Journal of Materials Science & Surface Engineering Vol. 2 (2), 2015, pp 114-119

Contents lists available at http://www.jmsse.org/

Journal of Materials Science & Surface Engineering

Investigation on Physical Properties of Al_2O_3/Water Nano Fluid

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Article history

Received: 11th-April-2015
Revised: 25th-April-2015
Available online: 29th April, 2015

Keywords:
Thermal conductivity,
Electrical conductivity,
Viscosity,
Nanofluid

Abstract

In this paper, Experimental and theoretical investigations to determine the effective thermal conductivity, electrical conductivity and viscosity of Al_2O_3/water nanofluid are presented. Nano Al_2O_3 particles with particle composition and microwave assisted chemical deposition method , were distributed in distilled water by Sonic device. In this study, nano particles of aluminum oxide with a partial thickness of about 20nm in different volumetric concentrations of (0.15.5-3%) at constant temperature were used . So far, few studies to measure the rheological properties of nanofluid at constant temperature have been performed .thermal conductivity, electrical conductivity and viscosity of nanofluid increases at constant temperature with particle volume fraction. Al_2O_3 Nano particles in water for different volume concentrations show Newtonian behavior at 15.5°C. Theoretical models to predict the thermal conductivity and viscosity of nanofluids are the HC model and Einstein model. The proposed model has good agreement with experimental results.

Introduction

Nanofluid is a novel heat transfer fluid prepared by dispersing nanometer sized solid particles in traditional heat transfer fluid such as water or ethylene glycol to increase thermal conductivity and therefore heat transfer performance. For example, when 0.3 volume percent of copper nanoparticles are dispersed in ethylene glycol, one can observe about 40% of increase in thermal conductivity (Eastman and Choi, 1995)[1]. Metal oxides such as aluminum oxide or titanium oxide are also feasible even though the amount of heat transfer increase is not as large as metal particles (Masuda et al., 1993)[2]. The effectiveness of heat transfer enhancement is known to be dependent on the amount of dispersed particles, material type, particle shape, and so on. It is expected that nanofluid can be utilized in airplanes, cars, micro machines in MEMS, micro reactors among others. Before the introduction of nanofluid, it was expected that heat transfer could be enhanced by dispersing micron sized particles. But the fluid with micron sized particles caused problems due to sedimentation and clogging(Xuan and Li, 2000)[3]. Since the concept of nanofluid has been first introduced by Eastman and Choi (1995)[1]and there have been many efforts to understand the mechanism of heat transfer enhancement together with experimental measurements of the thermal conductivity nanofluids and utilization methods. There have been some reports on the rheological behavior of nanoparticle sin suspension. Xiao-Bing et al. (2001)[4] reported the of nanofluid viscosity by using the molecular dynamic simulation and kinetic theory. Zaman et al. (2002)[5]and Zaman (2000)[6] reported on the rheological properties and surface charge of polyethylene coated silicone oxide particles. Chandrmalar (2000)[7] reported on the rheological properties of aqueous solution of titanium oxide under the presence of cellulose. Aoki et al. (2003)[8] considered the carbon black dispersed system. Bently (1984)[9] reported the dispersion stability and rheological properties of a latex system with adsorbed copolymers. However the particles used in those researches were low thermal conductivity materials and heat transfer experiments were not performed hence we cannot directly apply their results to nanofluid systems. Choi [10] conceived the concept of nanofluids in 1995 which can enhance heat transfer without a large pumping power increase at Argonne National Laboratory of USA. Subsequent researches of Eastman et al.[11] and Choi et al.[12] triggered great interest in nanofluids when they reported anomalously high thermal conductivities of nanofluids at low nanoparticle concentrations. Hence in the past few years, many experimental investigations on the thermal conductivity of nanofluids have been reported which showed that nanofluids exhibit much higher thermal conductivities than their base fluids even when the concentrations of suspended nanoparticles are very low and the nanofluid thermal conductivity increase significantly with nanoparticle volume concentration. Reported results of the effective thermal conductivity of nanofluids from various research groups were well summarized by Murshed et al. [13] in a recent review.Recently, Choi et al. [14] showed that the thermal conductivity of transformer oil can be increased by more than 20% at 4% volume concentration of Al_2O_3 nanoparticles while with aluminium nitride (AlN) nanoparticles at a volume concentration of 0.5%, the thermal conductivity is enhanced by 8% and also Suvankar Ganguly et al, investigated the effective electrical conductivity of alumina nanofluid at different volume fractions. It is seen that the electrical conductivity of alumina nanofluid increases almost linearly with increase in the volume fraction of the alumina nanoparticles. The experimental data also indicates that for a given volume fraction, the electrical conductivity of the suspension will increase with increases in the temperature. The highest value of electrical conductivity, 351 μS/cm, was recorded for a volume fraction of 0.03 at a temperature of 45 °C; the corresponding value at room temperature (T=24 °C) was 15.58

