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# Influence of ultrasonication duration on rheological properties of nanofluid: An experimental study with alumina–water nanofluid☆

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ABSTRACT

Nanofluid is being considered as a promising fluid for heat transfer and other applications. The performance of nanofluid is depends on its preparation processes, including the ultrasonication period. The objective of this study was to analyze the influence of ultrasonication period on rheological properties of nanofluids. A 0.5 vol.% of $Al_2O_3$ nanoparticle was suspended in distilled water and ultrasonicated for the periods of 0 to 5 h. Before and after dispersion, micrographs of nanoparticles were observed by electron microscopes. Rheological properties as viscosity at different shear rates were measured for different temperatures from 10 °C to 50 °C. Other flow characteristics as the flow behavior index and consistency index were also studied for the nanofluids prepared by different periods of ultrasonication. Better colloidal dispersion and lower viscosity were observed for the increase of sonication time. Furthermore, with the increase of temperature, viscosity decreased rapidly, but moved towards non-Newtonian fluids. The research concluded that better colloidal dispersion as well as lower viscosity could be achieved with the use of possible higher periods of ultrasonication.



## 1. Introduction

Rheological properties define the flow characteristics of a fluid. For the practical implementation of nanofluids, it is essential to analyze the rheological properties of nanofluid. Nanofluid is a new field in engineering and medicine; therefore, appropriate rheological models need to be identified based on experimental results for different nanofluids [1]. Different fluids have various flow characteristics, which is more prominent for nanofluids. Different types of flow behaviors (Newtonian and non-Newtonian) were observed for the same ethylene glycol (EG)-based nanofluid [2]. Extensive use of numerical models (e.g. thermal conductivity, viscosity, density) related to Newtonian fluids used for non-Newtonian nanofluids have been observed in the literature [1]. For example, Einstein's equation [3] is unsuitable to assume the viscosity of nanofluids in most cases, as it is suitable for Newtonian fluids with spherical particles. Even this model has been used to estimate the viscosity of tubular-shaped particles (carbon nanotube (CNT), titanate nanotube) suspended nanofluids, which is not appropriate. It has been observed that even for a little concentration of nanoparticles, typical Newtonian fluids often become non-Newtonian fluids [1].

The preparation of stable nanofluids is a critical issue, which, in some cases, is ignored in the literature. Sound energy (ultrasonic level ~ 20 kHz or above) is being used to break up cluster formation of nanoparticles and to disperse into a base fluid [4]. According to an NIST report, ultrasonication is a complex physicochemical procedure that can break down a cluster of particles and can make even further aggregation [5]. Chemical reactions and/or some other outcomes could also be caused. The varying results of thermal conductivity, viscosity and many other properties of nanofluids could be due to the variation of ultrasonication processes and durations. It was observed in the literature that researchers had been using different ultrasonication periods to prepare nanofluids and the reason for choosing these specific durations have not been reported in most cases. For instance, Kole and Dey [6] have used 3 h of ultrasonication and 1 h of magnetic stirrer agitation to prepare $Al_2O_3$–car radiator coolant nanofluid. On the other hand, Elias et al. [7] simply utilized ultrasonication of 30 min to prepare similar nanofluids. Once again, Chandrasekar et al. [8] applied 6 h of ultrasonication to prepare $Al_2O_3$–water nanofluid; however, Sohel et al. [9] ultrasonicated for 1 h for the same nanofluid.

