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Development and characterization of aluminium oxide nanofluids as coolants for heat transfer applications

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Abstract : The current research work involves the development of aluminium oxide based nanofluids using water as the base fluid for potential use as a coolant for heat transfer applications. Three different concentrations 1%, 3% and 5% of the aluminiumnanofluids are developed. The characterization of the synthesized nanofluids is done by fourier transform infrared spectroscopy (FT-IR), scanning electron microscope (SEM), energy dispersive spectroscopy (EDS) and x-ray diffraction (XRD) techniques. The thermo-physical properties (thermal conductivity and viscosity) measurements were carried out and the interesting results obtained are discussed. **© Trade Science Inc.**

Keywords : Nanofluids; Thermal conductivity; Viscocity; Fourier transform infraredspectroscopy; X-ray diffraction.

INTRODUCTION

Ultrahigh-performance cooling is one of the most vital needs of many industrial technologies. Nanofluids, fluid suspensions of nanometer-sized particles, have recently been demonstrated to have thermal conductivities far superior to that of the liquid alone[1–4]. This and their other distinctive features offer unprecedented potential for many applications in various fields including energy, bio and pharmaceutical industry, and chemical, electronic, environmental, material, medical and thermal engineering. Conventionally, heat transfer fluids, such as water, oil, ethylene glycol, etc., have been playing an important role in the working of many thermal systems for centuries. The scope for the design of thermal systems, like heat exchangers, with respect to the thermo-physical properties is limited since these liquids possess low values of thermal conductivity. Low heat transfer characteristics of these fluids affect the enhancement of performance and in turn the compactness of heat exchangers. However, it is possible to engineer fluids with suspended metallic particles to artificially enhance the thermal conductivity. Particles in the order of millimeter and micrometer suspended in fluids were earlier recommended, but problems, such as the clogging of fluid paths, abrasion, pressure drop, etc., are the major negative features. With the unprecedented increase in the heat loads and heat fluxes caused by a variety of products, such as computers, defense and high-powered lasers, X-rays, Klystron tubes, etc., efficient cooling is the need of the hour. Thus, there is a growing demand for better heat transfer fluids with significantly higher thermal conductivities and improved heat transfer characteristics[5].

A nanofluid (nanoparticle fluid suspensions in a base fluid), a term first suggested by Choi in 1995 and later experimented by notable researchers, is a new type of heat transfer fluid that exhibits thermo-physical properties superior to those of the conventional fluid and microparticle fluid[1]. Besides the enhanced heat transfer, nanofluids eliminate the problems arising with the microparticle fluids. Thus, nanofluids have greater potential ability for heat transfer enhancement and are highly suited to the application in practical heat transfer processes. The thermophysical properties of nanofluids, such as thermal conductivity and viscosity are of significant importance in every heat transfer application involving a fluid system[6].

Recent experiments on nanofluids have indicated that a significant increase in thermal conductivity could be achieved when compared with liquids without nanoparticles or larger particles[7–11]. For example 0.3 vol. % copper nanoparticles dispersed in ethylene glycol is reported to increase its inherent poor thermal conductivity by 40%[7]. In this method aluminium oxide nanofluids comprising of metallic aluminium oxide dispersed in water are synthesized by a simple method.

EXPERIMENTAL

Preparation of aluminium oxide nanofluids

Alumininum oxide (Al2O3) nanoparticles was purchased from M/s. Alpha Aesar. The size of nanoparticles was 45 nm as it was mentioned by the company. Nanofluids were prepared by two step process[12, 13]. Aluminium oxide nanofluids of concentration of 1 %, 3 %, and 5 % were prepared by mixing 1 gm, 3 gm, and 5 gm of nanoparticles in 100 ml of distilled water. To make the nanoparticles more stable and remain more dispersed in water, ultra sonicator was used. Sonication was done for 3-4 hours before testing any thermo physical property of the nanofluids. By this nanoparticles become more evenly dispersed in distilled water.

Characterization

Characterization of the synthesized aluminium oxide nanofluid was done by FT-IR, SEM, EDS and XRD. Thermo-physical properties (thermal conductivity and viscosity) measurements were carried out.

