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Thermo Physical Properties and Heat Transfer Performance of Ethylene Glycol + Water mixture based Al_2O_3 Nanofluids: A Review

Lalit B. Chintamani[1], N.C.Ghuge[2]

[1] PG Student, Department of Mechanical Engineering, Matoshri College of Engineering & Research Center, Nasik, Maharashtra University of Pune, Maharashtra, India

[2]Associate Professor, Department of Mechanical Engineering, Matoshri College of Engineering & Research Center, Nasik, Maharashtra, University of Pune, Maharashtra, India

Abstract: ***Nanofluids are the liquids added to the list of new generation heat transfer fluids and are being preferred over conventional heat transfer fluids in recent years. Thermal performance of nanofluids profoundly depends on their thermo physical properties. Water, EG and EG +water mixture fluids are normally used to lower the freezing point of heat transfer liquids in heat exchangers of ice plants. In the present work, thermo physical properties, pressure drop, and heat transfer performance of Al_2O_3 nanoparticles suspended in EG +water mixture based fluids are reviewed at different temperatures for different concentrations. A nanoparticles suspension is considered as a three phase system including the solid phase (nanoparticles), the liquid phase (fluid media) and the interfacial phase, which contributes significantly to the system properties because of their extremely high surface to volume ratio in nanofluid. The review show that the thermal conductivities of Al_2O_3 nanofluid increases with the increase in the Al_2O_3 nanoparticle concentrations in the base fluids. Also the viscosities of nanofluid found to decreases exponentially with increase in the nanofluids temperature and marginally increases with increase in the nanoparticles concentration in the base fluids. This review would be useful in the field of secondary refrigerant.***

Keywords: Nanofluids, conventional heat transfer fluids, heat exchangers of ice plants, interfacial phase, secondary refrigerant.

1. Introduction

Efficient transfer of energy in the form of heat from one body to another is often required in almost all industries. Thermal and nuclear power plant, refrigeration and air conditioning system, chemical and processing plants, electronic devices, space shuttles and rocket-launching vehicles, satellites are a few to name where the productivity as well as safety depends on efficient transfer of heat. Often a fluid is chosen as a medium for transferring heat and accordingly the mode of heat transfer is convection. The rate of heat transfer in convection is given by an apparently simple looking relationship; popularly known as Newton's law of cooling.

$$q=hA\,\Delta T$$

where the q is the rate of heat transfer, h is coefficient of convective heat transfer, A is the surface area and ΔT is the temperature difference across which the transfer of thermal energy take place. It has been always the pursuit of the thermal engineers to maximize q for given ΔT or A. This can be done by increasing h. However, this is easier said than done. Heat transfer coefficient is a complex function of the fluid property, velocity and surface geometry. Out of different fluid properties, thermal conductivity influences the heat transfer coefficient in the most direct way as this is the property that determines the thermal transport at the micro-scale level. [6]It is well known that metals in solid form have much higher thermal conductivity than that of fluids. Heat transfer by conduction through solid is orders of magnitude larger than that by convection/conduction through a fluid. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil. [1] Therefore, fluids containing suspended solid particles are expected to display significantly enhanced thermal conductivities relative to those of conventional heat transfer fluids. [2] In fact, numerous studies about the effective thermal conductivity of fluids that contain solid particles in suspension have been conducted. Such fluids are called as nanofluids. Thus, 'nanofluid' is a new class of heat transfer fluid that utilizes dispersion of fine scale metallic particles in a heat transport liquid in appropriate size and volume fraction to derive a significant enhancement in the effective heat transfer coefficient of the mixture. In comparison to dispersing micron-size ceramic particles, nanofluids consist of suspension of ultra-fine or nanometric metallic particles.

