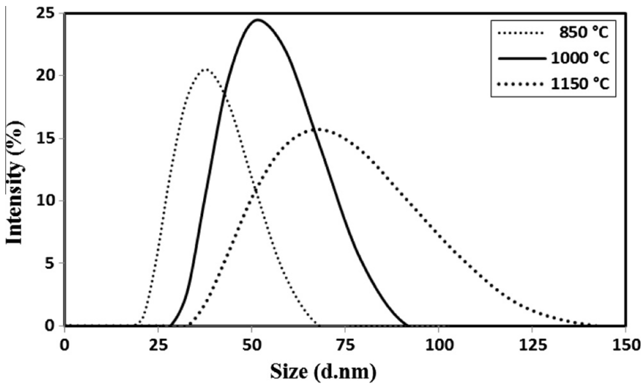

Fig. 3. Particle size distribution of synthesized Al_2O_3 NPs.

which is also confirmed by XRD in Fig. 5. For Al_2O_3 nanoparticles combusted at 1000 °C, Fig. 4(b) shows average particle size of 52 nm (standard deviation of 2 nm) and the presence of small elongated shaped nanoparticles. Diffraction rings in SAED pattern in this case shows that Al_2O_3 nanoparticles are mostly in α phase at this combustion temperature. A tiny proportion of aggregation with an average particle size of 72 nm (standard deviation of 4 nm) was observed for Al_2O_3 nanoparticles combusted at 1150 °C, shown in Fig. 4(c). SAED patterns indicated the presence of polycrystalline α-Al_2O_3 nanoparticles with no trace of γ phase. TEM images of the three samples show that increasing combustion temperature increases particle size along with transition from metastable γ phase to stable α phase.

3.4. XRD

XRD provides the diffraction pattern by which material, phase and structure can be identified. Various diffraction peaks arise out due to diffraction from different planes. Fig. 5 exhibits the diffraction pattern of three samples recorded using XRD (PANalytical; X'Pert PRO) with Cu (K_α = 1.54060 Å) for 2θ (20–80° in steps of 0.03° with step scan time 0.6 s). Peaks obtained in the diffraction pattern of sample combusted at 850 °C are consistent with JCPDS card (029-0063) that shows sign of γ-Al_2O_3 [46]. At 1150 °C only α-Al_2O_3 was observed by matching the XRD pattern with JCPDS card (042-1468). In the diffraction pattern of Al_2O_3 nanoparticles combusted at 1000 °C, peaks correspond to α-Al_2O_3 except one low intensity peak of γ-Al_2O_3 (440), which indicates presence of residual γ phase at this temperature. No impurity peak is observed in the XRD pattern.

Change in combustion temperature leads to change in phase that in turn gives diffraction from different planes, which results in different values of diffraction angle. Although it can be observed from Fig 5(b) and (c) that diffraction angles coincide for most of the peaks as at that combustion temperature Al_2O_3 nanoparticles are mostly in stable α-phase. Particle size increases with γ to α conversion results in gaps between the chains, corresponding to crystal defects gradually reducing and finally disappearing - accomplishing the crystallization. Similar increases in crystallite size accompanying the formation of α-Al_2O_3 have been reported [47]. The results confirm the synthesis of Al_2O_3 nanoparticles for which phase variation was observed with change in combustion temperature.

Summary of characterization results for Al_2O_3 nanoparticles combusted at 850, 1000 and 1150 °C are listed in Table 2. Results

