A comparative study of nanofluid (Al$_2$O$_3$) and distilled water in terms of thermal conductivity

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DOI: https://doi.org/10.22271/chemi.2020.v8.i2r.8923

Abstract

The transfer of heat energy between fluids is frequently used in various processes in industries. The subject of potential heat energy enhancement is great attention in research. With increase in thermal conductivity of fluid, the efficiency of heat transfer in machines can be improved. In this research work, a comparative study is carried out to investigate the effect of Al$_2$O$_3$ Nanofluid on the thermal conductivity with distilled water. KD2 pro thermal property analyzer is used in this work to measure the thermal conductivity. The Al$_2$O$_3$ nanoparticles of the nanofluid have been characterized by using Scanning Electron Microscope, Transmission Electron Microscope, UV-VIS-NIR. Experimentally, it is found that maximum enhancement in thermal conductivity was 8.7% at 80 °C of 0.1 wt % concentration.

Keywords: Nanofluid introduction, thermal conductivity, SEM, TEM, UV-VIS-NIR

1. Introduction

There are so many industrial processes which involve the transfer of heat energy. In any industrial process heat must be added or removed. It can also be transfer from one to another stream. Heat become plays a major role to fulfill the necessity of industries. In past decades, solid micro sized particles even millimeter sized particles were used with base fluid. These large sized particles created many problems in industries and troublesome in machines such as corrosion, deposition of debris in fluid flowing pipes which reduces the efficiency of machines. By using nanofluids these problems could be sort out and efficiency of heat transfer can be improved. Nanofluids having high dispersion stability, better lubrication, ability to ultrafast heat transfer, reduce friction coefficient, high specific surface area. (Uher et al. 2004).

Nano fluid may be defined as a fluid which containing nano sized particles or nano particles. In nanofluids there is colloidal suspension of nano particles in base fluid. If we add nanoparticles of metal in the fluids then it is called metallic Nano fluids. It has been reported that maximum enhancement in thermal conductivity of heat transfer of fluids have been observed when less amount of metallic and other particles were dissolved in these fluids. Thermal conductivities of nanofluids which contain solid particles are mainly greater than predicted values by theories of different materials. There are many research groups which are experimentally studied and reported the thermo physical properties of CNT suspensions are more than those of other nanoparticles which have the same volume fraction [1-3]. Choi [4] who proposed first time nanofluids found that the thermal conductivity of coolant increased by addition of nanoparticles in base fluids and it could improve the heat transfer performance of the coolant. After that a new name nanofluids came into existence in this field. The Thermal conductivity of fluids is low. Nanofluids can improve the thermal conductivity of fluids. There is following some mechanism by which enhancement in the thermal conductivity in nanofluid can be predicted.

1.1 Mechanism behind the enhancement of thermal conductivity of Nanofluids

1.1.1 Brownian motion

It is the random movement of particles suspended in the fluid and gases resulting from their collision or dispersion with fast-moving nanoparticles /molecules in the fluid. Farah et al. (2005), Jang et al. (2004), and Koo et al. (2005) suggested Brownian motion plays a major role to control the thermal conductivity of nanofluids at micro level.
With an increase in temperature the thermal conductivity and particle motions also increases. Brownian motion produces slow motion of the nanoparticles when heat transfer takes place from one place to another. So, in the heat transfer it cannot be supposed utmost factor.

1.1.2 Thermophoresis
Thermophoresis is a phenomenon in which molecules of hot region counted high energy compared to cold region (Yu et al. 2003). Film boiling of nanofluids effects the enhancement in heat transfer compared to a vertical cylinder (Malvandi et al. 2016).

1.1.3 Nano-layer/Liquid layer
Nano layers can be formed at different interfaces between the homogeneous and heterogeneous layers of solid, liquid and gases that depend on the different processes. It plays a vital role in the field of nanotechnology. For instance, 2D Nano additives are most common in the field of food packing industries. Enhancement of thermal conductivity of 10nm particle size was shown by Yu et al. (2004). They found that this enhancement was due to nanoliquid layer.

1.1.4 Clustering
Clustering also affects the thermal conductivity. It is a basically a grouping of objects on the basis dissimilarity and similarity between the objects. When high concentration nanofluids are placed for a long time, clustered form of nanofluid observed. Now, due to this clustering the effective area of the thermal interaction of particles is reduced and caused decreasing in the thermal conductivity of the fluid. The difference between models developed to account for nano particle clustering and models which reflect the spatial arrangement of particles is that the nano particle clustering models include particle size dependence. The smaller particle size creates greater attraction between the individual particles, which leads to a greater extent of aggregation. To determine the thermal conductivity of an aggregate model, this includes the backbone of nanoparticles, the dead end nanoparticles and the fluid surrounding the particles.

