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Viscosity of Nanofluids Based on ZnO Nanoparticles

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Abstract: A new set of fluid has been an area of interest for many researchers now a days called Nano-fluids. Nanofluids are dispersion of nanoparticles (viz metal, metal oxides or ceramic particles) in base fluid (viz water, ethylene glycol etc.). Initially the nanofluids attracted the researches due to its different properties as compared to base fluid. The most important was increased (in most cases) convective heat transfer that has made nanofluids very suitable as a coolant where high thermal conductivity is required. But apart from heat transfer coefficient many other rheological properties of nanofluids have brought attention. One such most important property is viscosity. In the current study viscosity of ZnO (Distilled water as base fluid) based nanofluid has been measured. The synthesis of ZnO based nanofluids was done using a two-step method. Five different nanofluids with Wt/volume % concentration of 0.05, 0.1, 0.5, 1 and 2 were prepared. The results have been compared with the Eienstein's equation suggested by Drew and Passman for calculating viscosity of nanofluids. The results showed a variation of less than 4%.

Keywords: Nano-fluid, Nanoparticles, Viscosity, Synthesis, ZnO

INTRODUCTION

There are many applications that require high heat dissipation from many cooling devices. There has been a need of substances that can transfer high heat densities even where the temperature differences are low. Many such applications that require liquids to dissipate heat are automobiles heat exchangers, power plants, micro channels etc. Most abundantly available fluid for heat exchange is water however it has its limitations with the coefficient of heat transfer. Research has been done in increasing the thermal conductivity of water. A dispersion of micro metallic particles with water have been used but was not proved effective due to settlement of micro particles at the base of containment of fluid. Since few years, advanced technologies have permitted the manufacturing of a new class of fluids, called Nanofluids. Nanofluids is prepared by dispersing nano sized nanoparticles or nanowires or nanorods or nanosheet or nanofibers or nanotubes or droplets in Base fluids [1]. Thus, such fluids are new categories of fluids that are prepared to get enhancement in heat transfer. In such type of nanofluids base fluid is mostly water. However, organic liquids (e.g., ethylene, tri-ethylene-glycols, refrigerants, etc.), oils and lubricants, bio-fluids, polymeric solutions and other common liquids can work as base fluids. The dispersed nano materials are normally chemically stable metals (e.g., Aluminium, copper), metal oxides (e.g., alumina, silica, ZincOxide), oxide ceramics, metal carbides, carbon in various forms (e.g., carbon nanotubes, fullerene) etc. Choi [2] conducted various research experiments at Argonne National Laboratory in USA and based on outcome of these experiments, the concept of nanofluids was first materialized by him. The first experiments were done by Masuda et al. [3] to show the elevated values of thermal conductivity of nanofluids. Nanofluids are believed to have better properties compared to usual heat transfer fluids, as well as fluids containing micro-sized metallic particles. Nanoparticles provide relatively larger surface area compared to usual particles and hence it is highly stable as well as it provides significantly higher heat transfer potential. Keblinski et al. [4] discussed the properties of nanofluids and future challenges in an interesting simple review. The studies of nanofluids are still hindered by various factors like lack of agreement between results, poor characterization of suspensions, and the lack of theoretical understanding of the mechanisms. Rheology is the science of flow and deformation of matter. The study of the rheological behavior of a nanofluid helps in understanding the structure of the nanofluids. Viscosity is an important parameter of nanofluid in determining the pressure drop required when used in heat exchangers, micro-channels etc. In a laminar flow, the pressure drop and viscosity are directly proportional. Also, convective heat transfer coefficient is influenced by viscosity. Hence, determination of viscosity is an essential property of nanofluids where the application requires fluid flow. Drew and Passman [5] suggested a very well-known Einstein's equation for calculating viscosity of nanofluids:

$$\mu_{nf} = (1 + 2.5\varphi)\mu_{bf} \qquad (1)$$

where μ_{nf} is the dynamic viscosity of nanofluids and μ_{bf} is the dynamic viscosity of base fluid. φ is the volumetric concentration of nanopartcles in base fluid.