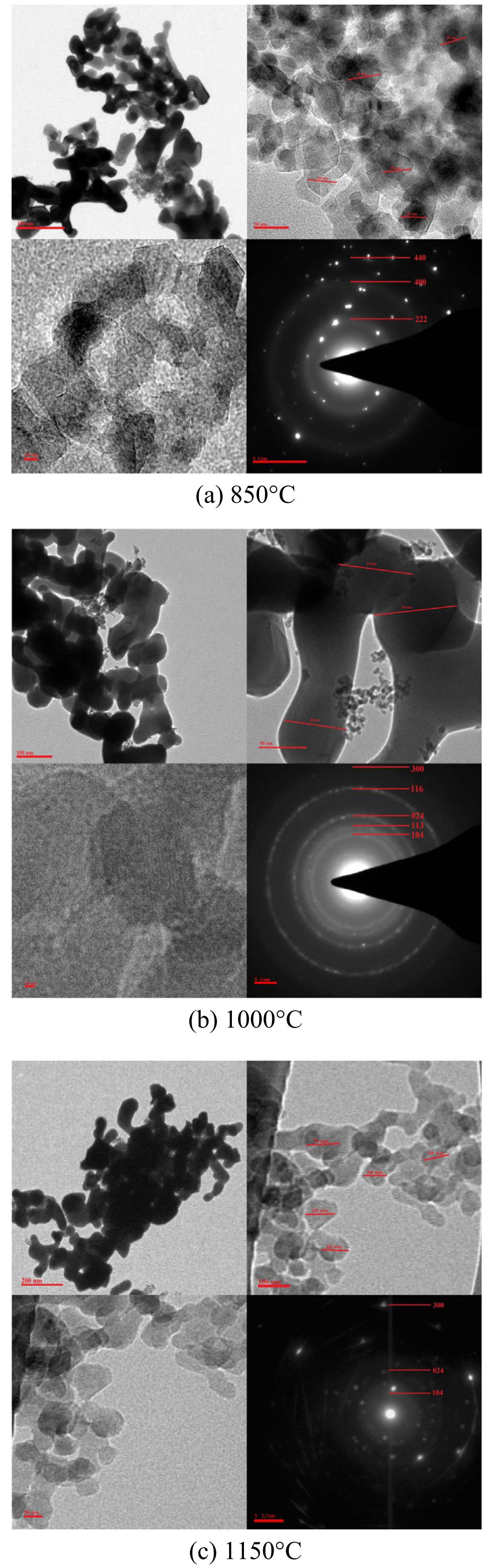

Fig. 4. TEM images of combusted Al_2O_3 NPs.

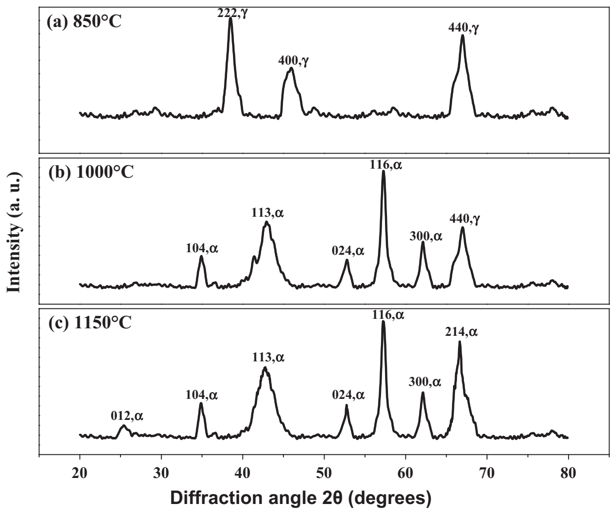

Fig. 5. XRD pattern of synthesized Al_2O_3 NPs.

show an increase in particle size with the increase of combustion temperature.

4. Preparation of Al_2O_3 nanofluids

Nanofluids from synthesized Al_2O_3 nanoparticles were prepared in distilled water (Polisher; Biopak) and ethylene glycol (Merck; AR) base fluids using the two-step approach. It is well known that Al_2O_3 has many phases among which α-phase is thermodynamically most stable [48]. Different phases of Al_2O_3 undergo a variety of transitions until the most stable α structure is formed at around 1000 °C [49]. It has been also reported that thermal conductivity enhancement in Al_2O_3 nanofluids decreases as particle size decreases below about 50 nm [21] that can be attributed to phonon scattering at the solid–liquid interface [27]. Based on the above findings synthesized Al_2O_3 nanoparticles combusted at 1000 °C, having average particle size of 53 nm, were used for preparation of nanofluids throughout the investigations.