Here, we represent some comparative studies related to the required ultrasonication duration to prepare a chemically stable nanofluid. Kwak and Kim [10] prepared CuO–EG nanofluid by using an ultrasound generator (20 kHz, 100 W) for 1 to 30 h. Dynamic light scattering (DLS) and zeta potential were used to analyze the effect of ultrasonication and observed that 9 h of ultrasonication is the optimum duration. Lee et al. [11] used 0, 5, 20 and 30 h of duration to prepare $Al_2O_3$–water nanofluid. They have applied comparatively higher frequencies (30–40 kHz) of ultrasonic vibration. The authors reported ~5 h of duration is the optimum by analyzing transmission electron microscopy (TEM) and zeta

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potential. Mahbubul et al. [12] investigated the effect of the ultrasonication duration (up to 180 min) by using an ultrasonic probe (20 kHz, 500 W) for 0.5 vol.% of alumina–water nanofluid. They reported a continuous decrease in the individual particle and particle aggregate sizes with the increase of ultrasonication duration. Ruan and Jacobi [4] and Amrollahi [13] studied the effect of ultrasonication with CNT–EG nanofluids and reported that prolonged ultrasonication was better. However, Garg et al. [14] studied CNT in deionized water (DIW) and ultrasonicated the samples for durations of 20, 40, 60 and 80 min with a 130 W, 20 kHz ultrasonic probe and observed optimum performance at 40 min of ultrasonication.

Yet, the effect of ultrasonication and dispersion properties on rheological behavior like Newtonian or non-Newtonian (shear thinning or thickening) behavior was not reported in most cases. Yang et al. [15] analyzed the influence of ultrasonication on rheology of the CNT–oil dispersions for 0.3–8 wt.% of dispersant concentrations. They observed clear shear thinning behavior at very low and high concentrations of dispersant. However, in the case of 3 wt.% dispersant, nearly Newtonian trend was observed. Again, for higher applied shear stress, almost similar and Newtonian flow curves were observed. The authors indicated that prolonged ultrasonication breaks the CNT, as a result, agglomeration size and viscosity were decreased [15]. Kabir et al. [16] studied carbon nanofiber-doped polymers and investigated the influence of sonication time (up to 40 min) on compressive yield strength. They found maximum compressive yield strength for 22 min of ultrasonication. Garg et al. [14] examined the consequence of ultrasonication on rheological properties of CNT with DIW and gum arabic. They observed a non-Newtonian behavior (shear thinning or pseudoplastic) as decreasing viscosity with increasing shear rate, especially at 15 °C. Almost unique flow characteristic was observed for the nanofluid prepared by 20, 40, 60 and 80 min of ultrasonication. The unique flow characteristics may be due to the lower applied shear rate ranges throughout the study, which were up to 75 $s^{-1}$ of shear rate. They suggest more related studies to understand these criteria. They also reported that viscosity was increased until 40 min of the ultrasonication period and after that it declined with increasing ultrasonication time. Ruan and Jacobi [4] also studied rheological properties of MWCNT but with the base fluid EG and a shear thinning behavior was observed. However, they found various flow behaviors for the nanofluids. For example, viscosity of nanofluid prepared by 40, 140, and 520 min showed high viscosity and they rapidly decreased with increasing shear rates. In contrast, nanofluid prepared for 1355 min showed slower viscosity variation with shear rates. Even at higher shear rates, viscosity values were found to be near the viscosity of base fluid. Conversely, nanofluid prepared without sonication (0 min) showed various flow characteristics as initially, viscosity decreased with the increase of shear rate and then it increased and finally was unchanged with shear rates.

Most of the related studies (as discussed above or available in the literature) are related to CNT nanofluid. Although CNTs have higher thermal conductivity, however, they are insoluble in most liquids. Moreover, complex flow behaviors were observed for the utilization of surfactants or dispersants to dissolve CNT [14,17]. On the other hand, Alumina is a prospective nanoparticle as it is easily dispersed in most liquids and it is cheaper. Therefore, this research is designed to determine the influence of ultrasonication time on the colloidal dispersion and rheological properties of 0.5 vol.% of $Al_2O_3$–water nanofluid. Hopefully, this study will shed light on the effect of the ultrasonication period (used during the preparation of nanofluids) on dispersion characteristics and rheological properties as well as the relation of colloidal dispersion and rheology.