Table 1.1: Thermal conductivities of various solids and liquids [2]

Materials	*Thermal conductivity (W/m-K)*
Metallic solids	
Copper	401
Aluminum	237
Nonmetallic solids	
Silicon	148
Alumina (Al_2O_3)	40
Metallic Liquids	
Sodium	72.3
Non metallic Liquids	
Water	0.613
Ethylene Glycol (EG)	0.253
Engine Oil (EO)	0.145

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2. Sample Preparation Methods

Preparation of nanofluids is the first key step in experimental studies with nanofluids. Following are the some methods used for preparation of nanofluids:

a) Two Step Method: The nanosized powder will be dispersed into a fluid with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing and ball milling. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled upto industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate.

b) One-Step Method: The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized and the stability of fluids is increased.

3. Experimental Procedure

A) Thermal Conductivity Measurement of Nanofluids

The transient hot-wire technique is the most widely used methodology to measure thermal conductivity of fluids. Several researchers have used this technique, and a good explanation of the working principle can be found in [5, 11, 12]. The advantage of using this technique is that it gives accurate and fast measurement and also eliminates the effect of natural convection. It consists of two measuring cells (each of diameter 50 mm), an electrical circuit, a power source and a computer. One measuring cell acts as a compensating cell and the two cells are of different lengths (15 cm and 10 cm respectively). Glass is used as the body for the measuring cell to prevent any reaction with the nanofluid. Platinum wires of diameter 50.8 mm and length 10 cm and 15 cm are soldered between brass nuts and bolts in their respective cells. The ratio of diameter of the measuring cell to that of the platinum wire is sufficiently large. The measuring cells are connected in series via a copper wire and also to the power source. Both ends of each cell are connected to the electrical circuit, to be explained in the following paragraph, for measuring the voltage across the cells at specific time intervals. One thermocouple is used to measure the temperature of the nanofluid. The thermal conductivity of nanofluids is calculated from the following equation [14]

$$K = \frac{q}{4\pi\Delta T} In\left(\frac{t2}{t1}\right)$$

where K is the thermal conductivity, q is the applied electric power per unit length of the wire, and ΔT is the temperature rise of the wire between time t1 and t2.

b) Specific Heat Measurement of Nanofluids

A simple calorimeter used for the specific heat measurement.(Fig.1) It consists of an outer insulated vessel, an inner plastic vessel and an innermost copper vessel. A known mass of the fluid whose specific heat is to be measured is contained in the inner plastic vessel and a known mass of hot water is kept in the innermost copper vessel. The heat transfer takes place from hot water to the fluid whose specific heat is to be measured.

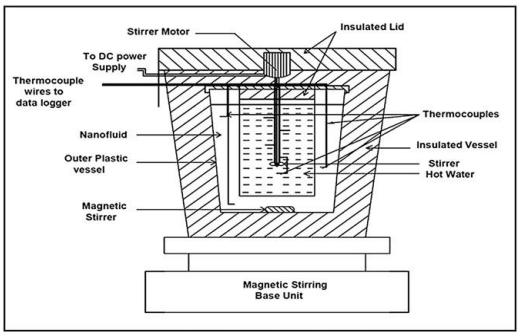


Figure 1: Schematic diagram of the calorimeter for specific heat measurement [13]

c) Viscosity Measurement of Nanofluid

DV-III Ultra Viscometer (Fig.2) is used for measuring viscosity of nanofluids. It contains of a small adaptor and adapter further consists of a cylindrical sample holder, a water jacket and a spindle. The viscometer drives the spindle immersed into the sample holder containing the test fluid sample. It measures viscosity by measuring the viscous drag of the fluid against the spindle when it rotates. The spindle CPE-42 is used. The sample holder can hold a small sample volume of 1 mL and the temperature of the test sample is monitored by a temperature sensor embedded into the water bath. Other equipment used is sonicator, which sonicate the solution by using ultrasonic vibrations.[12]



Figure 2: DV-III Brookfield Viscometer Measurement [12]

d) Pressure Drop Measurement of Nanofluids

Differential pressure gauges can be used to measure the pressure drop in the flow of nanofluid within the test section. [14]

