Synthesis and Characterization of Silica Nanoparticle-Based Nanofluid from Geothermal Mud for Solar Panel Cooling Material

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Abstract. Silica nanoparticles are an essential nanofluid ingredient for absorbing heat in photovoltaic systems. Silica powder is extracted from geothermal sludge using the sol-gel method with acid-base treatment. The gel formed is stored at 12 and 18 h aging to control the particle size and microstructure. XRD, FTIR, SEM, TEM and BET were employed to characterize the resulting silica particles' microstructure, morphology and surface area. It is found that the silica nanoparticle contains a crystalline phase microstructure, with an average particle size of 40 nm, embedded in an amorphous matrix. The resulting silica nanoparticles meet the requirements and are suitable for forming nanofluids.

Keywords: geothermal sludge, sol-gel method, silica nanoparticle, nanofluids.

1 Introduction

The General Plan for Electricity Development (RUPTL) serves as a strategic document that defines the direction of energy sector development in Indonesia. In recent years, there has been a significant paradigm about energy, focus on renewable resources, particularly Solar Power Plants. The solar panels available on the market today still experience degradation caused by various factors, which affect their life time. During its operational lifetime, solar panels are exposed to various environmental stresses such as light, heat, humidity, and mechanical pressure, most of which are responsible for this phenomenon. Figure 1 shows that the highest degradation is due to the temperature factor. Cooling material for solar panels have been developed by manufacturers and researchers. The use of nanoparticles allows nanofluids to have higher thermal conductivity, thereby improving efficiency [1].

The nanofluid is a designed fluid created by dispersing nano-sized particles (1–100 nm) of metals, non-metals, or their oxides within a base. The inclusion of

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nanoparticles made from metals or non-metals with high thermal conductivity, along with their oxides, significantly improves the base fluid's thermal conductivity and heat transfer capabilities. These nanoparticles are produced through bottom-up techniques (such as the sol-gel method, chemical vapor deposition, and hydrothermal synthesis) or top-down methods (like optical, electron beam, scanning probe microscope nanolithography, and milling processes) [2].

Silica can be used as the main material for cooling systems. Technological advancements now enable methods to produce pure silica, which can be used as a base material for manufacturing nanofluids. This silica is derived from geothermal mud, which can be refined to obtain pure silica.

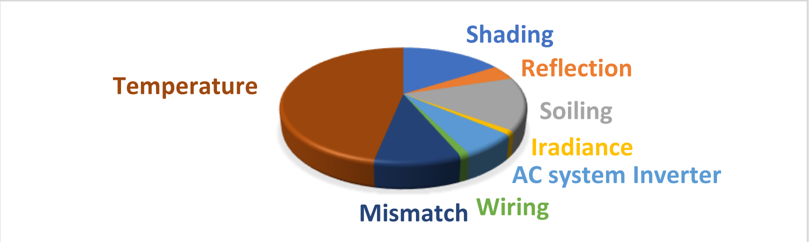

Figure 1 Degradation Factor [3]

Based on current research developments, silica has become commonly used as a material for nanofluids. An abundant supply of silica can be utilized as a material for nanofluids, particularly from geothermal mud [4]. This cheap material is used to produce silica nanoparticles, which in turn increases the value of geothermal silica. The solid waste contains metallic elements, some of which are heavy metals such as Cu, Pb, Zn, Mn, Fe, Cd, As, Sb, Au, Ag, Hg, and Se. Additionally, this solid waste also contains a high amount of silica [5].

2 Materials

The primary material used is silica obtained from geothermal waste, which forms a silica crust generated by the pipes of geothermal power plant installations. This solid waste contains metallic elements, including some heavy metals such as Cu, Pb, Zn, Mn, Fe, Cd, As, Sb, Au, Ag, Hg, and Se. Additionally, it has a high silica content [5]. The geothermal waste was obtained from the PT Pertamina Geothermal Energy power plant in the Karaha area of West Java, Indonesia.

To obtain pure silica from geothermal waste, several materials need to be prepared. First, distilled water (aquades) is used to thoroughly wash the geothermal waste. Second, a 1.5N NaOH solution is used to mix with the geothermal waste to form sodium silicate (Na_2SiO_3). Then, a 2N HCl solution is used to titrate the sodium silicate solution.