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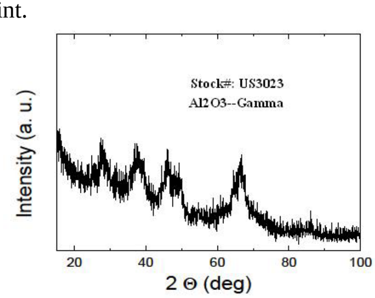
μS/cm. Duangthongsuk and Wongwises [15] experimentally found that the TiO_2 nanoparticles dispersed in water gave (3–7%) greater thermal conductivity than water with volume concentration ranging between 0.2% and 2.0%. Li et al. [16] recommended simultaneous control of both the pH and chemical surfactant to improve the thermal conductivity of Cu/H_2O nanofluids for practical applications. They reported a maximum thermal conductivity enhancement of 10.7% at 0.10% weight concentration. The effective thermal conductivities of Al_2O_3/water nanofluids with low volume concentrations from 0.01% to 0.3% were measured at 21℃ by Lee et al.[17]. They observed a maximum enhancement of 1.44% at a volume concentration of 0.3%.Regarding the flow behavior, Namburu et al. [18] have shown that at relatively low CuO nanoparticle concentration(b6.12 vol.%) dispersed in ethylene glycol and water mixture, nanofluids exhibit Newtonian flow behavior. In contrast, a nanoparticle cobalt-based magneto rheological fluid shows a nonlinear shear stress-shear rate behavior [19]. Rheological study of TiO_2 nanoparticle suspensions by Tseng and Lin [20] has indicated pseudo plastic behavior in the volumetric solids concentration of 5–12%. The effect of pH and solids concentration on the rheological behavior of TiO_2 suspensions has been studied by Guo et al. [21]; a remarkable role of pH on the colloids stability has been reported. Similar results have been reported for Al_2O_3 nanoparticles by Tseng and Wu [22]. Suspension rheology of aqueous indium tin oxide(ITO)nanoparticles indicated the importance of shear rate on the flow behavior, i.e. Newtonian behavior in the range of 10 to 500 s^{-1} and shear thickening response at the higher rates [23].

