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Preparation of bauxite/deionized water nanofluid and experimental investigation of its thermophysical properties

Boksit/deiyonize su nanoakışkanının hazırlanması ve termofiziksel özelliklerinin deneysel olarak incelenmesi

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Preparation of Bauxite/Deionized Water Nanofluid and Experimental Investigation of Its Thermophysical Properties

Highlights

- *Bauxite/ deionized water was prepared by using SDBS as surfactant.*
- *8.47% thermal conductivity enhancement at 2% nanoparticle concentration was observed.*
- *Heat capacity of the bauxite nanofluid was 4.4% higher than the deionized water.*

Graphical Abstract

In this study, bauxite/deionized water nanofluid was prepared by two-step method and its thermopyhsical properties were experimentally investigated.

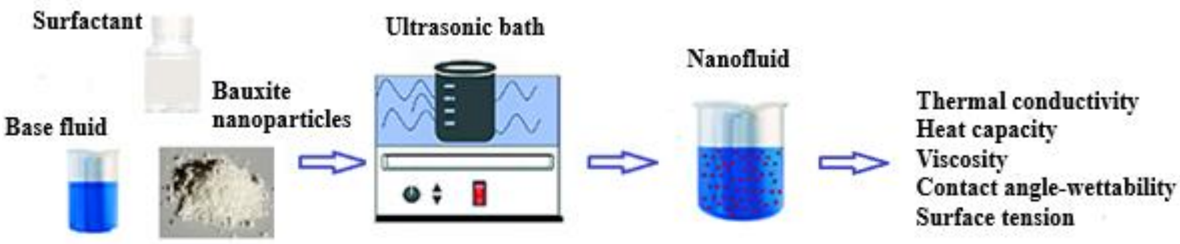

Figure. Experimental method

Aim

The aim of the study is to prepare bauxite/deionized water nanofluid by two step method and to determine its thermophysical properties such as viscosity, thermal conductivity, heat capacity and surface tension of bauxite nanofluid.

Design & Methodology

Bauxite nanoparticles was obtained by using spex-type ball milling attritor. Nano bauxite particles were dispersed in deionized water at the rate of 2 wt % and 0.5 wt % Sodium Dodecyl Benzene Sulfonate (SDBS) was added as surfactant. Thermal conductivity, viscosity, heat capasity and surface tension of nanofluid were experimentally determined.

Originality

Bauxite nanofluid has not been prepared before and its thermophysical properties have not been investigated in the literature. This study showed that bauxite has superior thermophysical properties when used in a nanofluid because of hybrid effect due to the minerals it contains.

Findings

It has been observed that the thermal characteristics of bauxite nanofluid are better than deionized water. Thermal conductivity and specific heat of bauxite nanofluid are 8.47% and 4.4% higher than deionized water, respectively. In addition, while the surface tension of water is 72.75 dyn.cm^{-1} at 20 ° C, the surface tension of bauxite nanofluid containing SDBS was measured as 37.93 dyn.cm^{-1} .

Conclusion

The results show that a significant efficiency enhancement of thermal systems can be obtained with the use of bauxite nanofluid which has superior thermophysical properties and lower surface tension and contact angle compared to deionized water.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Preparation of Bauxite/Deionized Water Nanofluid and Experimental Investigation of its Thermophysical Properties

Araştırma Makalesi / Research Article

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ABSTRACT

In this study, bauxite/deionized water nanofluid was prepared by two-step method and its thermopyhsical properties were experimentally investigated. Bauxite was milled by high-energy spex type ball milling attritor. Bauxite nanoparticles with a size of 38 nm (2% by weight) and Sodium Dodecyl Benzene Sulfonate (0.5% by weight) were doped into the deionized water while preparing the bauxite nanofluid. Ultrasonication was applied for two hours to obtain stable colloidal dispersions of nanoparticles. It has been seen that the thermal characteristic of bauxite nanofluid is better than that of deionized water. The bauxite nanofluid has the lower surface tension and smaller contact angle than that of base fluid. However, the thermal conductivity and the specific heat of bauxite nanofluid increased by 8.47% and 4.4% compared to deionized water, respectively.

Anahtar Kelimeler: Bauxite, nanofluid, thermal conductivity, viscosity.