4. Results and Discussion

a) The Thermal Conductivity of EG+Water Based Al_2O_3 Nanofluids:

1) Effect of temperature on thermal conductivity of EG+Water based Al_2O_3:

1.1) EG +Water with 20 nm (spherical) Al2O3 nanoparticles:

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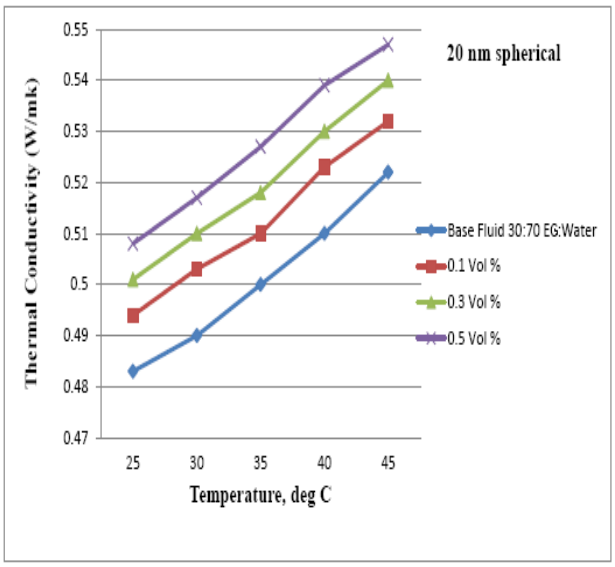


Figure 3: Thermal conductivity v/s Temperature at 0.1, 0.3 and 0.5% volume conc. For 20 nm nanoparticles[8]

1.2) EG + Water with 40 nm (spherical) Al2O3 nanoparticles:

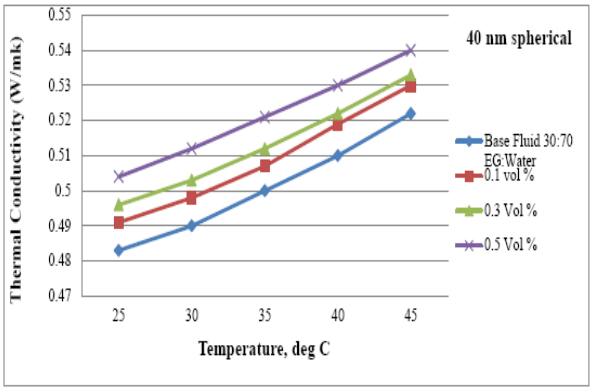


Figure 4: Thermal conductivity v/s Temperature at 0.1, 0.3 and 0.5% volume conc. For 40 nm nanoparticles[8]

Thermal conductivity of EG+water (base fluid) and Al_2O_3 increases almost linearly with temperature (25 to 45 ºC).At constant volume concentration (0.1%, 0.3% and 0.5%) of nanoparticles (Al_2O_3) the thermal conductivity enhancement is almost liner w.r.t temperature. At lower temperature increase in thermal conductivity is less, as compared to increases in thermal conductivity at higher temperatures (35 – 45 º C).The mechanism behind the thermal conductivity enhancement such as Brownian motion, micro convection, explains the conductivity enhancement. At high temperature Brownian motion assisted micro convection are responsible for the Thermal conductivity enhancement. Brownian or random motion increases with increases in temperature that is why the thermal conductivity increases with temperature.