Different concentration nanofluids (0, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00 vol%) were prepared by mixing the required amount of synthesized Al_2O_3 nanoparticles in 100 ml distilled water and ethylene glycol base fluids using mortar and pestle. The suspension was stirred for 1 h using a magnetic stirrer (Tarsons; SPINOT) followed by 30 min of sonication using a probe ultrasonic processor (Electrosonic; E1-250). Nanofluids were further subjected to ultrasonic vibrations for 90 min using a water bath ultrasonic cleaner (Toshcon; SW4) for increasing stability and removal of agglomeration. Significant settling does not occur in static suspensions even after 10 days. This illustrates a good stability of the prepared nanofluids. Further, zeta potential of prepared nanofluids was also measured for 10 days. Zeta potential was centred on 39.8 mV without any significant deviation which confirms that prepared nanofluids suspensions were stable and nanoparticles in suspension were well segregated.

5. Measurement of thermophysical properties of Al_2O_3 nanofluids

Thermal conductivity of the as prepared nanofluids was investigated at 10, 20, 30, 40, 50, 60 and 70 °C. Measurements were performed using a transient line heat source method based KD2 Pro (Decagon Devices; KS-1 sensor). Dimensions of nanofluid container taken were (30 mm × 120 mm) sufficiently large to be considered as infinite in comparison to sensor needle (1.3 mm × 60 mm). For convection free and temperature controlled measurement of thermophysical properties, each sample was heated or cooled to achieve desired temperature using a refrigerated/heating circulator (Julabo; F30) with the sensor needle inserted and oriented vertically in sample without touching walls of container for 2 h. Samples were allowed to become absolutely still for 10 min and then the measurement was taken. To reduce measurement uncertainties, the average of three different measurements were taken for each sample. Less than ±5% variation in results illustrates the accuracy of measurement. Sensor performance was verified by following the above mentioned procedure using a standard sample of glycerine provided by the manufacturer with a reported value of thermal conductivity as 0.285 W/(m·K) at 20 °C. The average thermal conductivity of three sets of reading for the standard falls in the ±5% of value as reported by manufacturer.

Fig. 6 shows variation in the thermal conductivity of aluminum oxide nanofluids with distilled water and the ethylene glycol base fluid. For each graph the thermal conductivity is plotted against the increasing concentration of nanoparticles in base fluid at different temperatures. Fig. 6(a) shows that for the distilled water base fluid, an increase in concentration of aluminum oxide nanoparticles in base fluid enhances thermal conductivity that further enhances with an increase of temperature. At 10 °C the increase in thermal conductivity was 13% with an increase in concentration from 0 to 2 vol% which exhibits significant enhancement in thermal conductivity with increasing concentration. Further increasing the temperature increases thermal conductivity values. Results are summarized in Table 3.

The main mechanism of thermal conductivity enhancement in Al_2O_3 nanofluids can be thought as the Brownian motion of nanoparticles which depends on fluid temperature [50]. At low temperatures, the Brownian motion would be less significant but an increase in temperature would lead to significant Brownian motion that in turn leads to the enhancement of thermal conductivity. Suspending smaller particles is more effective to improve thermal conductivity of nanofluids as the surface-to-volume ratio of particles increases as particle size decreases, due to which incorporating nanoparticles in base fluids will result in the enhancement of thermal conductivity. This increase in thermal conductivity may also be attributed to the formation of a solid-like nanolayer that acts as thermal bridge between the solid nanoparticle and bulk liquid [51]. Thermal conductivity of the nanolayer on the surface of the nanoparticle is not known. However, the layered molecules are in an intermediate physical state between bulk liquid and solid [52] so the solid-like nanolayer of liquid molecules would be expected to have higher thermal conductivity than that of bulk liquid.