## 2. Methodology

### 2.1. Preparation of nanofluid

The procedure followed here was the same as that used in our previous studies [18,19]. The readily available $Al_2O_3$ nanoparticles were procured from Sigma-Aldrich, Malaysia (produced in USA). The manufacturer-defined specification of the materials includes: 13 nm of average diameter, spherical shape and 99.5% purity. The desired amount of nanoparticles was weighted by using a precision analytical balance (GR-200, AND, Japan). The nanoparticles (0.5 vol.% of $Al_2O_3$) were suspended in distilled water. Then, the mixture of nanoparticles and water was agitated for about 1 min in a thin glass tube (2.5 mm diameter) to completely subside the nanoparticles into water. Later, the mixtures were ultrasonicated for 1, 2, 3, 4 and 5 h by using a sonic dismembrator (Model 505, Fisher Scientific, USA) that has a capacity of 20 kHz and 500 W. The 1/2-in. (12.5 mm) standard tip, 50% amplitude and 2 s ON and 2 s OFF pulses were applied for ultrasonication. A refrigeration-circulating bath (Model C-DRC 8, CPT Inc., South Korea) was used to keep the outside temperature at 15 °C to avoid evaporation. Another sample named "0 h" (zero hour) was also considered in this study, which means that the sample was prepared without ultrasonication process, just arranged by shaking the glass tube.

### 2.2. Dispersion analysis

A field emission scanning electron microscope (FESEM) (Model AURIGA, Zeiss, Germany) was used to characterize the microstructure of the nanoparticles. First, nanoparticles without any treatment were characterized by FESEM at 1 kV accelerating voltage with 50,000 magnification scales to imprint the image within 100 nm plot. Again, after the preparation, the colloidal dispersions of the nanofluids were examined by TEM (Model LIBRA 120, Zeiss, Germany). The micrographs were captured in 50 nm scale by using 31,500 magnifications at 120 kV accelerating voltage. After the sonication of each sample, the particle size distribution (PSD) was examined by using a Zetasizer 3000HS instrument (Malvern Instruments, UK) at 25 °C temperature and without diluting the concentration.

### 2.3. Rheology measurement

Viscosity values of the nanofluids at different shear rates were measured by using a programmable rheometer (LVDV-III Ultra, Brookfield, USA). The rheometer was connected to a PC and Rheocalc 32 software was used for data collection. An ultra low adapter (ULA) was utilized for a lower amount of sample. To maintain constant temperature, an advanced digital refrigerated water bath (Model AD07R-40-12E, Polyscience, USA) was used. The experimental procedure is represented in Fig. 1. In this experiment, the viscosities of all samples were measured at shear rates from 36.69 to 305.75 $s^{-1}$ while the ULA spindle rotating was 30 to 250 RPM. Speed ramp was changed by 10 RPM (12.23 $s^{-1}$ shear rate) and it was held for 20 s at each speed. A data point was taken just before the changing of each speed. Later, two samples prepared for 0 and 1 h of ultrasonication were investigated again at 50, 100, 200 and 300 $s^{-1}$ shear rates and the ramp speeds were held constant at a point until it reached the final steady state viscosity to study the variation of steady state viscosity with the measured viscosity. As torque range exceeds the limit of 100% at 300 $s^{-1}$ shear rates due to higher viscosity at 10 °C temperature. Therefore, for these purposes, 250 $s^{-1}$ shear rates were used in lieu of 300 $s^{-1}$ shear rates for the samples at 10 °C temperature. It was observed that in most cases, it took only 15 s to reach the steady state viscosity. Therefore, the measured viscosities of this study are very close to the viscosity at the steady state for each rate. To get more precise values, each experiment was conducted at least four times but the average value was considered throughout the analysis. The average uncertainties were for a confidence probability of 97.70%. Viscosities were measured for the temperature range of 10 °C to 50 °C with 10 °C intervals and the precisions of temperatures were maintained in the range of $\pm 0.5$ °C.