The Study of Gum Arabic as Surfactant on the Stability of Water-based Alumina Nanoparticle Suspensions

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Abstract. The stability study of alumina nanoparticle suspensions has been investigated by using gum arabic as a surfactant. The effect of particle volume fraction of alumina nanoparticle and gum arabic concentration were observed. The stability of the suspension was characterized using zeta potential and particle size distribution analysis. Several volume fractions of alumina and gum arabic concentration were dispersed in water as a solvent for suspension stability. The result showed that the stability of water-based alumina nanoparticle suspensions was improve with the decreasing of particle volume fraction and increasing of gum arabic concentration. The particle size distribution was narrow with decreasing particle volume fraction and increasing gum arabic concentration. The hydrodynamic diameter of the particles was smaller with the increasing of gum arabic concentration. The smallest particle size recorded was 164.6 nm at 0.5% gum arabic concentration. Zeta potential values were increased with the increasing of gum arabic concentration. The highest zeta potential was recorded at -36.0 mV. It can be concluded that gum arabic can be used for stabilization of water-based alumina nanoparticle suspensions.

Introduction

It has long been known that the suspensions of solid particles in liquids provide useful advantages in industrial fluid systems, including heat transfer fluid, magnetic fluid, and lubricant fluid. Since the working fluids have the limitation of heat transfer performance, solid particles were dispersed in the working fluids to improve their thermal properties or heat transfer characteristics [1, 2]. However, rapid sedimentation, erosion, clogging and high-pressure drop caused by these particles have kept the technology far from practical application[3, 4].

Preparation of stable nanoparticles suspension is the key step in the use of nanoparticles to improve the thermal conductivity of fluids. Two kinds of methods have been employed in producing nanoparticle suspensions. One is a one-step method, and the other is a two-step method. The one-step direct evaporation method represents the direct formation of the nanoparticles inside the base fluids, and the other is the two-step method which represents the formation of nanoparticles and then dispersion of the nanoparticles in the base fluids. The preparation of a uniformly dispersed nanofluid is essential for obtaining a stable reproduction of physical properties or superior characteristics of the nanofluids [5, 6].

Although various methods have been developed to prepare nanofluids, those previous approaches still had instability problems caused by particle agglomeration in the base fluids. Numerous investigations on colloidal dispersions have been conducted to prepare stable nanoparticle suspension given particle motion analysis in various flow conditions and sedimentation characteristics studies on suspended nanoparticles in base fluids. Simple techniques such as ultrasonic agitation or the addition of surfactants to the fluids are often used to minimize particle aggregation and improve dispersion behavior. Since nanopowder synthesis techniques have already been scaled up to industrial production levels by several companies, there are potential economic advantages in using two-step synthesis methods that rely on the use of such powders. But a significant problem that needs to be solved is the
stabilization of the suspension prepared [7, 8].

Alumina nanoparticle suspension is one of the most interesting observed material by the researchers due to its thermal properties. Many investigators have been studied the stability of alumina nanoparticle suspension using various surfactants. Several authors studied the stability of alumina nanofluids using sodium dodecylbenzenesulfonate (SDBS) [7, 9, 10], cetyltrimethyl ammonium bromide (CTAB) as surfactant [9], sodium dodecyl sulphate (SDS)[11], polyvinylpyrrolidone (PVP)[11] and sodium salt of poly methacrylic acid (SPMAA)[8].

Many attempts have been made towards the preparation of stable alumina nanoparticles suspension. However, it still presents a big challenge. The most important parameter in the preparation of this materials is the stability of the suspension[6, 12].

In this research, The stability of alumina nanoparticle suspension was studied using gum arabic as a surfactant at different concentrations and volume fraction of nanoparticle.

Experimental Methods
The materials used in the experiment are alumina nanoparticle with a particle size of <50 nm and Gum arabic obtained from Sigma-Aldrich Chemical. The materials are used as received without any purification or preparation.

Nanoparticle Suspension Preparation
Alumina nanoparticle suspension was prepared by dilution of a known weight of alumina nanoparticle and gum arabic in deionized water at a different of particle volume fraction of 0.1, 0.2, 0.3, 0.4, and 0.5% volume fraction. The concentration of the nanoparticle suspension in percent volume fraction can be estimated by Eq. (1).

$$\phi = \frac{m_p}{m_f + m_p} \times 100\%$$ (1)

where:  
$\phi$ : particle volume fraction  
$m_p$ : mass of nanoparticles  
$\rho_p$ : density of nanoparticles  
$m_f$ : mass of base fluids  
$\rho_f$ : density of base fluids

Characterization
Characterization techniques for determining the stability of the suspension are zeta potential analysis and particle size distribution. The measurements are conducted by the Malverns Zetasizer equipment at 25 °C. Zeta potential analysis and particle size distribution were conducted at different particle volume fraction of alumina nanoparticle and gum arabic concentrations. The stability of alumina nanosuspension was predicted by the zeta potential values obtained. While the particle size distribution was obtained by light scattering of samples in the suspension.