Table 2
Characterization results of synthesized Al_2O_3 nanoparticles combusted at different temperatures.

Characterization	Parameter	850 °C	1000 °C	1150 °C	#
UV–Vis	Absorption maximum peak wavelength (nm)	215	218	227	1
UV–Vis	Tauc relation direct band gap (eV)	4.20	4.15	4.09	2
DLS	Weighted average particle size (nm)	38	53	70	3
TEM	Average particle size (nm)	37 (SD 3)	52 (SD 2)	72 (SD 4)	4
XRD	Material identification	γ-Al_2O_3	α-Al_2O_3 (γ@440)	α-Al_2O_3	5

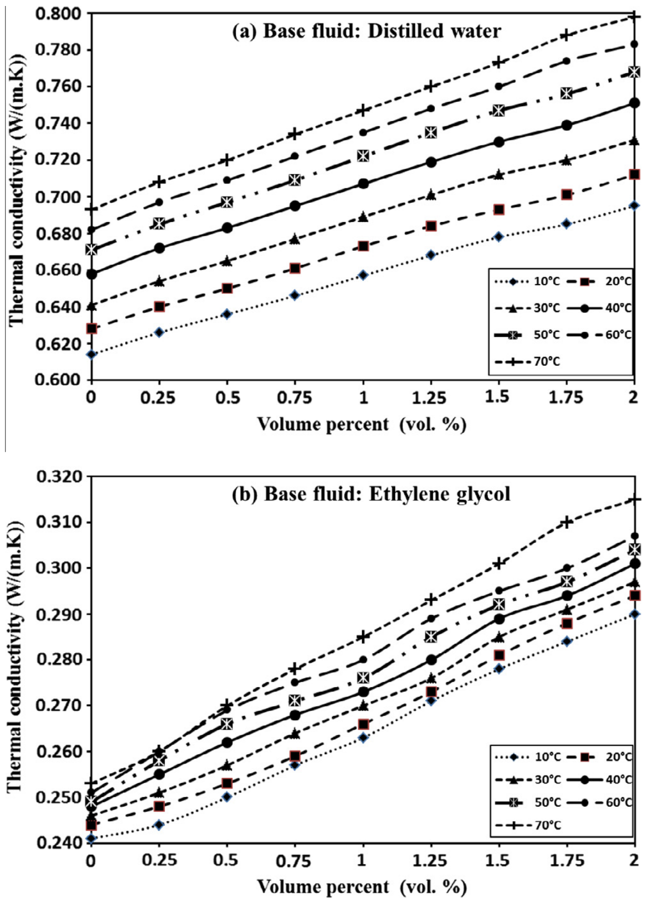

Fig. 6. Enhancement in thermal conductivity of nanofluids with increase in concentration of Al_2O_3 NPs in different base fluids at different temperatures.

Table 3
Percent increase in thermal conductivity of Al_2O_3 NPs based nanofluids for different base fluids at different temperature in the concentration range of 0–2 vol%.

Temperature (°C)	Base fluids	
	Distilled water	Ethylene glycol
10	13	20
20	13	20
30	14	21
40	14	21
50	14	22
60	15	22
70	15	25

If the concentration of nanoparticles is constant, an increase in temperature will lead to an increase in thermal conductivity. At 2 vol% a 15% increase in thermal conductivity was obtained through altering the temperature from 10 °C to 70 °C. Also at lower concentrations, a similar rate of increment was obtained as listed in Table 4. Increased rates of thermal conductivity were almost consistent with respect to the increase in temperature or concentration. The highest increment in this case was of 30% between sample at 10 °C having 0% aluminum oxide nanoparticles (i.e. the base fluid distilled water) and sample at 70 °C having 2 vol% aluminum oxide nanoparticles in distilled water. A similar trend of results was also obtained from existing literature.