2) Effect of volume concentration on thermal conductivity of EG+Water based Al_2O_3 nanofluid:

2.1. EG + Water with 20 (spherical) nm Al2O3 nanoparticles:

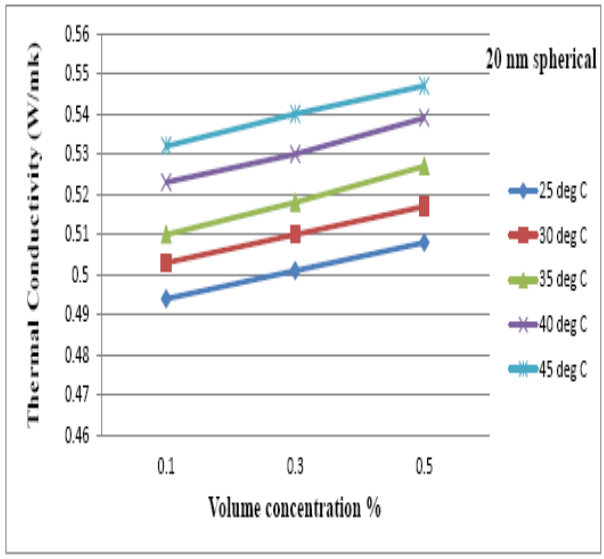


Figure 5: Thermal conductivity v/s Volume concentration % with 20nm (spherical) nanoparticles[8]

2.2) EG + Water with 40 nm (spherical) Al_2O_3 nanoparticles:

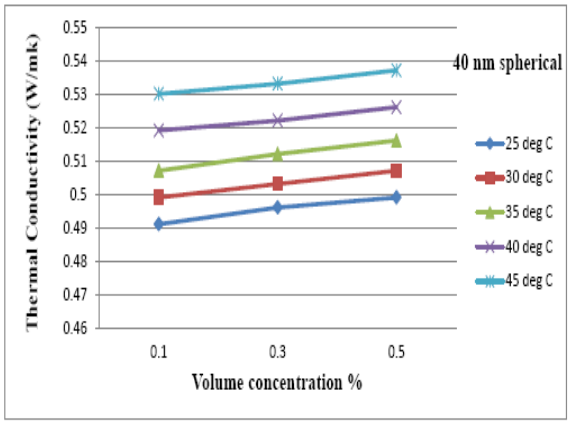


Figure 6: Thermal conductivity v/s Volume concentration % with 40nm (spherical) Nanoparticles[8]

Thermal conductivity of EG + water based Al_2O_3 nanofluid increases with the increases the volume concentration (0.1%, 0.3%, and 0.5%) loading, at constant temperature. The enhancement in thermal conductivity with respect to volume concentration % showed linear behavior at constant temperature. At a particular temperature results shown increase in thermal conductivity with increase of volume concentration % and also results shows there is less difference in thermal conductivity enhancement from 0.1 to 0.5 % volume concentration. The reason behind this behavior is clustering of nanoparticles at higher concentrations.

3) Effect of Nanoparticle size on thermal conductivity of EG+Water based Al_2O_3 nanofluid:

3.1) Size effect with 0.1 % vol. fraction:

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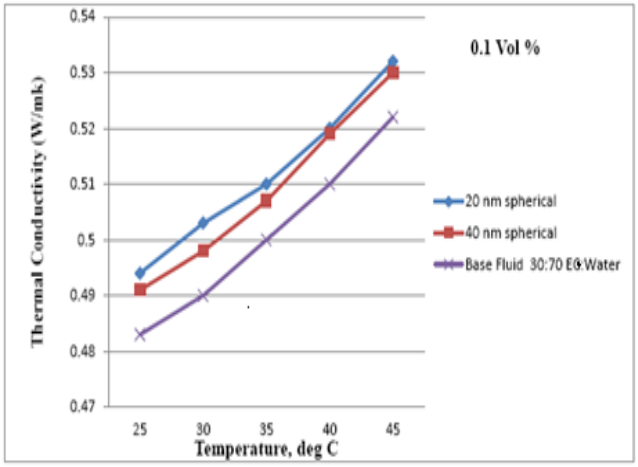


Figure 7: Thermal conductivity v/s Temperature at 0.1% volume concentration [8]

