THE EFFECT OF TETRAETHIL ORTHOCILICATE (TEOS) ON Fe₃O₄ NANOPARTICLES ADDITION IN ELECTRICAL

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ABSTRACT

Magnetite Nanoparticles of pure (Fe₃O₄) and Fe₃O₄ with TEOS addition have been successfully synthesized from natural iron sand using the coprecipitation method. The purpose of this study is to provide information on the effect of TEOS to Fe₃O₄ on the electrical properties. The effect of TEOS addition to Fe₃O₄ indicates that the increase in true density results is 4.95 gr/cm³. The stability of nanolubricant on Fe₃O₄ nanoparticles with the addition of TEOS 1.2 ml was dispersed homogeneously. The value of thermal conductivity also increases due to TEOS addition on Fe₃O₄ nanoparticles in a volume fraction of 0.8% of 1,631 W/m.K and the heat of the type produced was 718.44 J/kg.K. The effect of TEOS addition on Fe₃O₄ nanoparticles produces good electrical properties of stability in the nano-lubricant.

Keywords: Fe₃O₄ nanoparticles, TEOS, thermal conductivity, electrical properties.

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INTRODUCTION

Magnetite (Fe₃O₄) nanoparticles, a common magnetic iron oxide, have a cubic inverse spinel structure with oxygen forming an FCC closed packing and Fe cations occupying the interstitial tetrahedral and octahedral sites [1]. The electrons can hop between Fe²⁺ and Fe³⁺ ions in octahedral sites even at room temperature, rendering magnetite an important half-metallic material [2].

Figure 1. Sketches related to electrons moving between Fe2+ and Fe3+ ions
Figure 1 shows a sketch of the ability to transfer electrons Fe2+ and Fe3+ due to oxidation and reduction processes\textsuperscript{[2]}. Magnetite (Fe\textsubscript{3}O\textsubscript{4}) nanoparticles are used in several applications, such as nanofluid for heat transfer applications\textsuperscript{[3-4]}, thermal conductivity, density and adsorbent materials\textsuperscript{[5-8]}.

Fe\textsubscript{3}O\textsubscript{4} nanoparticle synthesis has been carried out using various methods, including the coprecipitation method\textsuperscript{[9-11]}, high energy milling\textsuperscript{[12]}, sol gel\textsuperscript{[13]} and others. The coprecipitation method is the most effective method because this method can be carried out under normal environmental conditions. The synthesis method of Fe\textsubscript{3}O\textsubscript{4} nanoparticles used in this study is the coprecipitation method. Synthesis of inorganic compounds is based on the deposition of more than one substance together when it passes the saturation point. This means that coprecipitation is a method that can precipitate metals together during the formation of a precipitate. When a precipitate separates from a solution, the precipitate is not always perfectly pure, it may contain various amounts of impurities, depending on the nature of the precipitate and the conditions of deposition dissolving or precipitating a solid in a solution is determined by the saturation condition or the limit of a solid substance that can dissolve in a liquid\textsuperscript{[13]}. The advantages of the coprecipitation method are using room temperature and easily controlling particle size so that the time needed is relatively shorter\textsuperscript{[14]}.

This study was conducted with the aim of dispersing Fe\textsubscript{3}O\textsubscript{4} nanoparticles with the composition of TEOS into the lubricant and knowing the density before mixing TEOS and after mixing TEOS and potential zeta testing that affects nano-lubricant stability viewed from the electrical properties.

**METHOD**

The process of coating magnetite Fe\textsubscript{3}O\textsubscript{4} nanoparticles with Tetraethyl Orthosilicate (TEOS) and then the characterization of these results were obtained. Aquades solution and Ethanol solution act as solvents, Ammonia solution acts as sedimentary solution and Tetraethyl Orthosilicate (TEOS) acts as coating material. In the research, 0.2 grams of Fe\textsubscript{3}O\textsubscript{4} powder was combined into 60 ml of Aquades, 240 ml of Ethanol, and 7.5 ml of Ammonia 18%. Then, TEOS was added with variations of 0.9 ml, 1.2 ml, 1.5 ml, and 2.5 ml. Then it was stirred using a magnetic stirrer for 6 hours with a speed of 500 rpm and a temperature of 25 C to produce a homogeneous solution. Then, the results of the mixture will produce powder in the form of a precipitate. The precipitate was separated from the solution using a permanent magnet and washed using Aquades, and then the precipitate of washed wet powder was then dried in the oven for 24 hours at a temperature of 60 C. After the sediment dries, the dried powder was mashed using mortar. To produce Fe\textsubscript{3}O\textsubscript{4} nanoparticles powder, 0.2 gram of Fe\textsubscript{3}O\textsubscript{4} nanoparticles was mixed into 100 ml of lubricating oil and stirred using a spatula until homogeneous. The Nano-lubricant was further analyzed using several measurements and characterizations. The thermal conductivity and specific heat of the nano-lubricant were measured using C-Therm, TCi thermal conductivity analyzer. Heat Type (HT, Linseis, STA PT 1600). The densities of nano-lubricants were measured using a Pycnometer. Transmission Electron Microscopy (TEM, Tecnai G2 S20 twin) was used to analyze the magnetite particle size and distribution. The magnetite particles' thermal behavior at two different conditions: with and without silica (TEOS) coating.
RESULTS AND DISCUSSION

Nano-lubricant Thermal Conductivity Model

The thermal conductivity of a nanofluid is an important data used in the application of nanofluid. The ratio as reference data increases the thermal conductivity of the nanofluid compared to the base fluid. Measurement of thermal conductivity was carried out to determine the effect of TEOS variation and stability of nanoparticles that have been tested with potential zeta. The sample used was to see the effect of TEOS on the thermal conductivity of nanofluid in which samples of Fe₃O₄ nanoparticles coated with TEOS with a variation of 1.2 ml of conductivity can be seen in Figure 2. The calculation was taken from the theory of the Maxwell model of solid-liquid mixture.