Fourier transform infra red spectroscopy (FT-IR)

FTIR spectra were recorded using Perkin Elmer 781 infrared spectrometer with KBr pellets. The aluminium oxide nanofluid samples were directly applied by dabbing onto a KBr pellet. FTIR brought greater versatility to structural studies. The spectra recorded for liquid samples were made into a thin film in between two KBr windows. The spectra could be scanned and recorded in a matter of seconds.

Scanning electron microscopy (SEM)

SEM technique was used to study the surface morphology. The images were obtainedwith a JEOL JSM- 6700F field emission gun-SEM, (JEOL, Tokyo, Japan), operating at anacceleration voltage of 20 kV in backscattering electron image (yttrium aluminium garnet-type detector)

Energy dispersive X-ray spectroscopy (EDS)

Energy dispersive X-ray spectroscopy (EDS) is an analytical technique used for theelemental analysis or chemical characterization of a sample. As a type of spectroscopy, it relies on the investigation of a sample through interactions between electromagnetic radiation andmatter, analyzing x-rays emitted by the matter in response to being hit with charged particles. Its characterization capabilities are due in large part to the fundamental principle that each elementhas a unique atomic structure allowing X-rays that are characteristic of an element's atomic structure to be identified uniquely from one another.

X-ray diffraction topography (XRD)

Aluminium oxide nanofluid was diluted with absolute ethanol followed by centrifugation at 4000 rpm for 60min. It was then washed with absolute ethanol and acetone. Further it wasvacuum dried at 80 æ%C for 2 h. X-ray diffraction topography of the obtained powder wasperformed on a X-ray Diffraction (XRD, MACMXP18) machine with wavelength: 1.54nm.

Measurement of thermal conductivity

For the measurement of Thermal conductivity, KD2 Pro was used. Different sensors were used for the measurement of these properties. As nanofluids are relatively low viscosity fluid, so KS-1 sensor was used to measure the thermal conductivity. These properties can be measured at various ranges of temperatures such as from 20 ºC to 80 ºC. Nanofluids were heated by hot plate till the steady state achieved at particular temperature. After attaining the steady state, the sensor was dipped in the bottle. It took approximately 1 minute for the measurement of thermal conductivity. After this the readings were noted corresponding to the temperature which shows on the screen. Same experiment was repeated for the different volume concentrations of nanofluids i.e. 1 %, 3 % and 5 % at different temperature.

Measurement of viscocity

For the measurement of viscosity of nanofluids, Ostwald viscometer was used. This apparatus is cheap and easily available. There are two bulbs such as one is at lower section on one side and other bulb is at upper side of another side. The lower bulb is filled with water and then water was drawn into the upper bulb by suction, and then was allowed to flow down through the capillary into the lower bulb. The time taken for the water to pass between the two marks of viscometer was noted down. This was done at various temperature ranges i.e. 20 ºC to 80 ºC. The same was repeated with the different concentrations of nanofluids. The time taken for nanofluid to pass between the two marks of the oswald viscometer was noted. Firstly, it was done for distilled water as distilled water is used as a base fluid for preparing nanofluids. Then, same method is done for the other samples i.e. 1 %, 3 %, 5 % volume concentrations of nanofluids and noted down the time at different temperatures.

RESULTS AND DISCUSSION

FT-IR Spectra

The FT-IR spectra of aluminum nanofluid film prepared in water is seen in Figure 1. The spectrum has absorption bands at about 3400 cm $^{-1}$and in the region 1250–400 cm^{-1}. The former is due to the O–H stretching vibration of the water which is the base fluid. The latter is due to the intrinsic vibrations of the alumina constituting the bulk of the film the band with a peak at 1246 cm-1as observed in Figure 1.