3.2) Size effect with 0.3 % vol. fraction

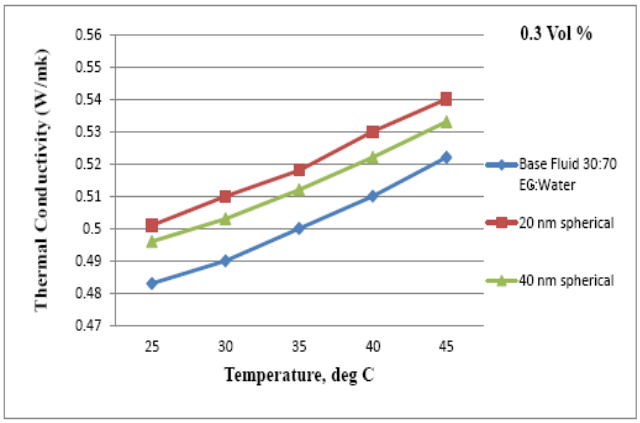


Figure 8: Thermal conductivity v/s Temperature at 0.3% volume concentration [8]

3.3) Size effect with 0.5% volume concentration:

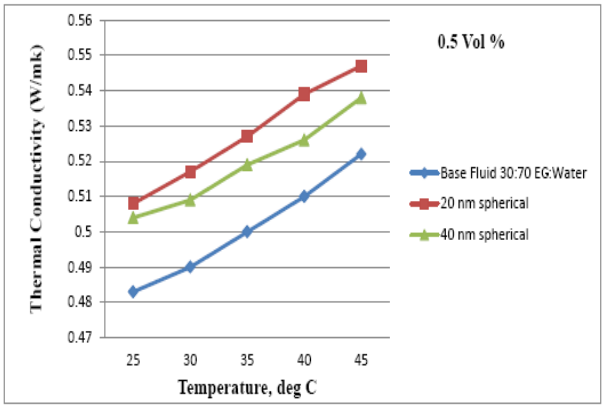


Figure 9: Thermal conductivity v/s Temperature at 0.5% volume concentration [8]

The size of nanoparticle has direct effect on the thermal conductivity of nanofluid; the size effect is compared between 20 nm and 40 nm Al_2O_3 (spherical) nanoparticles, thermal conductivity increased with decreases in the size of nanoparticle size. At 0.1% volume concentration, 20 nm had slightly high thermal conductivity than 40nm nanoparticles, but difference is very less at high temperature is almost same.

b) Viscosity Behavior of EG+Water Based Al_2O_3 Nanofluid

1) Effect Of Temperature on Viscosity Of EG+Water Based Al_2o_3 Nanofluid:

1.1 Effect of temperature (spherical 20 nm Al2O3) on Viscosity:

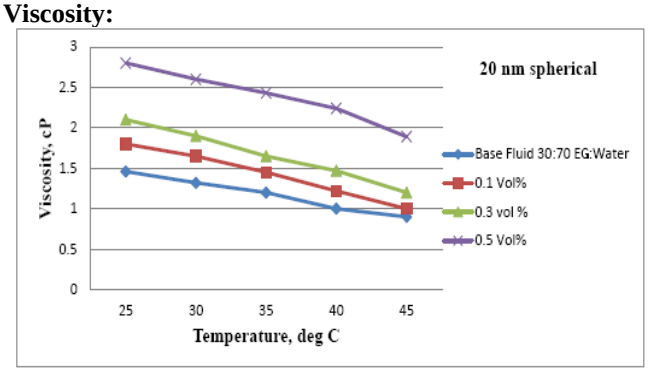


Figure 10: Viscosity v/s Temperature for 20 nm (spherical) Al_2O_3 nanoparticles[8]