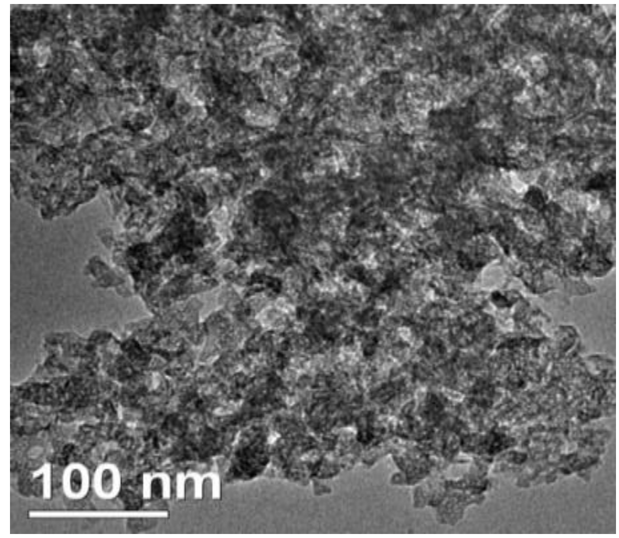
Experimental

Synthesis of nanoparticle and nano fluid

Nanocrystalline alumina (Al_2O_3) powder has been prepared from an aqueous solution of aluminium chloride by microwave assisted chemical precipitation method. 0.1 M of aluminium chloride was taken (aqueous solution) in a round bottom flask fitted with a reflux water condenser. The solution was hydrolyzed for 20 min and the resulting solution was neutralized with ammonia solution.
The precipitate formed is washed with distilled water and dried. The XRD spectra and the SEM image and TEM image of the prepared sample are shown in Figs. 1 (a,b,c) respectively. Nanofluid with a required volume concentration was then prepared by dispersing a specified amount of Al_2O_3 nanoparticles in water by using a ultrasonic vibrator (Toshiba, India) generating ultrasonic pulses of 100W at 36 ± 3 kHz. To get a uniform dispersion and stable suspension which determine the final properties of nanofluids, the nanofluids are kept under ultrasonic vibration continuously for 6 hr [8]. No surfactant or pH changes were used as they may have some influence on the effective thermal conductivity of nanofluids [22]. The pH of the prepared nanofluids at different concentrations were measured and found to be around 5 which is far from the isoelectric point of 9.2 for alumina nanoparticles [16]. This ensures the nanoparticles are well dispersed and the nanofluid is stable because of very large repulsive forces among the nanoparticles when pH is far from isoelectric point.



(a)



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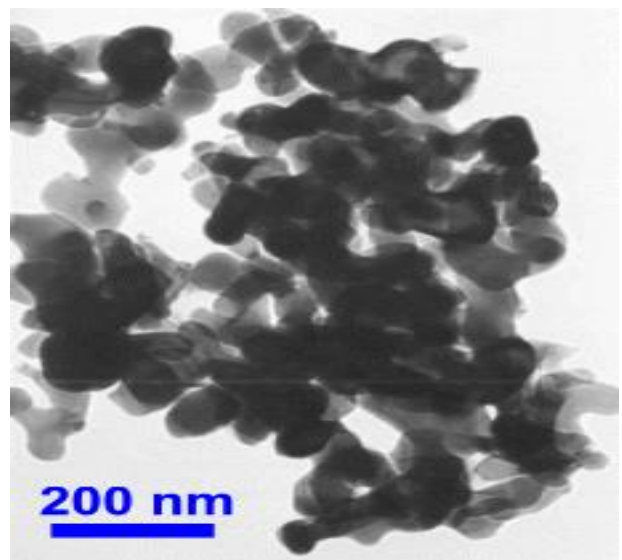

(c)

Figure 1: (a)XRD , (b) SEM and (c) TEM patterns of Al_2O_3 particles

Table 1:Alumina(gamma) Nano Particle Specification ($\gamma - AL_2O_3$)

Types of nanoparticles	Appearance	Percent purity	Special surface	Nano-sized particles	The apparent density
γ -Al_2O_3	White powder	+99	>160 m^2/g	20 nm	0.9 g/m^3

Chemical composition (Content of elements)

Al_2O_3	Ca	V	Cl	Na	Mn	Co
≥ 99 %	≤15.5 ppm	≤ 7 ppm	≤ 315 ppm	≤ 70 ppm	≤ 3 ppm	≤ 2 ppm

Applications

1. Transparent ceramics: high-pressure sodium lamps, EP-ROM window 2. cosmetic filler 3. single crystal, ruby, sapphire, sapphire, yttrium aluminum garnet 4. High strength aluminum oxide ceramic, C substrate, packaging materials, cutting tools, high purity crucible, winding axle, bombarding the target, furnace tubes 5.Polishing materials, glass products, metal products, semiconductor materials, plastic, tape, grinding belt 6.paint,

rubber, plastic wear resistant reinforcement, advanced waterproof material.