SEM Analysis

The SEM analysis was carried out as observed in Figure 2. It was observed that thealuminium oxide nanoparticles were uniformly distributed in the nanofluid and the size of thealuminium oxide particles was found to be in the nanometric range.. This device incorporates anenergy-dispersive X-ray spectrometer that was used to chemically characterize the samples. SEMsamples were prepared by deposition of the nanopowder on top of a carbon

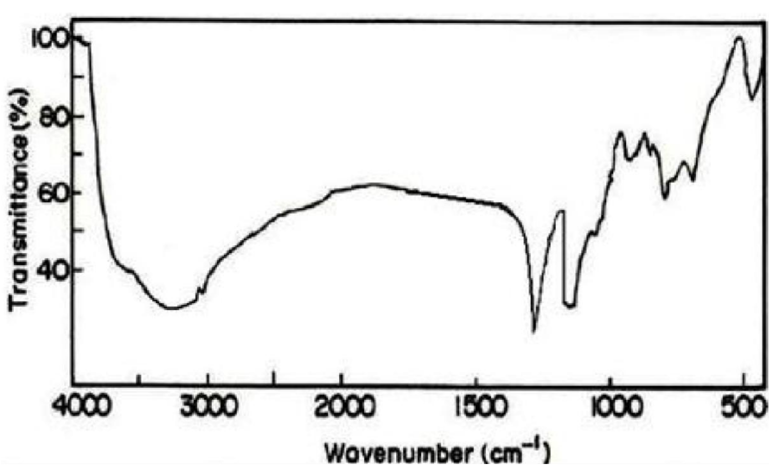
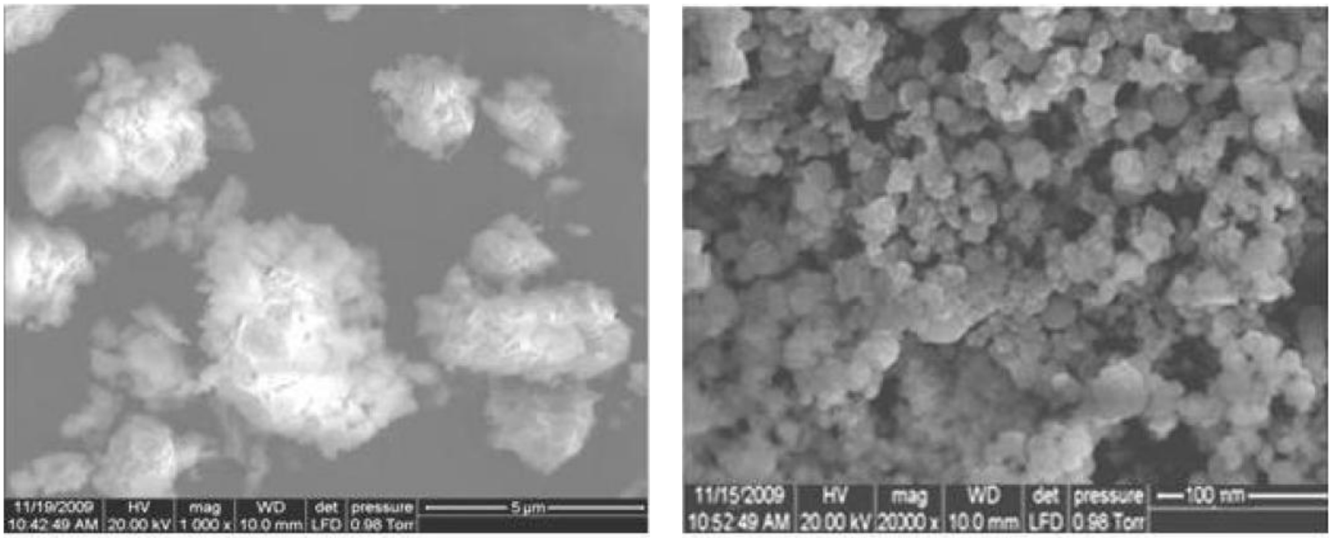
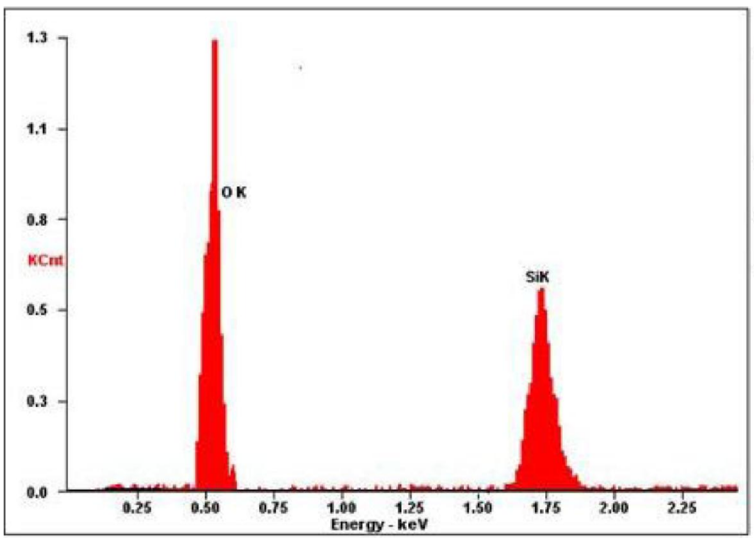