Results and discussion
The particle used in this research is alumina nanoparticle obtained from Sigma-Aldrich chemical. The characteristics of the alumina nanoparticle are a density of 4.000 g/cm³, a melting point of 2.040 °C, a boiling point of 2.980 °C, powder form with the particle size from TEM analysis <50 nm.

The SEM image of the alumina nanoparticle was shown in Figure 1. The Figure shows that the morphology of the sample in flake form.
Effect of Particle Volume Fraction

The stability of nanoparticles suspension is represented by the zeta potential value and the particle size distribution of the particle in the solution. The particle volume fraction plays an important role in the stability of the suspension. The stability of suspension is related to its electrokinetics properties. Therefore the study of electrophoretic behavior through measurement of zeta potential becomes important for understanding the stability of the suspension.

The effect of particle volume fraction on the stability of alumina nanoparticle suspension represented by zeta potential is presented in Fig. 2. It can be seen that the zeta potential values are shift from -25.7 mV at particle volume fraction of 0.1% to -21.3 mV at the particle volume fraction of 0.5%. It is noted that the suspension is stable if zeta potential is >25 mV and <25 mV. Hence it can be concluded that the suspension is stable at particle volume concentration of 0.1%. This value indicated that at smaller particle volume fraction, the suspension is more stable. It can be stated that at smaller particle volume fraction, there is a smaller number of particles in the suspension. Hence the interaction of the particle to agglomerate is smaller. The condition makes the suspension becoming more stable.

![SEM image of alumina nanoparticle](image)

**Fig. 1.** SEM image of alumina nanoparticle

![Zeta potential measurement](image)

**Fig. 2.** Zeta potential measurement of alumina nanoparticle suspension at different volume fraction.
The effect of particle volume fraction on the particle size distribution is showed in Fig. 3. It can be seen that the particle volume fraction influence the particle size distribution. Higher particle volume fraction gives wider particle size distribution, while lower particle volume fraction results narrow particle size distribution. It can be seen that at a volume fraction of 0.1%, the particle size distribution of alumina nanoparticle suspension is narrow with the average particle size is 230.0 nm, while at the volume fraction of 0.5%, the particles size distribution is wider with the average size is 814.5 nm. It should be noted that the particle size obtained from particle size distribution is the hydrodynamic size which is the size of the particle and its surrounding environment.

![Particle size distribution of alumina nanoparticle suspension at different volume fraction.](image)

**Effect of Gum Arabic Concentration**

Gum arabic is branched polysaccharide synthesized from acacia trees which are used in this experiment to stabilize the alumina nanoparticle suspension. The study was conducted at a different concentration of gum arabic. The stability of the suspension is characterized by measurement the zeta potential values and particle size distribution.

The effect of gum arabic concentration on the stability of suspension which is represented by zeta potential values is showed in Fig. 4. The graph indicates that zeta potential values of the suspension decrease with the increase of gum arabic concentration. The zeta potential is -25.7 mV at gum arabic concentration of 0.1% then decrease to -36.0 mV at the gum arabic concentration of 0.5%. This phenomenon can be explained that the function of gum arabic is to hindrance the interaction between the particles in the suspension to agglomerate. The higher concentration of gum arabic makes the ability of gum arabic molecules to cover the particles are higher. Hence, the interaction of the particles could be minimized.
The effect of gum arabic concentration on the particle size distribution is presented in Fig. 5. It can be seen that the particle size distribution give narrow particle size distribution at higher concentration of gum arabic which indicates that the alumina nanoparticles diameter reduces with increasing concentration of gum arabic. The smallest particle size is 164.6 nm which is obtained at gum arabic concentration of 0.5%. It can be explained that high concentration of gum arabic will suppress double layer of ions around the particles, enhancing the diffusion speed and resulting in smaller hydrodynamic diameter.

Conclusions
Stabilization of water-based alumina nanoparticle suspension has been done using gum arabic as a surfactant. The concentration of gum arabic is influence the stability of the suspension. Higher concentration of gum arabic gives the more stable suspension. On the other hand, decreasing particle volume fraction of alumina increase the stability of the suspension. The most stable suspension is achieved at gum arabic concentration of 0.5% that is zeta potential value of -36.0 mV, while the smallest particle size is 164.6 nm.
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