Viscosity measurement

In our experiments, we used Al_2O_3nanaoparticles with an average diameter of 20 nm for Al_2O_3. nano fluids with different volume concentration (0.15.5%, 0.5%, 1% , 2% , 3%.) were dispersed in water. The suspension of nanofluids was then stirred and agitated thoroughly for 1 hour With an ultrasonic agitator similar to sonicator. this ensures uniform dispersion of nanoparticles in the base fluid. viscosity of the nanofluids is measured by Brookfield programmable viscometer (model : LVDV-II+) connected to a PC controlled Julabo temperature controlled bath which can vary the fluid temperature 15.5℃. The viscometer drives a spindle immersed in nanofluids. When the spindle is rotaded, the viscous drag of the fluid against the spindle is measured by the deflection of the calibrated spring. This viscometer has a viscosity measurement rang of 1.5 and 30/000 mpas and can handle the viscosity measurement results within the temperature ranges of this experiment. Total volume of nonofluid required in UL adapter is≈20 (ml). the viscometer contains a sample chamber which is carefully monitored using a RTD temperature sensor during the viscosity measurements. The spindle type and speed combinations will produce satisfactory results when the applied torque is between 10% and 100%. therefore spindle types and speeds are selected in such way that torque values lie in this prescribed range. a wide range of spindle speeds are available in this viscometer (0- 200 RPM). Viscosity measurements were started at 15.5℃. Temperature of the fluid is measured by a calibrated pt–100 temperature sensor. The viscometer is connected to another computer as shown in fig 2, the operation of the viscometer and data collection ,viscosity, shear stress, shear rate, RPM, troque and temperature is performed using wingather software. All the viscosity measurements were recorded at steady state conditions (Fig.2).

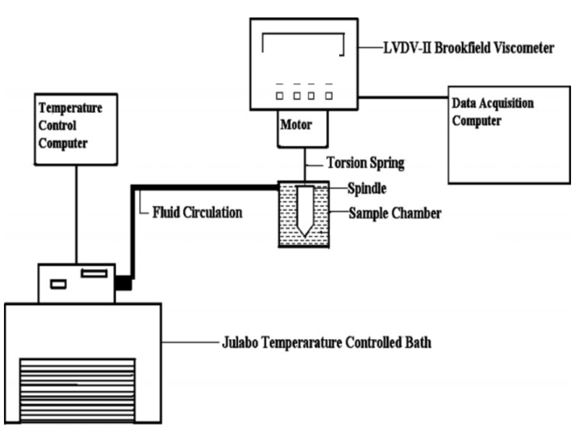

Figure 2: Experimental setup for viscosity measurement of nanofluid

Thermal conductivity and electrical conductivity measurement

The pocket-sized KD2 thermal properties analyzer uses a single sensor to measure thermal conductivity and thermal resistivity. It uses a simple yet precise heating and monitoring system to measure the slope and intercept of the sample specific temperature rise vs. time curve. The KD2 uses this data to calculate and display thermal conductivity in 90 seconds. The KD2 only weighs 4 ounces and is very durable, making it ideal for carrying from site to site. The small needle size results in very little compaction during installation and allows for a short heating time minimizing thermally induced drying around the probe. The thermal conductivity of Al_2O_3nanofluid was measured by using a KD2 Pro (Fig.3) thermal properties analyzer. It consists of a handheld microcontroller and sensor needle. The KD2 sensor needle contains both a heating element and a thermostor. The controller module contains a battery, a 16-bit microcontroller/AD converter, and power control circuitry. The sensor needle can be used for measuring thermal conductivity of fluids in the range of 0.2–2 $\left(\frac{w}{m\,k}\right)$with an accuracy of ±5%. Each measurement cycle consists of 90(s). During the first 30(s), the instrument will equilibrate which is then followed by heating and cooling of sensor needle for 30(s) each. At the end of the reading, the controller computes the thermal conductivity using the change in temperature (ΔT):

$$k = \frac{q(lnt_2 - lnt_1)}{4\pi(\Delta T_2 - \Delta T_1)} \quad (1)$$

Where q is constant heat rate applied to an infinitely long and small ‘‘line” source, $(\Delta T_2)$and (ΔT_1) are the changes in the temperature at times t_2 and t_1, respectively (Fig.3).

Figure 3: Thermal conductivity meter

Table 2: Conductivity Meter Properties

Accuracy:	5% Thermal Conductivity/Resistivity
Measurement Speed:	90 seconds
Range of Measurement:	K: 0.02 to 2 Wm^{-1} C^{-1} R: 0.5 to 50 mCW^{-1}
Operating Environment:	-10° to 60°C
KD2 Sensor:	Model: KD2-S Needle Material: Stainless Steel Needle Length: 60 mm Needle Diameter: 1.27 mm
Shipping Weight:	613 g

Measurements of the effective electrical conductivity of nanofluids:

The 4510 is easy to use but with the flexibility to meet the broadest range of applications and for those where greater accuracy is required the 4510 has automatic conductivity standard recognition and endpoint detection. Set-up options include cell constant, temperature coefficient and reference temperature To measure the electrical conductivity of nanofluids, a precision conductivity cell with an application range of 0.01μS /cm^{-2} S/cm has been used. Measurements of the electrical conductivity were carried out both as a function of nanoparticle volume fraction and temperature . The typical response time for measurement was about 20 s. The electrical conductivity of Al2O3-water nanofluid was measured at 15.5℃temperature.