Boksit/Deiyonize Su Nanoakışkanının Hazırlanması ve Termofiziksel Özelliklerinin Deneysel Olarak İncelenmesi

ÖZ

Bu çalışmada, boksit/deiyonize su nanoakışkanı iki aşamalı yöntem kullanılarak hazırlanmış ve termofiziksel özellikleri deneysel olarak incelenmiştir. Boksit minerali yüksek enerjili spex tipi bilyalı öğütücüde öğütülmüştür. Boksit nanoakışkanı hazırlanırken 38 nm boyutundaki boksit nanopartikülleri (kütlece %2) ve Sodyum Dodesil Benzen Sülfonat (kütlece %0,5) deiyonize suya karıştırılmıştır. Nanopartiküllerin kararlı koloidal dağılımını sağlamak için iki saat boyunca ultrasonikasyon uygulanmıştır. Boksit nanoakışkanının termal karakteristiğinin deiyonize suya göre daha iyi olduğu görülmüştür. Boksit nanoakışkanı, temel akışkana göre daha düşük yüzey gerilimine ve daha küçük temas açısına sahiptir. Ayrıca deiyonize suyla karşılaştırıldığında boksit nanoakışkanının termal iletkenliği ve spesifik ısı kapasitesi sırasıyla %8,47 ve % 4,4 artmıştır.

Keywords: Boksit, nanoakışkan, termal iletkenlik, viskozite.

1. INTRODUCTION

The enhancement of heat transfer in thermal systems is of great importance due to the lack of energy sources in many industrial applications. The use of extended surfaces technologies has increased in importance to enhance heat transfer by reducing energy loss [1]. In these applications, the using of working fluids that have high thermal characteristic increases the efficiency of the system. Conventional fluids such as water, ethylene glycol, mineral oil have poor thermophysical properties. In the last decade, there has been a trend in the use of nanoparticle-containing working fluids in thermal systems (heat pipes, heat exchangers, etc.) to improve thermal performance. Nanofluids are uniform and stable colloidal dispersions of nanoparticles (diameter less than 100 nm) of metallic/non-metallic substances in a liquid [2].

In general, a nanofluid is prepared by dispersing nanometer-sized solid particles (ceramics, metal oxides etc.) into a base fluid such as water, ethylene glycol, or oils. Surfactant is also adding into the suspension to lessen surface tension. Previous studies show that nanoparticles that are doped into the base fluid significantly improve the thermophysical properties of the fluid. Thermal and rheological properties of working fluids are important parameters in solving many heat problems. The most important parameter that determine the usage areas of nanofluid is their thermophysical properties. Thermal conductivity, heat capacity and

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viscosity are most important thermophysical properties for nanofluids in heat transfer applications. The thermal conductivity of a fluid plays an important role in the progressing of energy-efficient heat transfer equipment. It is well known that at room temperature, metallic solids have higher thermal conductivity than fluids. Therefore, the thermal conductivities of base fluids containing suspended solid metallic or nonmetallic (metallic oxide) particles would be expected to be significantly higher than those of conventional heat transfer fluids. The high thermal conductivity of nanofluids provide higher energy efficiency, better performance, and lower operating costs [3]. Thermal conductivity of different kind of nanofluids were investigated by some researchers [4-7]. Agarwal et al. studied thermal conductivity of Al_2O_3 nanofluids. They used distilled water and ethylene glycol as base fluids. They found that 30 and 31% increase in thermal conductivity at 2 vol% nanoparticle concentration, respectively [8]. Chopkar et al. studied the thermal conductivity of nanofluids prepared using 0.2–1.5 vol% Al_2Cu and Ag_2Al nanoparticles. They used water and ethylene glycol as based fluids. They observed that the increase in the thermal conductivity ratio depends on size, volume fraction and thermal properties of suspended solid nanoparticles. The results showed that the thermal conductivity increased by 50-150% compared to base fluids. [9]. The specific heat is the other important property and it plays a significant role in improving heat transfer rate of nanofluids. Specific heat is the amount of heat required to enhance the temperature of one gram of nanofluids by one degree centigrade [10]. Tiznobaik and Shin investigated the specific heat capacity of high-temperature molten salt-based nanofluids. Silicon-dioxide nanoparticles size of 5, 10, 30, and 60 nm in diameter were dispersed in a molten salt eutectic. They observed that particle size did not affect the specific heat capacity and heat capacity increased by 25% compared with the base fluid [11]. The viscosity of a fluid is directly related to the power required for pumping, pressure drop in the flow channels and wear on the channel surfaces. In the literature, there are many studies related to viscosity of nanofluid. According to studies, the viscosity of the nanofluid depends on many parameters such as nanoparticle type, size, shape, concentration and temperature [12-15]. The effective viscosity of nanofluids enhance with an increase in the volume fraction and decrease with an increase in the temperature [16].