Fig. 6(b) illustrates the thermal conductivity variation of aluminum oxide nanofluids for ethylene glycol base fluid. Graphs show that rate of increase in thermal conductivity is significantly higher with an increase in concentration of aluminum oxide nanoparticles for ethylene glycol base fluid as compared to distilled water. Results are illustrated in Table 3. In the case of distilled water, this rate of increase was in the range of 13–15%. Thus confirming a strong dependence of thermal conductivity enhancement on the concentration of aluminum oxide nanoparticles for ethylene glycol based nanofluids. On the other hand, increasing temperature at fixed concentration results in a relatively low rate of thermal conductivity enhancement as specified in Table 4. In case of distilled water this value was also ranging from 13 to 15%.

Table 4
Percent increase in thermal conductivity of Al_2O_3 NPs based nanofluids for different base fluids at different concentrations in the temperature range of 10–70 °C.

Concentration (vol%)	Base fluids	
	distilled water	Ethylene glycol
0	13	5
0.25	13	7
0.50	13	8
0.75	14	8
1	14	8
1.25	14	8
1.50	14	8
1.75	15	9
2	15	9

In summary, distilled water based nanofluids exhibit an almost constant rate of thermal conductivity increase with volume percent and temperature, whereas ethylene glycol based nanofluids are more sensitive to increase of concentration as compared to temperature for aluminum oxide nanoparticles. Thus distilled water based nanofluids would be more efficient in heat transfer applications where the rise in temperature is more prominent, whereas ethylene glycol based nanofluids would be better used in high concentration nanofluids samples for aluminum oxide nanoparticles. An increase in thermal conductivity for base fluid ethylene glycol at 10 °C and 2 vol% aluminum oxide based nanofluids at 70 °C was obtained to be 31% which is similar to distilled water. So distilled water and ethylene glycol based nanofluids for aluminum oxide nanoparticles show similar efficiency for heat transfer applications if temperature and volume percent of nanofluids samples are increased simultaneously. Results are in close agreement with the reported results of similar studies [53].

It is well known that different fluids have different thermal conductivity and heat carrying capacity. On mixing of nanoparticles in fluids the heat carrying capacity relates to the possible interaction between nanoparticles and fluids in terms of formation of solid like interfacial layer [51]. This is the reason for varying rate of thermal conductivity enhancement for two different base fluids. Kole and Dey have also reported similar findings [19].

6. Sensitivity analysis of Al_2O_3 nanofluids thermal conductivity

Sensitivity analysis shows that how much a quantity is sensitive to change in different parameters [54]. Here sensitivity analysis for thermal conductivity is performed with respect to definite change in concentration of nanoparticles in base fluid. The base condition is defined as the percent change of thermal conductivity for every 100% increase in volume concentration at different volume concentrations.

Fig. 7 illustrates the results of thermal conductivity sensitivity analysis for two base fluids (Distilled water and Ethylene glycol) at temperatures (10, 20, 30, 40, 50, 60 and 70 °C) for volume concentration (0.25, 0.50, 0.75 and 1%). Our results concluded that the thermal conductivity sensitivity for Al_2O_3 nanofluids is minute for a change in temperature at particular concentration but increases