Theoretical Model

The well known correlations for calculating the thermophysical properties of the nanofluid which are often cited by a number of researchers are expressed as follows:

Thermal conductivity

One well-known equation for computing the thermal conductivity of nanofluid is the Hamilton and Crosser [24] model, which is expressed in the following form:

$$k_{nf} = \left(\frac{k_p + (n-1)k_w - (n-1)\varphi(k_w - k_p)}{k_p + (n-1)k_w + \varphi(k_w - k_p)}\right) \quad (2)$$

$$n = \frac{3}{\Psi} \quad (3)$$

where n is the empirical shape factor and Ψ is the sphericity, defined as the ratio of the surface area of a sphere (with the same volume as the given particle) to the surface area of the particle. The sphericity is 1 and 0.5 for the spherical and cylindrical shapes, respectively. Moreover, φ is the volume, concentration, k_{nf} is the thermal conductivity of the nanofluid, k_p is the thermal conductivity of the nanoparticles and k_w is the thermal conductivity of the base fluid. Moreover, the thermal conductivity of the nanofluids is calculated from Yu and Choi [15.5], which is expressed in the following from:

$$k_{nf} = \left(\frac{k_p + 2k_w + 2(k_p - k_w)(1+\beta)^3\varphi}{(k_p + 2k_w - (k_p - k_w)(1+\beta)^3\varphi}\right) \quad (4)$$

An alternative formula for calculating the thermal conductivity was introduced by the Wasp [26] model, which is defined as follows:

$$k_{nf} = \left(\frac{k_p + 2k_p - 2\varphi(k_w - k_p)}{k_p + 2k_w + \varphi(k_w - k_p)}\right) \quad (5)$$

whereβ is the ratio of the nanolayer thickness to the original particle radius. Normally β = 0.1 is used to calculate the thermal conductivity of the nanofluid. For spherical particles, the results given by the Wasp model coincide with those of the H–C model.

Viscosity

Brinkman [30] suggested an equation to calculate the viscosity of the suspension, which is defined as follows:

$$\mu_{nf} = \frac{1}{(1-\varphi)^{2.5}}\mu_w \quad (6)$$

In addition, Wang et al. [31] proposed a model to predict the viscosity of nanofluids which is expressed as:

$$\mu_{nf} = (1 + 7.3\varphi + 123\varphi^2)\mu_w \quad (7)$$

Drew and Passman [32] suggested the well-known Einstein's equation for calculating viscosity, which is applicable to spherical particles in volume fractions less than 5.0 vol.% and is defined as follows:

$$\mu_{nf} = (1 + 2.5\varphi)\mu_w \quad (8)$$

Furthermore, Batchelor [33] introduced a correlation for calculating the viscosity of nanofluids with spherical shape nanoparticles which is defined as:

$$\mu_{nf} = (1 + 2.5\varphi + 6.2\varphi^2)\mu_w \quad (9)$$

whereμ_{nf} is the viscosity of the nanofluid and μ_w is the viscosity of the base fluid.

Results and Discussion

In this paper, we have experimentally investigated the effective thermal conductivities and viscosities of water based nanofluids containing Al_2O_3 nanoparticles (Al_2O_3 /water nanofluids). The thermal conductivity and viscosity of the nanofluid were measured using a KD2 Pro thermal properties analyzer and Brookfield. Fig.6 and Fig.7 show the thermal conductivity of Al_2O_3 /water nanofluids as a function of particle volume concentration. The viscosity of nanofluids increases when the volume concentration of nanoparticles increases.