Figure 1 : FT-IR spectra of aluminium oxide nanofluid



a) X 1000 b) X 20,000

Figure 2 : SEM graph of aluminium oxide nanopowder in two magnifications a) X 1000 b) X 20,000



Element	Weight %	At %
O K	68.80	76.67
Al K	09.38	07.74

Figure 3 : EDS of aluminium oxide nanopowder

substrate, coatedwith a thin (approximately 20 nm) carbon layer. The SEM pictures in Figure 2 show that underatmospheric condition, the nanopowder forms close agglomerates of micrometers in size (Figure 2a). A magnification of these aggregates (Figure 2b) allows identifying the individual nanoscalesize particles on the agglomerate surface. The shape of the individual nanoparticles is nearlyspherical. This device incorporates an energy-dispersive X-ray spectrometer that was used tochemically characterize the samples. SEM samples were prepared by deposition of thenanopowder on top of a carbon substrate, coated with a thin (approximately 20 nm) carbon layer. The pictures in Figure 2 show that under atmospheric condition, the nanopowder forms closeagglomerates of micrometers in size (Figure 2a). A magnification of these aggregates (Figure 2b)allows identifying the individual nanoscale size particles on the agglomerate surface. The shape of the individual nanoparticles is nearly spherical.

Elemental dispersive spectroscopy

The EDS spectroscopy showed the presence of aluminium and oxygen in the synthesized aluminium oxide nanofluids by the distinct peaks as observed

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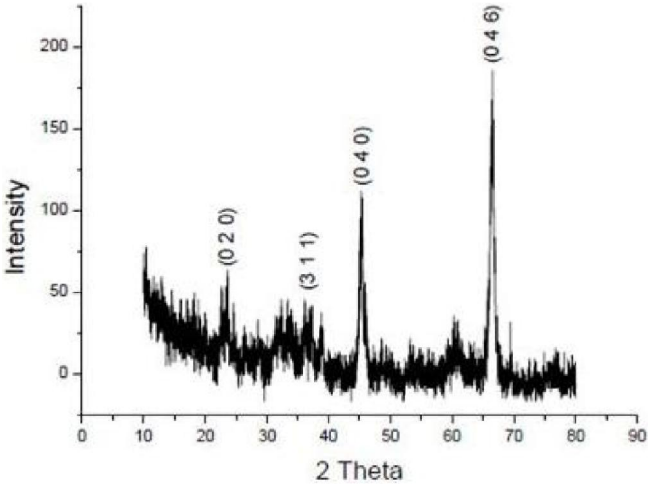

Figure 4 : XRD of aluminium oxide nanopowder

in the EDS spectrum shown in Figure 3.

XRD Analysis

The XRD results of the aluminium oxide nanoparticles, is shown in Figure 4. The XRD analysis for the crystalline phase of Aluminum Oxide (Al2O3) can be seen. The crystalline phase was determined by X-ray Diffraction (XRD, MACMXP18). All peaks obtained by XRD analysis were assigned by comparison with data from the Joint Committee on powder Diffraction Standards (JCPDS).