1.2 Effect of temperature (40 nm spherical Al2O3) on viscosity:

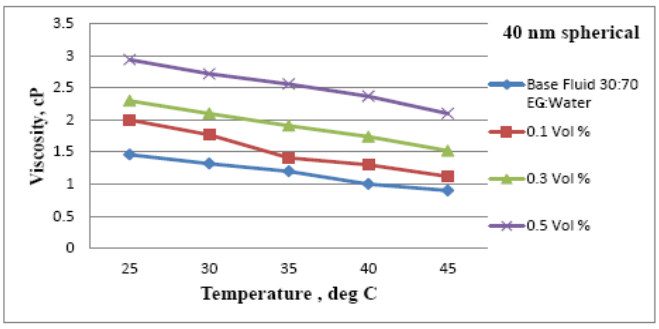


Figure 11: Viscosity v/s Temperature for 40 nm (spherical) Al_2O_3 nanoparticles[8]

Viscosity of nanofluid deceased with increases in temperature. Due to increase in temperature intermolecular bonding forces decrease which decrease viscosity. Viscosity decreased sharply in higher temperature ranges.

2) Effect of volume concentration % on viscosity of EG+Water Based Al_2O_3 Nanofluid

2.1 Effect of volume concentration % on viscosity with 20 nm Al2O3 nanoparticles

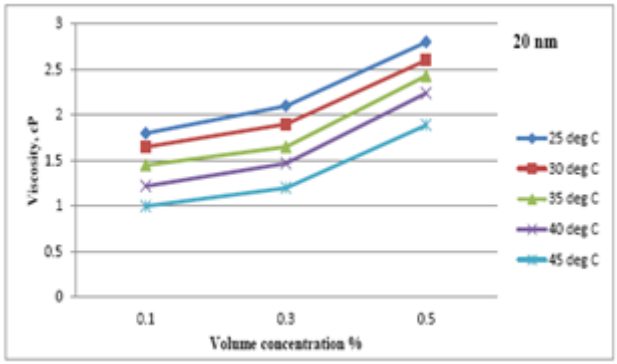


Figure 12: Viscosity v/s Volume concentration % for 20 nm (spherical) Al_2O_3 particles. [8]

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2.2 Effect of volume concentration % with 40 nm (spherical) Al2O3 nanoparticles:

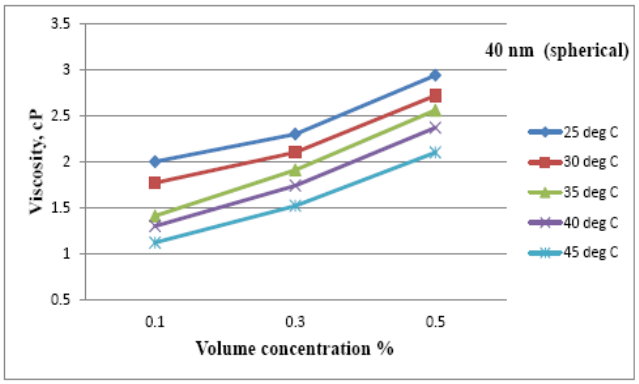


Figure 13: Viscosity v/s Volume concentration % for 40 nm Al_2O_3 nanoparticles[8]

Viscosity of nanofluid increased with the increases in nanoparticles loading at constant temperature. Due to increased in concentration of nanoparticle, particle to particle bonding increase which results in more rise in viscosity. The results show that viscosity increases with the nanoparticles concentration, while going from 0.3 to 0.5 %volume conc. viscosity increases very sharply shown in results.

1. At 25 ºC the enhancement in viscosity for 20 nm (spherical) nanoparticles:

a. In range (0.1 to 0.3% vol.) is 16% **b.** In range (0.1 to 0.5 % vol.) is 55.5%