EXPERIMENTAL SETUP AND METHODOLOGY

Nanofluids were prepared using ZnO nanopowder purchased from Alfa Aesar (product number: 44898, Lot: D28X017) having size of 40-100 nm with an average size of 60 nm. Sodium hexametaphosphate was used at a surfactant in the ratio of 1:5 of the weight of nanoparticles [6]. One liter of distilled water was taken and surfactant was added to it and the solution was stirred at 500 rpm for 10 mins. Then ZnO nanopowder was added in the required weight. Total five nanofluids were prepared before experimentation using different % concentration of wieght/volume. These concentrations are 0.05, 0.1, 0.5, 1 and 2. For instance, to make 2% weight by volume nano fluid, 20 gms of nanopowder was added to previously mixed solution of 5 gms of sodium hexametaphosphate in 1 liter of water. The aqueous dispersion of nanoparticles in water with surfactant was stirred for 1 hour with mechanical motor-based REMI LAB stirrer at 400 rpm. Then the mixture was sonicated for 3hours using probe sonicator at 380 watts by VIBRONICS ULTRA PROBE SONICATOR. The solution was taken for particle analysis using MALVERN ZATASIZER ZS90, based on differential light scattering. the result shows no agglomeration for 2% weight/volume, for 6 hours. Visible visualization shows that the solution is stable for weeks (figure 1). As the experimentation of measuring viscosity lasts for 3 hours, the above method of synthesis was used.

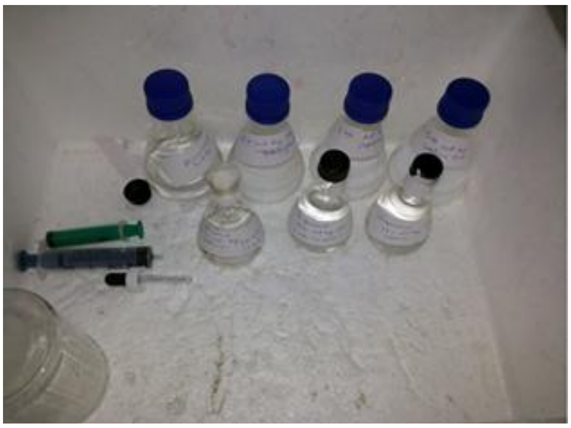

Figure 1. Samples of ZnO nanofluids tested for stability at Malvern Zatasizer ZS90

Measurement of Viscosity

Viscosity, was measured with Borosil Mansingh Survismeter [6] (cal.no. 06070582/1.01/C-0395, NPL, India) by flow time and pendant drop methods controlled by the Lauda Alpha KA 8 thermostat with ±0.05 K control. After attainment of thermal equilibrium, viscous flow times were recorded with ±0.1 s uncertainty. Three reading were taken and the average of the readings were kept (figure 2).

Figure 2. Viscosity measurement of ZnO nanofluid using Borosil Mansingh Survismeter

Data Reduction

For viscosity calculations using survisemeter were done as follows [7]:

$$\mu_s = \left(\frac{t_s}{t_{bf}}\right)\left(\frac{\rho_s}{\rho_{bf}}\right)\mu_{bf} \qquad (2)$$

where t_s is the time taken by the solution of surfactant and distilled water in survisemeter and t_{bf} is the time taken by distilled water in survisemeter to empty the bulb on capillary. Similarly, ρ stands for density and subscript has the same meaning. μ is for viscosity with subscript having same meaning. Viscosity of nanofluid was calculated using the following formula:

$$\mu_{nf} = \left(\frac{t_{nf}}{t_s}\right)\left(\frac{\rho_{nf}}{\rho_s}\right)\mu_{nf} \qquad (3)$$

where μ_{nf} is the viscosity of nanofluid and ρ_{nf} is density of nanofluid.

The volume concentration calculated using conventional weight and density method:

$$\varphi_{nf} = \left(\frac{\frac{W_{np}}{\rho_{np}}}{\frac{W_{np}}{\rho_{np}}+\frac{W_{bf}}{\rho_{bf}}}\right) \qquad (4)$$

Where *nf* subscript stands for nanofluid and *bf* stands for base fluid. W is weight and ρ is density.