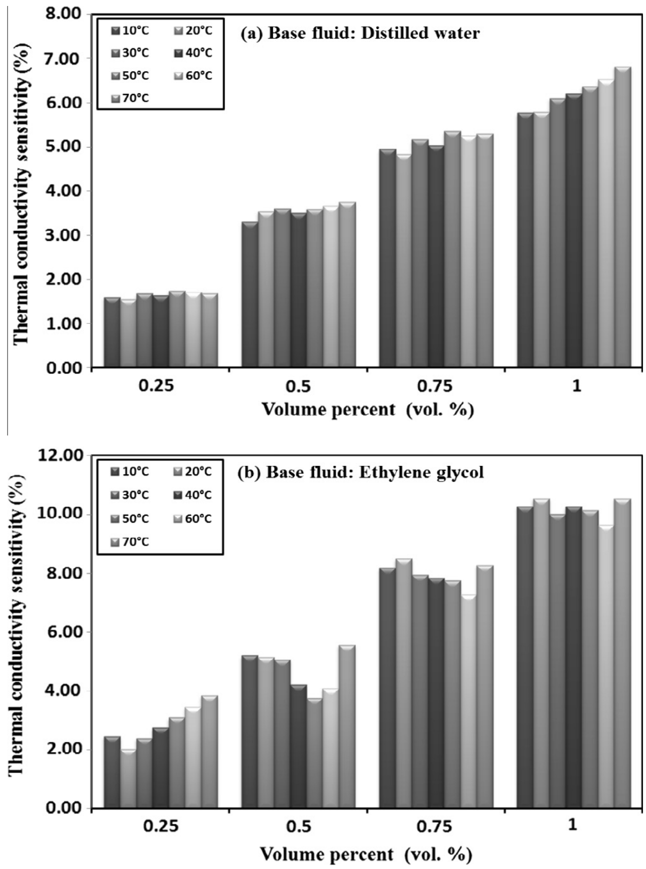

Fig. 7. Sensitivity analysis for thermal conductivity of nanofluids with increase in concentration of Al_2O_3 NPs in different base fluids at different temperatures and concentrations.

significantly with increase of concentration. It can be established that change in thermal conductivity is more sensitive for an increase in volume percent at higher concentration. For an increase in concentration from 0.25 to 1, sensitivity increases about 5 times which shows importance of adding nanoparticles in high volume fractions.

An enhancement in thermal conductivity occurs mainly due to formation of a solid like layer at the interface of solid particles and base fluids. At low volume concentration this layer is in the phase of formation but at the high volume concentration layer is already formed and a further increase in the concentration will increase its thickness that improves the heat carrying capacity of nanofluids. This is the reason for the increased sensitivity for the higher volume concentration as observed.

7. Conclusions

Al_2O_3 nanoparticles have been synthesized using the solution combustion synthesis at 850, 1000 and 1150 °C combustion temperature. It was observed that an increase in combustion temperature increases particle size which is in agreement with the established facts. Although synthesized particles were in nanometer range for all the temperatures, variation in their size and shape shows that the combustion temperature significantly affects particle properties. Weighted average particle size obtained from DLS was 38, 53 and 70 nm for particles combusted at 850, 1000 and 1150 °C. It can be stated that an increase in combustion temperature leads to the favourable condition for particle growth which in turn corresponds to an increase of particle size.

Existing literature states that at 1000 °C Al_2O_3 is mostly in α-phase which is thermodynamically the most stable phase. Moreover, size obtained at this temperature was around 53 nm which provides the best results of thermal conductivity enhancement. The aim of our work was to enhance thermal conductivity so nanoparticles combusted at 1000 °C were used for the study. Al_2O_3 nanofluids had shown enhanced thermal conductivity for different base fluids. It was observed that for the ethylene glycol based nanofluid the rate of increase in thermal conductivity corresponding to an increase in concentration was higher in comparison to distilled water based nanofluids. Comparatively an increase in the temperature of distilled water based nanofluids exhibited a higher rate of increase of thermal conductivity. Thus for heat transfer applications ethylene glycol based nanofluids would be more efficient in the case of Al_2O_3 nanoparticles where concentration changes rapidly and for conditions having significant temperature drift the use of distilled water based nanofluids would be more efficient.

Our results indicate that the rate of increase in thermal conductivity does not vary significantly with a particular base fluid at different temperatures or concentrations, but different base fluids exhibits a significantly different rate of increase. Changes in thermal conductivity are important in many engineering systems. Sensitivity analysis reveals that engineers should be more careful to increase the concentration at a higher volume percent as the sensitivity increases with increasing concentration. This work also emphasizes on the selection of correct base fluid as sensitivity for different base fluid varies significantly.

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