In this experimental study, bauxite/deionized water nanofluid was prepared at the rate of 2% (wt.) by two step method. The thermophysical properties such as viscosity, thermal conductivity, heat capacity and surface tension of bauxite nanofluid were experimentally determined and then obtained results were compared with the base fluid. The findings have illustrated that thermal characteristic of bauxite nanofluid are better than that of deionized water. Since it contains different metal oxides, it is thought that the using bauxite nanofluid in thermal systems will be effective for thermal performance.

2. MATERIALS and METHOD

2.1. Preparation of Nanofluid

Bauxite is a mixture of diasporite ($Al_2O_3.H_2O$), bohmit [AlO(OH)], gibbsite (hydrargilite) [$Al(OH)_3$] minerals and generally contains silica, iron oxides and TiO_2. The crystal system of bauxite is amorphous. It has quite wide spread in the world. Therefore, bauxite is easy to find. Bauxite nanoparticles was obtained by using spex-type ball milling attritor. The spex type ball mill has 12 chambers with a speed of 1000 rpm. The reactor volume is 10 g. Bauxite particle size was measured by Malvern particle size meter. Deionized water was used as a base fluid. Nano bauxite particles were dispersed in deionized water at the rate of 2 wt % and 0.5 wt% surfactant (Sodium Dodecyl Benzene Sulfonate (SDBS) was added. The Sodium Dodecyl Benzene Sulfonate which has a chemical formula of $C_{18}H_{29}NaO_3S$) is an anionic solid surface-active-agent. High surface area and activity cause agglomeration in nanofluids. Agglomeration is a major problem in preparing nanofluids. Ultrasonication was applied for two hours to prepare a stable mixture and prevent particle agglomeration.

2.2. Determination of Thermal Properties of Nanofluid

The thermal conductivity of the prepared nanofluid was measured by thermal conductivity experimental set-up. The test system consists of two nested axial cylinders made of brass. Dimmer circuit which can be adjust the value is used to energize the inner cylinder at the desired heater power. The system is cooled by passing cooling water around the outer cylinder. A flow meter was used to adjust the cooling water mass flow rate. Two thermocouples (k-type) were used for temperature measurements. All sections were insulated with insulation material to minimize heat loss in the system. The cooling water flow rate was set to 66 g/s. Tests were made by adjusting the heater voltage to 50 W, 60 W, 70 W and 80 W. Firstly, thermal conductivity test was carried out by using- deionized water and compared to literature data. The experimental system is given in Fig.1.

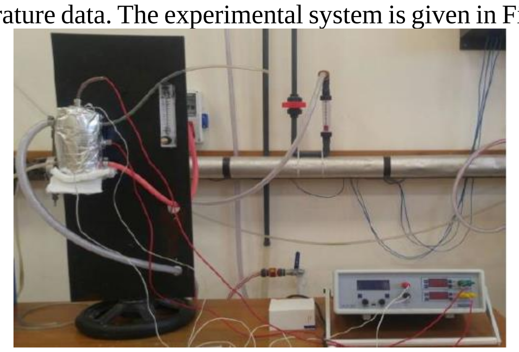

Figure 1. Thermal conductivity experimental set-up

Viscosity measurements were made with Brookfield DV-III rheometer. Viscosities of base fluid and nanofluids were measured at different temperatures (20 °C, 40 °C, 50 °C, 60 °C, 70 °C). Specific heat capacity was measured by using calorimetry experiment system. In the study, contact angles of water and bauxite nanofluid on copper plate were determined by apparatus of Kruss X-

100. When determining the surface tension, the method of counting the number of drops of liquid in a certain volume was used.

The surface tension of a liquid could be specified via Traube Stalagmometer presented in Fig. 2 with the help of another surface tension-known liquid [17].

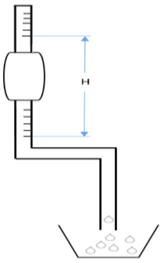

Figure 2. The Traube Stalagmometer

3. RESULTS and DISCUSSION

Spex type ball milling was conducted to obtain bauxite nanoparticles. The sample/ball ratio was fixed as 1:15 in reactor, milling periods were changed to 7, 9 and 11 hours. The particle size of bauxite has shown as Fig 3. at different milling periods. The smallest particle size for bauxite was obtained at milling time of 9 hours.