The density of a nanofluid, ρ, is the weighted average of the base fluid and nanoparticle densities is calculated according to Pak and Cho's [8] equation:

$$\rho_{nf} = (1+\varphi)\rho_f + \varphi\,\rho_n \qquad (5)$$

where ρ_f and ρ_n are the densities of base fluid and nanoparticles, respectively. It can be observed from this equation that the density varies nanofluid linearly with change in the volume fraction. Nanoparticle are higher in density compared to basefluid so in case of particular nanofluid with 1% volume fraction of nanoparticles, less than 5% change in the fluid density is expected. Also, the density of nanofluid, if calculated by conventional weight to volume ratio would give very close results as described in equation 5.

Table 1. Basic property data [9]

Sr. No.	Properties	Value
1	Density of distilled water at 35ºC	994 (kg/m^3)
2	Density of ZnO nanoparticles	5600 (kg/m^3)
3	Dynamic viscosity of distilled water at 35ºC	7.193×10^{-4} (Pa.s)
4	Density of surfactant water at 35ºC	994 – 998 (kg/m^3)

RESULTS AND DISCUSSION

For measuring viscosity and volume concentration use of Borosil Mansingh Survismeter was done. It gave time taken for the fluid to empty the specific measuring ball of the survismeter. Eq. 2 to 5 were used to calculate different parameters. Here in the experimentation the effect of surfactant is also considered. The role of a surfactant is to do capping around the nanoparticle and put similar charges on every particle, so that they repel each other and do not form clusters. But a drawback of using surfactant is, that they might affect the thermo-physical properties of nanofluid. So, in calculating the properties of nanofluid, the properties of surfactant/DW were calculated first and then this solution was taken as reference for ZnO nanofluids (refer equation 2 and 3). Through this method the effect of surfactant was considered in the nanofluid. The volume concentration used in equation 1 was derived from equation 5.

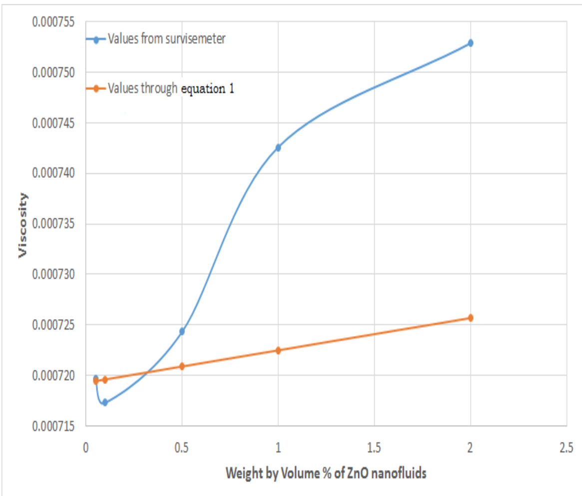

Figure 3. The variation of viscosity with increase in concentration and comparison of experimental and calculated results through equation 1.

The experimental results and the results with conventional known Einstein's equation were compared and it was found out that the maximum variation is less than 3.7 %.

Figure 3 represents the variation of viscosity (Pa. s) between measured value from survismeter and calculated value from Eq. 1. It can be clearly seen from the figure that the variation in viscosity is not linear. This can be due to the effect of surfactant in the nanofluid, which is completely neglected in Eq.1. It can also be inferred that the variation of viscosity increases with the increase in concentration. The maximum difference is viscosity of 3.7% with that of viscosity calculated by Einstein's equation at 2% ZnO nanofluid concentration. Also, it can be seen that the viscosity of 0.05%wt by vol. conc. increases abruptly w.r.t 0.1% wt. by vol. conc. The value of former matches the one calculated from classic equation. The reason can be lack of effect of surfactant on base fluid. Moreover, the viscosity of 0.1% wt. by vol. conc. decreases abruptly. The reason is still to be figured out or it may be due to human error. Also, the viscosity of 0.05% conc. is very close to the viscosity of water.

CONCLUSION

It is observed that the variation of viscosity determined using the experimental values and the one calculated from equation 1 follow a very close pattern. The maximum variation observed is 3.7 percent. Hence it can be inferred that use of Einstein's equation for calculation of viscosity for ZnO based nanofluids (DW as Base fluid) can be used for concentration values upto 2% weight by volume. However, for higher concentration of nano particle and use of more surfactant the variation may become significant so it is advisable verify it with model used to predict the viscosity or use experimental values of viscosity.

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