![Graph](image)

**Figure 2.** Value of thermal conductivity of Fe₃O₄+TEOS (1.2ml) sample to the variation in volume concentration

![Graph](image)

**Figure 3.** Sketch of the thermal conductivity measurement
Figure 2 and Figure 3 show that there is an increase in the value of thermal conductivity from a volume concentration of 0% (pure Fe₃O₄) of 0.144 W/m.K, while Fe₃O₄ with the addition of TEOS 1.2 ml with a volume concentration of 0.81% is 1.631 W/m.K. These results indicate that the effect of TEOS addition increases the value of thermal conductivity in Fe₃O₄. The greater the volume concentration of the sample, the greater the value of thermal conductivity [17, 18]. The conductivity value increases due to the effect of volume concentration because the nanoparticles are suspended in the base fluid, causing heat transfer in suspension in the solid-liquid phase on the surface of the particles [19], consequently the heat transfer properties in the sample are more efficient. In addition, another cause is the occurrence of Brownian movement in the base fluid [20-21].

**Heat Type Model of Nanofluid**

Heat type is one of the properties that affect nanofluid. Figure 4 explains the effect of TEOS addition on samples of Fe₃O₄ nanoparticles on the heat of their type. The heat value was obtained from the calculation using a model that was previously used in the study conducted by Ping Zhou et al. in (2010) [26].

![Figure 4](image_url)

**Figure 4.** Heat value of Fe₃O₄ + TEOS (1.2ml) sample to the variation in volume concentration

**Table 1.** Heat value of the sample with TEOS volume concentration

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>0</td>
<td>1909</td>
<td>1910</td>
</tr>
<tr>
<td>0.29</td>
<td>1039.138</td>
<td>1039.438</td>
</tr>
<tr>
<td>0.39</td>
<td>934.4656</td>
<td>934.4755</td>
</tr>
<tr>
<td>0.49</td>
<td>858.5157</td>
<td>859.5159</td>
</tr>
<tr>
<td>0.81</td>
<td>718.4456</td>
<td>718.4467</td>
</tr>
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</table>

Based on Table 1 above, it can be concluded that the heat value of nanofluid tends to decrease as the volume concentration of nanofluid increases [27].
Density

The synthesized ferro-lubricant and the density of ferro-lubricant as a function of particle addition variation are shown in Figure 5. The density of 0.84 g/cm$^3$ is obtained at 0.3 g of magnetite particles coated using 1.2 ml of TEOS that acts as the silica precursors. Then, the particles (0.1 g) were immersed in 100 ml of lubricant. The TEOS and particle addition in the lubricant was chosen because showing better liquid stability, as analyzed in our previous investigation [26]. Based on the graph, the increase of the silica-coated magnetite particles (0.1 to 0.4 g) used as the additive could enhance the density of ferro-lubricant from 0.84 to 0.88 g/cm$^3$. A similar trend was also observed by Syam Sundar et al. [27] when the volume concentration was increased in the magnetite-water nanofluid. Viscosity is another critical factor of thermophysical properties, representing the internal resistance of fluid flow [26], and viscosity correlates with temperature [27]. Ferro-lubricant’s viscosity analysis and comparison.

![Figure 5](image)

**Figure 5.** a) Ferro-lubricant that have been synthesized in the laboratory; b) Density of ferro-lubricant as a function of particle addition variation

Transmission Electron Microscopy (TEM)

Transmission Electron Microscopy (TEM, Tecnai G2 S20 twin) was used to analyze the magnetite particle size and distribution. The magnetite particles’ thermal behavior at two different conditions: with and without silica (TEOS) coating.

![TEM images](image)

**Figure 6.** a) TEM image of uncoated magnetite particles; b) Histogram of uncoated magnetite particles size; c) TEM image of silica-coated magnetite particles; d) Histogram of silica-coated magnetite particles size.
Figure 6. The results suggested that the particles coated using silica (TEOS) have a larger average diameter of 150 nm than the uncoated particles with an average size of 120 nm. Thus, silica layers have been successfully coated on the surface of the magnetite particles. The coating layer of silica, which has an oleophilic characteristic, is essential for the particles to be easily dispersed in the lubricant and improve stability \cite{23-27}. This is one of the proofs that the TEOS nanoparticles are coated with Magnetite (Fe$_3$O$_4$) and can be clearly seen by TEM measurements of the properties of pure magnetite (Fe$_3$O$_4$) and (Fe$_3$O$_4$) with TEOS \cite{23-27}.

CONCLUSION

Magnetite nanoparticles of pure (Fe$_3$O$_4$) and Fe$_3$O$_4$ with TEOS were successfully synthesized from natural iron sand using the coprecipitation method. The effect of TEOS addition to Fe$_3$O$_4$ indicates that the increase in true density results is 4.95 gr/cm$^3$. The stability of nano-lubricant on Fe$_3$O$_4$ nanoparticles with the addition of TEOS 1.2 ml was dispersed homogeneously. The thermal conductivity value also increases due to the addition of TEOS to Fe$_3$O$_4$ nanoparticles in a volume fraction of 0.8% of 1,631 W/m.K and the type of heat produced was 718.44 J/kg. K.

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