Measurement of thermal conductivity

Thermal conductivity can be measured by thermal property analyzer i.e. KD2 Pro by using KS-1 sensor needle as this needle is preferred for low viscosity fluids. It is measured at different ranges of temperature such as from 20 °C to 80 °C for the different concentration of nano-particles such as 1 %, 3 % and 5 % and data calculated by experiment is mentioned in TABLE 1, 2 and 3. The graphical representation is shown in Figure 5.

TABLE 1 : Values of thermal conductivity at different temperatures for 1 %Al2O3

S.No.	Temperature, °C	Thermal Conductivity (W/m/K)
1	20	0.610
2	40	0.689
3	60	0.891
4	80	1.108

TABLE 2 : Values of thermal conductivity at different temperatures for 3 %Al2O3

S.No.	Temperature, °C	Thermal Conductivity (W/m/K)
1	20	0.631
2	40	0.694
3	60	0.920
4	80	1.281

TABLE 3 : Values of thermal conductivity at different temperatures for 5 %Al2O3

S.No.	Temperature, °C	Thermal Conductivity (W/m/K)
1	20	0.658
2	40	0.719
3	60	1.115
4	80	1.390

The effective thermal conductivity can be measured by thermal property analyzer such as KD2 Pro at different ranges of temperature. The experimental results show that a dramatic increase in the enhancement of thermal conductivity of Al2O3. This is due to the fact that as the temperature increases, the rate at which Al2O3 particles moving in the nanofluid

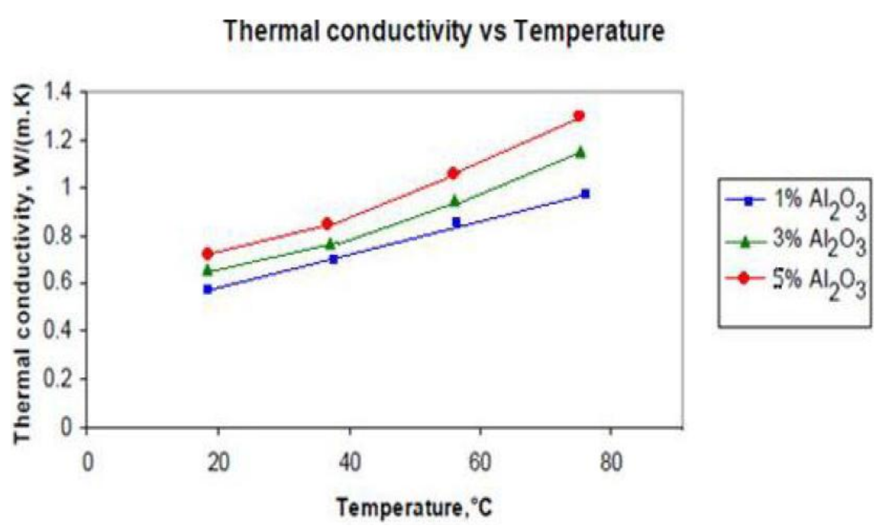

Figure 5 : Thermal conductivity Vs temperature graph of Al2O3 nanofluids

TABLE 4 : Viscocity at different temperatures for 1%, 3% and 5 %Al2O3

S.No.	Temperature, °C	Viscocity, (Cp) 1% Al2O3	Viscocity, (Cp) 3% Al2O3	Viscocity, (Cp) 5% Al2O3
1	20	0.7126	0.7512	0.7983
2	40	0.5932	0.6210	0.6837
3	60	0.2780	0.2970	0.3204
4	80	0.1590	0.1598	0.1839