2. At 25 ºC the enhancement in viscosity for 40 nm (spherical) nanoparticles:

a. In range (0.1 to 0.3% vol.) is 15% **b.** In range (0.1 to 0.5% vol.) is 47%

3) Effect of Nanoparticle size on viscosity of EG+Water Based Al_2o_3 Nanofluid

3.1 Size effect on viscosity with 0.1% volume concentration of nanoparticles

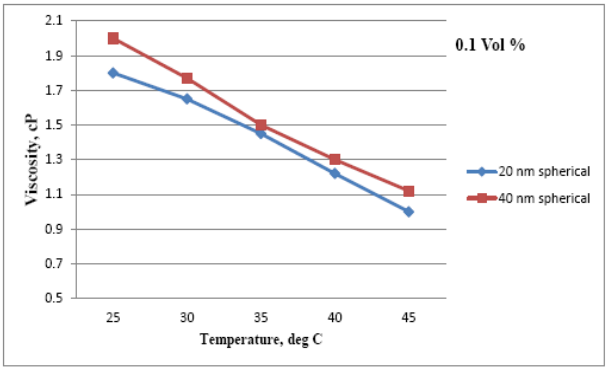


Figure 14: Viscosity v/s Temperature at 0.1 volume %concentration. [8]

3.2 Size effect on viscosity with 0.3% volume concentration of nanoparticles

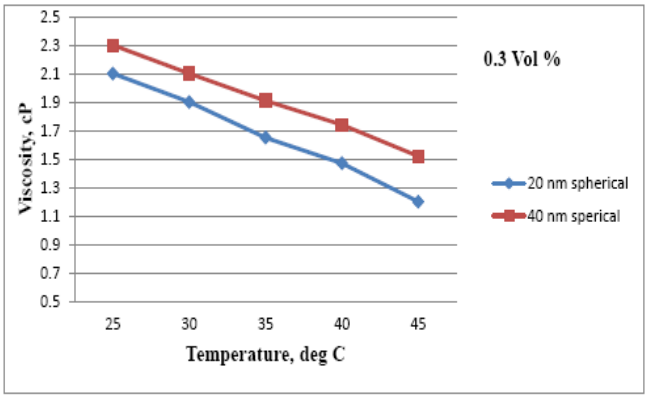


Figure 15: Viscosity v/s Temperature at 0.3% volume concentration. [8]

3.3 Size effect on viscosity with 0.5% volume concentration of nanoparticles

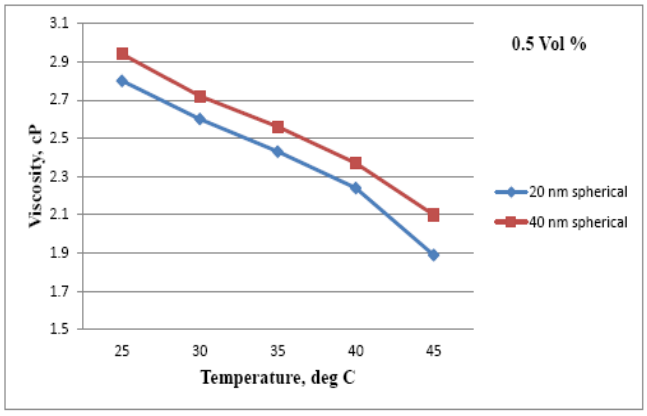


Figure 16: Viscosity v/s Temperature at 0.5% volume concentration [8]

On the basis of size effect, viscosity of nanofluid increased with the increases size of nanoparticles at constant temperature. The results had showed that 40 nm (spherical) nanoparticles have greater viscosity than 20 nm (spherical) at constant temperature

1) At 0.5% volume concentration, 40 nm (spherical) nanoparticles have 5% higher viscosity as compared to 20 nm (spherical) nanoparticles at constant temperature.
2) Results showed that in comparison to base fluid at 0.5% vol. conc. for 20 nm size; the enhancement in viscosity is 91.7%.
3) Results also showed that in comparison to base fluid at 0.5% vol. conc. for 40 nm size the enhancement in viscosity is 101%.

5. Concluding Remarks

From the above reviewed parameters we can conclude that thermal conductivity of EG+ water (base fluid) and Al2O3 increases almost linearly with temperature (25 °c to 45°c), viscosity of nanofluid deceased with increases in temperature. Due to increase in temperature intermolecular bonding forces decrease which decrease viscosity. Viscosity decreased sharply in higher temperature ranges.

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