In this article, firstly, nanofluid preparation methods are discussed briefly. It also describes the preparation technique of nano fluid with 0.1 wt% of Al2O3. Different characterization techniques are deliberated. It also shows that thermal conductivity of Al2O3 nanofluid with distilled water as base fluid is better than water. Correlation is also developed and compared with well-defined correlations.

2. Literature review
This section describes the review on enhancement in thermo physical properties and thermo hydraulic performance of nanofluid Al2O3 and other nanofluids using different concentration at different temperature and different flow rate by different researchers.

Masuda et al. [5] experimentally studied the enhancement in heat transfer using Al2O3/water based nanofluid which had particle size and volume concentration are 13 nm and 1.30-4.30% respectively. They used two-step method for it and found that heat enhancement was 1.109-1.324 ratio. Akbaridoust et al. [6] investigated the difference between dispersion and experimental model of different helical coils using nanofluids and found that in helical coil 1, 2, 3 the coefficient value of water-CuO (0.1%) is 3.22, 3.76, 2.63 respectively and the coefficient value of water-CuO (0.2%) is 2.99, 4.27, 3.1 for same helical coils. The difference between these models was about 4% and it had been decreased. Wen et al. [7] experimentally studied the effects in convective heat transfer of γ-Al2O3 nanopowder in a tube of copper by using pure water. The maximum enhancement in heat transfer enhancement was observed at inlet and after that it continuously decreased. When x/D is 63 the enhancement is 47% and when x/D is 173 it decreased to 14% at Reynolds number = 1600. Bianco et al. [8] numerically studied the hydrodynamic and thermal behaviour of Al2O3 water based nanofluid in a circular tube. By them the single-phased model is issued. They find out the difference between their values which results the augmentation in heat transfer. Eastman et al. [9] found that the thermal conductivity of Cu EG nanofluids is increased about 40%. Liu et al. [10] experiment the thermal conductivity of Cu/water nanofluids. In result 23.8% improvement were found and thermal conductivity of nanofluid increases with increases in particles volume fraction & decreases with elapsed time. Lee et al. [11] revealed due to addition of surfactant in the nanofluid during preparation of nanofluids thermal conductivity of nanofluids is largely affected. This addition of surfactant (sodium dodecyl benzene sulfonate) in the nanofluid leads to enhancement of thermal conductivity of Cu/water (0.1%) nanofluid was 10.7%. Lee and Mudawar [12] compared the stability of nanoparticles of Al2O3. They found when Al2O3 nanofluids kept for 30 days exhibits some settlement of nanoparticles at the bottom of container compared to fresh nanofluid. This was indicated for the long time, degradation in the thermal properties of Al2O3 nanofluids could be found. Vasu et al. [13] studied the effect on pressure drop in compact heat exchanger along with nanofluids (Al2O3) and they found the pressure drop of 4% Al2O3/water nano fluids was almost double that of the water. So, it is cleared from this study the pressure drop also increases by adding nanofluids in compact heat exchanger. It is also effects the thermal conductivity of nanofluid. Suresh et al. [14] Experimentally studied the pressure drop and convective heat transfer characteristics of Al2O3/Cu-water hybrid nanofluids with 0.1% volume concentration in a uniformly heated circular tube through fully developed circular tube. The experimental results shows the maximum enhancement of 13.56% in Nusselt number of nanofluids compared to Nusselt number of water at Reynolds number of 1730. The friction factor of Al2O3-Cu/water hybrid nanofluids at 0.1% is slightly higher than 0.1% of Al2O3-Cu/water based nanofluids. Chandrashekar et al. [15] experimentally studied that friction factor and heat transfer characteristics of Al2O3/water based nanofluid of 43nm size and 0.1% vol. concentration flowing through uniformly heated circular pipe under laminar flow with wire and without coils inserts. In fully developed region the Nusselt number were measured and found that there is increment of 12.24% at the Re=2275. At Reynolds number of 2275 the increase in nusslet number has been recorded by 15.91% and 21.53% after the two wire coil inserts with pitch ratio 2 and 3 respectively of Al2O3 nanofluid compared to distilled water. Pastoriza-Gallego et al. [16] experimentally studied the thermo physical properties of nanofluid. Thermal conductivity changes with both concentration (6.9 vol%) & temperature for nanoparticles in EG were measured. The results found that the enhancement in thermal conductivity 45% at T = 343.14 K and 6.9% volume fraction. Table 1 shows the enhancement in thermal conductivity as studied in above said literature.
Table 1: Thermal Conductivity Enhancements