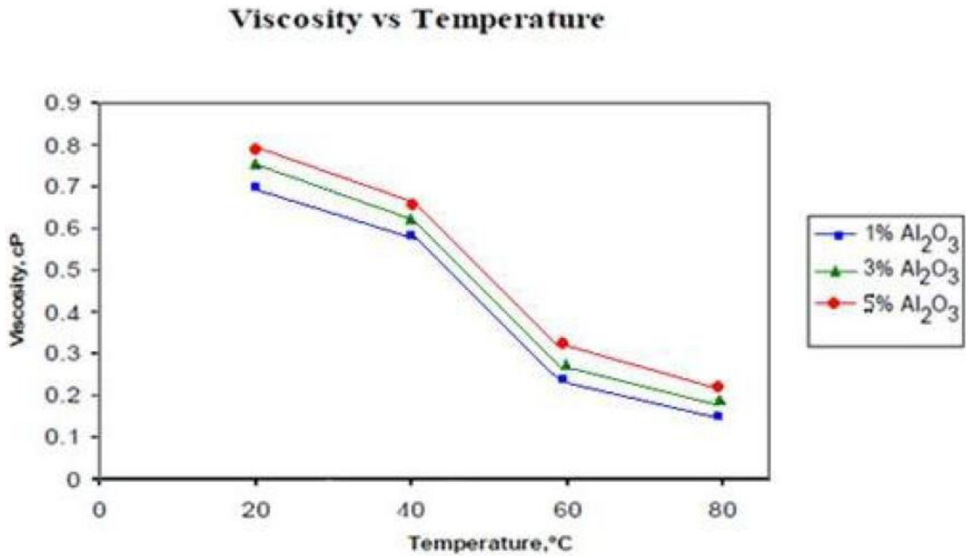

Figure 6 : ViscocityVs Temperature graph of Al2O3 nanofluid

increases. The average kinetic energy or energy of motion of the nanoparticles increases with temperature and hence the rate at which heat is transferred in the nanofluid also increases[14].

Measurement of viscosity

Viscosity can be measured by Ostwald viscometer at various ranges of temperatures such as 20°C, 40 °C, 60 °C and 80 °C. It can be measured for distilled water, 1 %, 3 %, 5 % volume concentrations of Al2O3. The final experimental values which are drawn by the experiment are mentioned in TABLE 4. Viscosity of nanofluids can be measured by Ostwald viscometer. From the experimental results, it is observed that nanofluids have lower viscosity and higher thermal conductivity. Viscosity was found to decreases with increases in temperature. As temperature increases, the average speed of the molecules in the nanofluid increases and the amount of time the nanoparticles dispersed in the base fluid spend "in contact" with their nearest neighbors decreases. Thus, as temperature increases, the average intermolecular forces decrease in between the nanoparticles. These properties are also depending upon the nanoparticle volume concentration present in the base fluid. Viscosity increases by increasing the particle volume concentration of Nanofluids[15]. The graphical representation is shown in Figure 6.

CONCLUSIONS

In the current research study, three different concentrations of 1%, 3% and 5% of aluminium oxide nanofluids were synthesized. These synthesized nanofluids were characterized by FT-IR, SEM, EDS and XRD studies. Thermo-physical properties (thermal conductivity and viscosity) measurements were studied.

From the FT-IR analysis of the synthesized nanofluids the structure of the aluminiumnanofluids was ascertained. SEM analysis was carried out to study the morphology of the aluminium oxide nanoparticles. It was observed that the aluminium oxide particles are spherical in shape. The chemical composition was studied by EDX and this showed the presence of aluminium and oxygen. The XRD analysis carried out on the aluminium oxide nanoparticles showed the crystalline nanometric

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phases of aluminium oxide nanoparticles. Thermo-physical properties (thermal conductivity and viscosity) measurements were carried out and it was observed that among the three different nanofluids prepared, 5% aluminium oxide containing nanofluids showed the maximum conductivity and the conductivity was found to increase with temperature. The viscocity studies carried out on the three different concentrations of the nanofluids showed that the viscosity was found to decreases with increases in temperature. These properties are also depending upon the nanoparticle volume concentration present in the base fluid. Viscosity was found to decrease by increasing the particle volume concentration of nanofluids. Hence it could be concluded that the aluminium oxide nanofluids prepared can be effectively used as coolants for automobile and heat transfer applications.

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