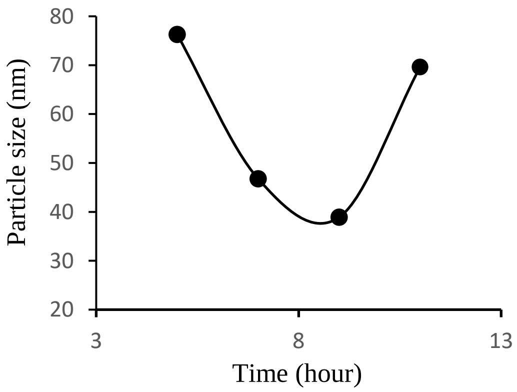

Figure 3. Effect of milling period on bauxite particle size

The particle size of the sample milled at 9 hours was found to be 38 nm. As the ball milling period enhance, particle size increase due to agglomeration. Fig. 4 shows the particle size distribution of bauxite obtained in optimum period.

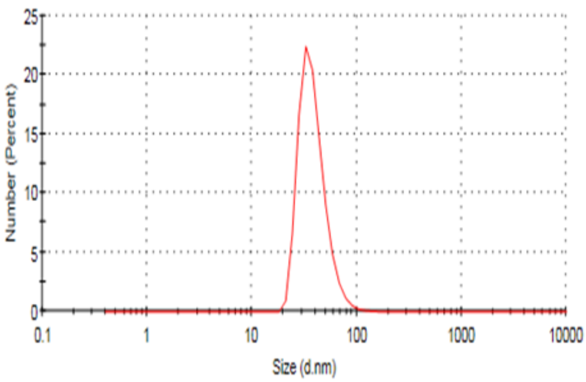

Figure 4. Size distribution graph of bauxite particles

The thermal conductivity tests were conducted at different heater voltage values (50 W, 60 W, 70 W, 80 W). Firstly, thermal conductivity of water was determined and it was seen that the average difference does not exceed 4% between literature data [18]. Then, the experiment was repeated for bauxite nanofluid. Thermal conductivity results of water and bauxite nanofluid at different heating powers were given in Fig 5.

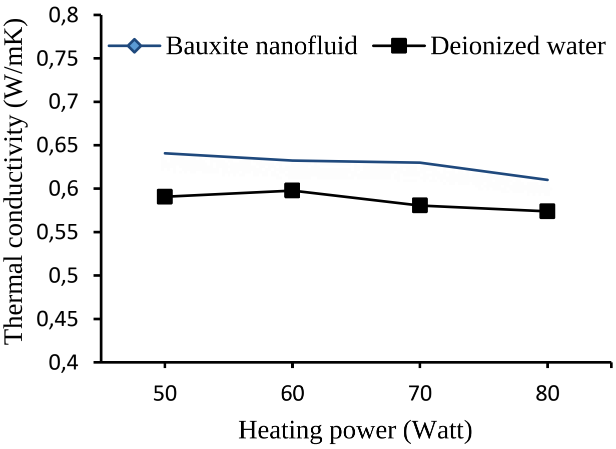

Figure 5. Thermal conductivity results of deionized

The thermal conductivities of the water and bauxite nanofluid were measured as 0.59 W/m. K and 0.64 W/m. K, respectively at 50 W heating power and 66 g/s cooling water mass flow rate. According to this result, thermal conductivity incresing rate was found to be 8.47%. Thermal conductivity is the most important thermophysical property for nanofluids. The particle material, particle size, temperature, pH value of base fluids have impact on the thermal conductivity of the nanofluids. The addition of very low mass fraction particle to a base fluid enhance the thermal conductivity of base fluid [10].

The specific heat values of water and bauxite nanofluid by the calorimeter experiment system were given in Table 1.

Table 1. Specific heat capacities of water and bauxite nanofluid

Fluid	Specific heat capacity
Water	4.180 J/g. °C
Bauxite nanofluid	4.365 J/g. °C

As results, the heat retention and heat carrying capacity of bauxite nanofluid are higher than water. Viscosity values were determined with Brookfield viscometer at different temperatures (20 °C, 40 °C, 50 °C, 60 °C, 70 °C). The viscosity values of water and bauxite nanofluid with 2% concentration were given in Fig. 6.

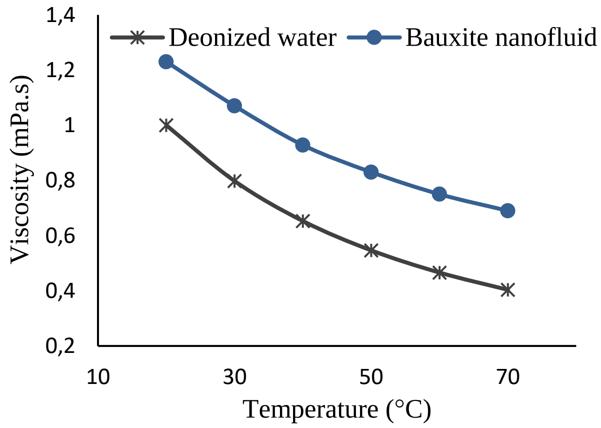

Figure 6. Viscosity values of deionized water and bauxite nanofluid depending on temperature