As can be seen in Figures 4 and 5 as well as some limited data from other researchers for discussion and comparison are shown. As expected, viscosity and thermal conductivity of aluminum oxide nanoparticles in a volume increase with the rise of temperature. Thus, for example, for water and aluminum oxide nanofluid thermal conductivity compared to the size of 20nm (4.34,6.02,8.3,9.76,14.44 and 19.49%), respectively, for the percentages by volume (% 0.15.5-0.5-1-2 and 3%) increases. Another interesting point that the data in Figures 4 and 5 show the formula well, gentlemen, Einstein, Hamilton, Crosse is a close match to the experimental data. Furthermore, when comparing data with results from other researchers, we measured an apparent contradiction in the behavior of nanofluids on the impact of nanoparticles, we have Yu and choi research results obtained for aluminum oxide nanofluid was much higher than the results, while others, Einstein, Hamilton, Crosser results are lower and closer to the results we achieved.

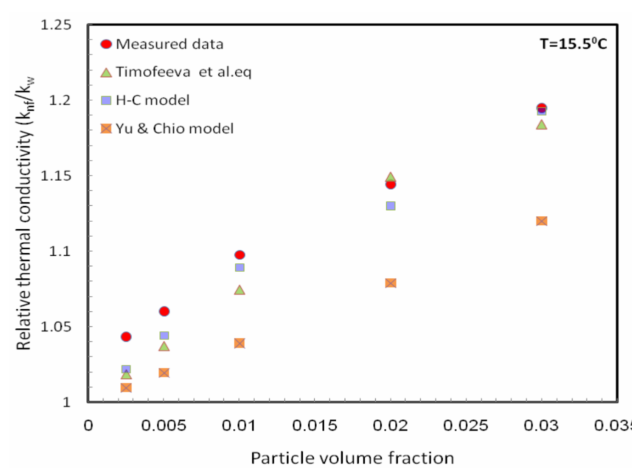

Figure 4: Thermal conductivity ratio of Al_2O_3/water nanofluids

In our opinion, the definitive interpretation of the results is very hard and difficult to express except that this behavior may be related to a variety of factors including particle size, preparation method of nanofluids, nanofluid type, etc. However, for higher particle density, viscosity and thermal conductivity increase with the percentage of particle volume. a high rate of thermal conductivity within the molecular structure itself is a mixture of special factors. It can be also seen that relationship Yu, choi for nanofluid water is not suitable for aluminum oxide. Figure 6 shows the shear stress versus shear deformation rate for different concentrations of aluminum oxide nanoparticles in water at a temperature of 15.5℃.despite a small cut on the shear strees axis due to themeasurement uncertainty,thisnanofluid clearly shows the Newtonian behavior, hence, with respect to Figure 6,this nanofluid shows rheological properties and composition similar to Newtonian fluid with low concentrations of nanoparticles (0.15.5 to 3%)and it is characterized that this fluid is Newtonian. In Figure7,it can be clearly seen that the shear stress changes with the volume fraction at low concentrations of particles are linear.

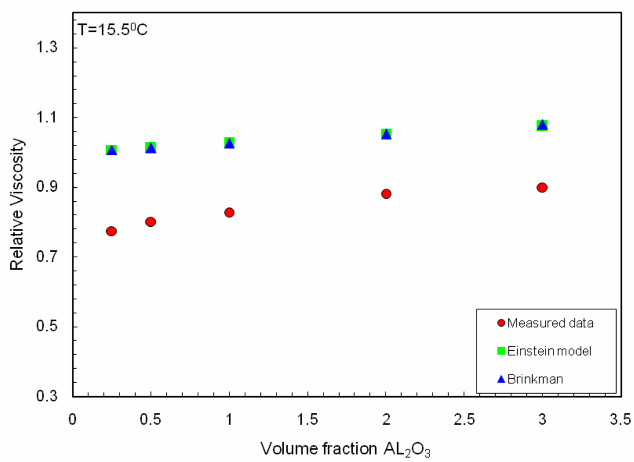

Figure 5: Viscosity ratio of Al_2O_3/water nanofluid as a function of volume concentration