| Author                | Concentration (vol. %) | Nano particle used | Nanofluid used    | Method of preparation | Particle size (nm) | Enhancement (ratio) |
|-----------------------|------------------------|--------------------|-------------------|-----------------------|-------------------|---------------------|
| Lee et al. [17]       | 1.00-4.30              | Al₂O₃              | Distilled Water   | Two-step method       | 38.4              | 1.03-1.10           |
| Wang et al. [18]      | 3.00-5.50              | Al₂O₃              | Distilled Water   | Two-step method       | 28                | 1.11-1.16           |
| Xie et al. [19]       | 1.80-5.00              | Al₂O₃              | Distilled Water   | Two-step method       | 60.4              | 1.07-1.21           |
| Das et al. [20]       | 1.00-4.00              | Al₂O₃              | Distilled Water   | Two-step method       | 34.8              | 1.02-1.09           |
| Chon et al. [21]      | 1.00                   | Al₂O₃              | Distilled Water   | Two-step method       | 11                | 1.09                |
| M.J. Pastoriza-Gallego et al. [23] | 1%            | ZnO                | Ethylene Glycol   | Two-step method       | 30-60             | 45% at T = 343.15 K and 6.9% volume fraction |
| M. Chandra Sekhara Reddy et al. [24] | 0.2% to 1.0%  | TiO₂               | ethylene glycol–water | Two-step method       | 21                | 10.64% and 14.2% respectively. |
| Madhusree Kole, T.K. Dey [25] | 0.016         | ZnO                | surfactant free and stable ethylene glycol (EG) | Two-step method       | <50               | ~22%                |
| Wei Yu, et al. [26]   | 5.0%                   | ZnO-EG             | Ethylene Glycol   | Two-step method       | 10–20             | 26.5%,              |
| L. Godson et al. [27] | 0.04%                  | Silver             | Water             | Two-step method       | 54 nm             | 12.4%               |
| Arun Kumar Tiwari et al. [28] | 0.75 vol. %,          | CeO₂               | distilled water   | Two-step method       | 30 nm             | 39%                 |

3. Nanofluid preparation method
There are two different techniques to prepare the nanofluids.

3.1 Single Step Preparation Methods
In this process two nanoparticles are mixed with the synthesis of the nanofluids. In this we take two reactants and combine them physically as shown in Fig.1.

3.2 Two Step Preparation Method
It is another type of preparation of nanofluid [37]. In this existing nanopowder are mixed with base fluids by using various methods which are mechanical or chemical methods such as stirring, ultrasonication etc. The two step method as shown in Fig.2.

3.3 Physically Belongings of Al₂O₃ Nano powder

Table 2: The table shows the physical belongings of Al₂O₃ Nano powder

| Molecular Formula | Al₂O₃ Nano powder |
|-------------------|-------------------|
| Mean Particles size | < 80 nm          |
| Al₂O₃ content    | 99%               |
| Specific surface area | 15 – 20 m²/g     |

3.4 Flow chart Nanofluid Preparation Methods
As shown in Fig.3. Step by step preparation of nanofluid and after the preparation, the thermal conductivity of fluid will be measured.
From the above flow chart as shown in Fig. 3, it is clear that in upcoming study of the preparation and syntheses of Al₂O₃ nanofluid would not to be too complicated. It would be easy to measure the thermal conductivity of nanofluid. The ultra sonication and magnetic stirring processes would be also easily performed. Nanopowder of Al₂O₃ was purchased from High Purity Chemicals Private Limited (HPCL), Mumbai. Characterization such as SEM (Scanning electron microscope), TEM (Transmission electron microscope) images of the nanoparticles were performed at NIPER, Mohali (Chandigarh). Nanofluids are prepared by addition of Al₂O₃ nanoparticles at the certain concentrations into base fluid. Two step methods were performed for the synthesis of Al₂O₃ nanoparticles with distilled water as base fluids. The weight concentration of Al₂O₃ nanoparticles was 0.1% (Fig. 4). Cetyl tri ethyl ammonium bromide was used as a surfactant to more dispersion of nanoparticles in water. For mixing the nanoparticles properly in distilled water ultra sonicatıon process was performed at department of bio & nano technology, GJU S&T Hisar. After the sonication, the magnetic stirring for 4-5 hours was also performed. At last, for experimental work the KD2 pro thermal analyzer was used to measure the thermal conductivity of Al₂O₃ nanofluids.

4. Characterization Techniques
There are different form of characterization techniques of Al₂O₃ nanoparticles are discussed below.