Viscosity is an important thermophysical property in heat transfer applications for nanofluids. Because the pumping force and pressure drop depend on this property of nanofluids. The increase in viscosity of nanofluids is a disadvantage compared to water. As seen in Fig. 6, the viscosity of bauxite nanofluid was higher than water. Viscosity of water was 1 mPa.s while the viscosity of the bauxite nanofluid was 1.23 mPa.s at 20 °C. The important parameters influencing viscosity of nanofluids are temperature, nanoparticle volume fraction, size, shape, pH, and shearing rate. As the concentration of the nanoparticle in the base fluid increases, the viscosity of the nanofluid also increases. However, as the temperature increases, the viscosity decreases [19]. The viscosity also increases with the reduction in the particle size of the nanofluids [10].

The contact angles-wettability measurements of water and bauxite nanofluid (Fig. 7.) have been conducted at 20 °C.

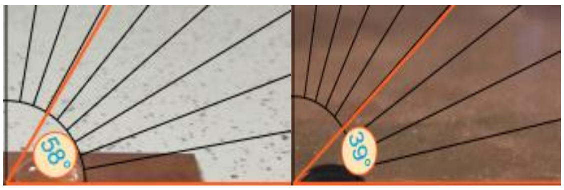

Figure 7. Images of dropletss of (a) water (b) bauxite nanofluid

In a three phase system making of solid, liquid and gas, the static angle structured by the liquid on the polished or pressed solid surface is defined as the contact angle [17]. When contact angle increases, the solid surface is no longer wetted by the liquid; as a consequence, the solid surface is called as hydrophobic. If the contact angle diminishes, then wettability goes up and therefore fluid turns into the hydrophilic structure. The surfactants reduce the solid-liquid interface tension on the solid surface and reduce the contact angle. It could be readily observed from the contact angle-wettability measurements, the contact angle of the deionized water is 58°, while the contact angle of the bauxite-deionized water nanofluid is 39°. The smaller contact angle is more applicable in a heat pipe because wettability increases. This provide a positive effect on heat transfer. Also, the use of SDBS surfactant increased the ability of the fluid to wet the surface.

The number of droplets in a specific volume was counted by Traube Stalagmometer and the surface tension value of bauxite nanofluid was specified with reference to the surface tension known deionized water.

$$\frac{m_1}{m_2} = \frac{\gamma_1}{\gamma_2} \quad (1)$$

Where m_1 and m_2 represent the mass of droplets and γ_1 and γ_2 are the surface tensions of deionized water and bauxite nanofluid, respectively. The surface tension of water is 72.75 dyn.cm^{-1} at 20 °C [17]. Surface tensions of SDBS containing bauxite nanofluid was determined to be 37.93 dyn. cm^{-1}. The bauxite nanofluid has the minimum surface tension amount than that of base fluid. This is because surface-active-agent doped into the nanofluid prohibits the intramolecular attractions to a great extent. Surface tension measurements showed that adding of surface-active-agent to the base fluid decreases significantly the surface tension as well.

4. CONCLUSION

Thermophysical properties of bauxite nanofluid prepared by using deionized water as the base fluid were investigated experimentally and compared with the base fluid in this study. 38 nm nanobauxite particles was obtained as a result of grinding in high energy spex type ball mill. Nano bauxite particles were dispersed in deionized water by %2 concentration and 0.5 wt% surfactant used. The findings obtained from the experimental study are as follows;

- According to thermal conductivity measurement results, thermal conductivity of bauxite nanofluid increased by 8.47% compared to deionized water.
- The different minerals present in the bauxite produced a hybrid effect and the specific heat capacity of the bauxite nanofluid was 4.4% higher than the deionized water.
- It has been determined that the resistance to flow increases due to the particle-particle interaction formed by the nanoparticles contained in the bauxite nanofluid, and thus the viscosity increases compared to water. In addition, as the temperature increased, the viscosity reduced due to decreasing the in the interaction between the nanoparticle and the base fluid.
- It is considered that the efficiency of thermal systems such as heat pipes, heat plates and heat exchangers will be much higher with the use of bauxite nanofluid which has superior thermophysical properties and lower surface tension and contact angle compared to deionized water.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Duygu Yılmaz Aydın: Performed the experiments and wrote the manuscript.

Metin Gürü: Analysed the results.

Adnan Sözen: Analysed the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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