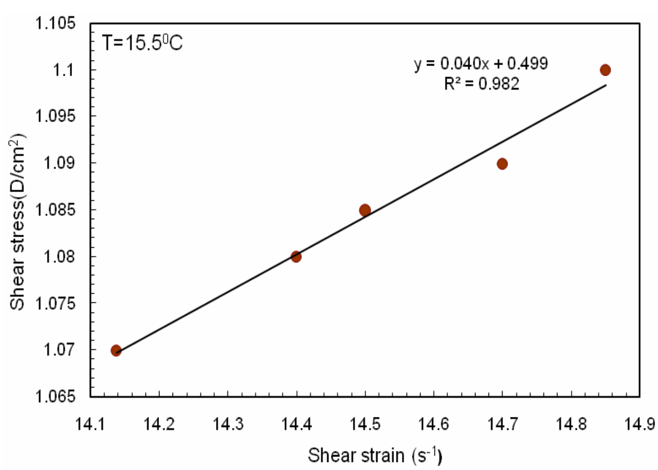

Figure 6: Shear stress as a function of shear rate

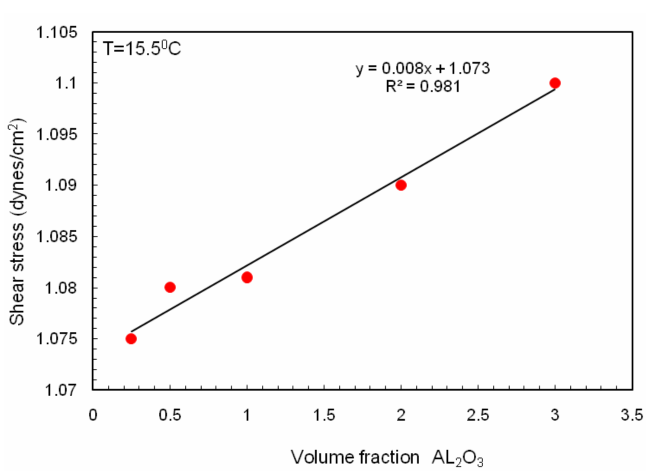

Figure 7: Shear stress as a function volume fraction

The Fig. 8 shows the effective electrical conductivity of alumina nanofluid at different volume fractions and at 15 °C. It can be found that the electrical conductivity of nanofluid increases linearly with increase in the volume fraction of the alumina nanoparticles. The enhancement in electrical conductivity of the alumina. The enhancement in electrical conductivity of the alumina nanofluid is with compared to the base fluid.

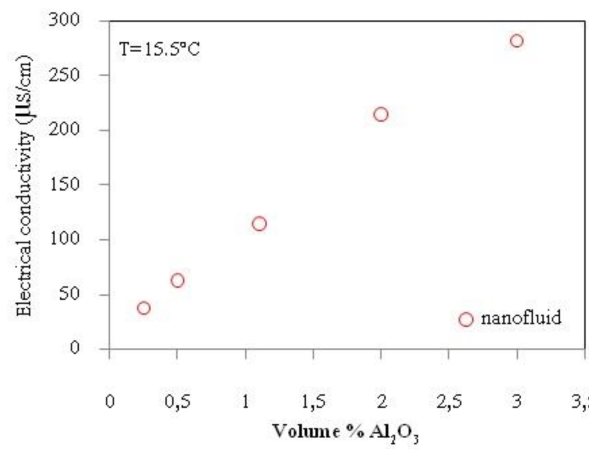

Figure 8: Measured effective electrical conductivity of alumina nanofluid

Conclusions

In this paper we have experimentally investigated the effective thermal conductivities and viscosities of water based nanofluids containing Al_2O_3nanopartilcles.

1. Ideal nanofluids should not only possess high thermal conductivity but also should have low viscosity.
2. Al_2O_3nanofluids exhibit Newtonian behavior in water for concentrations varying from 0.15.5% to 3% with 15.5℃.
3. The viscosity and thermal conductivity of nanofluids increase when the volume concentration of nanoparticles increases.
4. The viscosity of nanofluids is dependent on volume percentage. Higher concentration of nanofluids posses higher viscosity.
5. The pure base fluid displays Newtonian behavior at 15.5℃.
6. The viscosity is as critical as thermal conductivity in engineering systems that employ fluid flow.
7. Nanofluid (Al_2O_3) with different volume concentration (0.15.5%-3%) are appropriate for pumping in heat exchangers setup.
8. The results show that the thermal conductivity of Al_2O_3nanofluids significantly increases linearly with increasing particle volume concentration.
9. The results indicate considerable enhancement of electrical conductivity with increase in volume fraction.
10. The experimental results show that the electrical conductivity of alumina nanofluid is significantly greater than the base fluid.

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