4.1 SEM (Scanning Electron Micrograph)
SEM is a technique that produces an image of sample by focusing the beam of electrons on the surface of it. The scanning electron micrograph (SEM) of Al₂O₃(0.1wt.%) nanoparticles shows the presence of dumble shape of particles. The particles size distribution of Al₂O₃ nanoparticles shows the average size is 100nm (Fig.5). To break and facilitate dispersion in distilled water ultrasonication was done.

4.2 TEM (Transmission Electron Microscopy)
This is a technique in which a beam of electrons passes/transmitted through the sample to forming an image of nanoparticles. Al₂O₃ water based nanofluid is used in work are dumble shaped (Fig.6).
4.3 UV-VIS-NIR
This device is used to measure the absorption of light of chemical substance. Process of this spectroscopy is done by measuring the difference amount of light passes through the sample and base fluid. Fig. 7 Shows the UV image of Al₂O₃ nanofluids (0.1 wt%) which describes the highest of Abs were recorded 3 at the wavelength of 300 approximately.

5. Results and discussion
5.1 Measurement of Thermal Conductivity
The KD2 pro was used for measuring the thermal conductivity 0.1% weight concentrations of Al₂O₃ nanofluids and distilled water. KD2 is decagon devices and battery-operated which is very used for measuring the thermal properties of nanofluid. It is a handled device. KD2 has a sensors kit in which three different sensors (KS1, SH1, and TS1) applicable for measuring the thermal conductivity of various liquids and solids. Thermal conductivity and resistivity of nanofluid is measured by single needle sensors. While Dual-needles sensors measures the volumetric specific heat capacity and diffusivity. Because nanofluids possess low viscosity, So KS-1 type is used for measuring as it is best suited for the liquid samples. The different Values of thermal conductivity were obtained at different temperatures. Following are the specifications of KD2 pro thermal property analyzer. Dip the sensor in the bottle and switch on the KD 2 pro. Readings at different temperatures will be recorded. Thermal conductivity of Distilled water and Al₂O₃ nanofluid (0.1 wt%) has been measured by KD2 pro at different temperatures 30°C, 40°C, 50°C, 60°C, 70°C and 80°C.

5.2 Comparison of thermal conductivity of distilled water and prepared Al₂O₃ nanofluid.

Enhancement in thermal conductivity of nanofluid (%), \( k_{\text{eff}} = \frac{k_{\text{nanofluid}} - k_{\text{distilled water}}}{k_{\text{distilled water}}} \times 100 \)

Where

\( k_{\text{nanofluid}} \) = Thermal conductivity of Nano fluid.
\( k_{\text{distilled water}} \) = Thermal conductivity of Distilled water.

Fig 8: Comparison of thermal conductivity and distilled water at different temperature
Fig. 8 shows the enhancement in thermal conductivity is much higher than enhancement in distilled water with increasing temperature. As the temperature increase, thermal conductivity of fluids increases due to rapid Brownian motion at higher temperatures. Maximum enhancement is observed at 80 °C.

5.3 Developed correlation
After measuring the thermal conductivity values, a correlation is developed using linear regression analysis. Fig. 9 shows the comparison of experimental values with theoretical values predicted from developed correlation. A quite similar trend is obtained in both values. The maximum and minimum deviation of predicted and experimental values is well within +1.39296 and -0.008085 respectively.

\[ K_{\text{corr.}} = 0.41327^{0.12573} \]

Where,
\[ T = \text{Temperature (varies from 30-80 °C).} \]

6. Conclusions
In this study the enhancement in thermal conductivity has been tested of Al2O3 Nanofluid. Nanofluid had been prepared by using Al2O3 nanoparticles and distilled water as base fluid. Weight concentration of 0.1% have been prepared by using Two-step Method. The Characterization of Al2O3/ Distilled water Nanofluid have been also prepared by using SEM, TEM, UV-VIS-NIR. Enhancement in thermal conductivity of Al2O3 (0.1 wt%) found 4.1%, 5.7%, 6.2%, 6.6%, 7.9%, 8.7% while compared to thermal conductivity of distilled water at 30°C, 40°C, 50°C, 60°C, 70°C, 80°C respectively. So, maximum enhancement in thermal conductivity of nanofluid experimentally found 8.7% at 80°C of 0.1 wt%. Apart from the enhancement in thermal conductivity of Al2O3 nanofluid, the following conclusion can be drawn:

- SEM, TEM images shows dumble shaped particles.
- UV-VIS-NIR has recorded Abs from 0.4 to 3 relative to wavelength of range 200-600 nm.
- It is also found that with the increment of temperature the thermal conductivity of both distilled water and Al2O3 nanofluid also increases.
- A correlation for thermal conductivity is developed from measured values.

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