3 Methods

Synthesis was carried out using the sol-gel method. The folowchart of the preparation of SiNP from geothermal silica is shown in Figure 2. Ten grams of washed silica powder was mixed with 400 mL of 1.5 N sodium hydroxide (NaOH) in a beaker to form sodium silicate (Na_2SiO_3). The mixture is then stirred using a magnetic stirrer while maintaining a constant temperature of 90ºC for 60 minutes. The resulting sodium silicate solution was separated from any remaining solids using a sonication apparatus. The solution was then titrated with 2 N HCl to form a gel at pH 5. The gel was allowed to age for either 12 or 18 hours. Subsequently, the formed gel was separated using a centrifuge and washed with distilled water until neutral. Finally, the neutralized gel was dried in an oven at 100°C for 12 hours, yielding the final product: silica nanoparticles (SiNP).

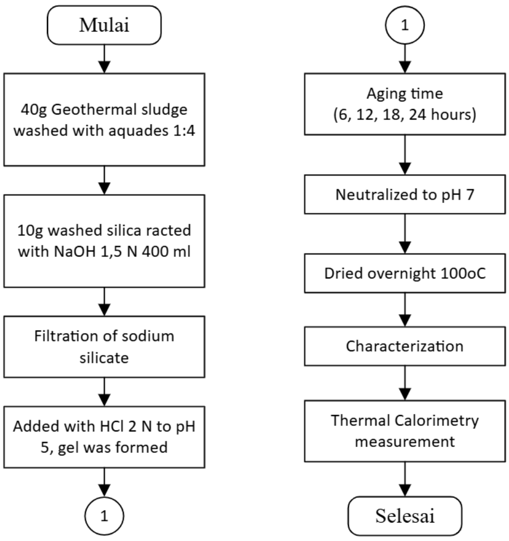

Figure 2 Flowchart of the preparation of SiNP from geothermal silica

The SiNP samples aged 12 h and 18 h were characterized using X-ray diffraction (XRD) to reveal their microstructure, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) to observe the sample morphology, Fourier transform infrared spectroscopy (FTIR) to show functional groups and chemical bonds, and Brunauer–Emmett–Teller (BET) to determine the specific surface area of materials.

4 Result and Discussion

Figure 3 shows the XRD spectra of SiNP aging at 12 h and 18 h. After an aging time of 12 h, the XRD spectra reveal that the SiNP was in the mix of crystalline and amorphous phases. Bump peaks can recognize the amorphous phase at 2 thetas around 25o. The crystalline phases were shown by the diffraction peaks located at 2 theta of 31.80^o, 45.69^o, 56.59^o, and 75.45^o, which indicate the formation of silica (SiO_2). These diffraction peaks disappear when the aging time is extended to 18 h and leave behind the amorphous phase with a slightly larger bump peak. It indicates a transformation of crystalline to amorphous phases [5].

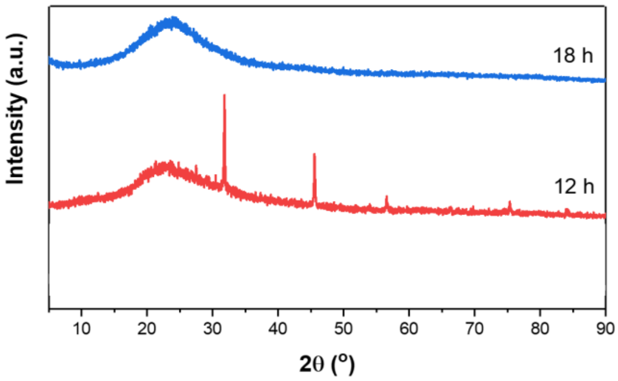

Figure 3 XRD pattern of aged SiNP.

The crystallite size of the samples was determined using the Debye Scherrer equation, as shown in Table 1. Table 1 indicates that prolonging the aging time increased the crystallite size.

Table 1 Crystallite size of the aged SiNP

Sample #	Aging time (h)	Size (nm)
01	12	1.23
02	18	1.56

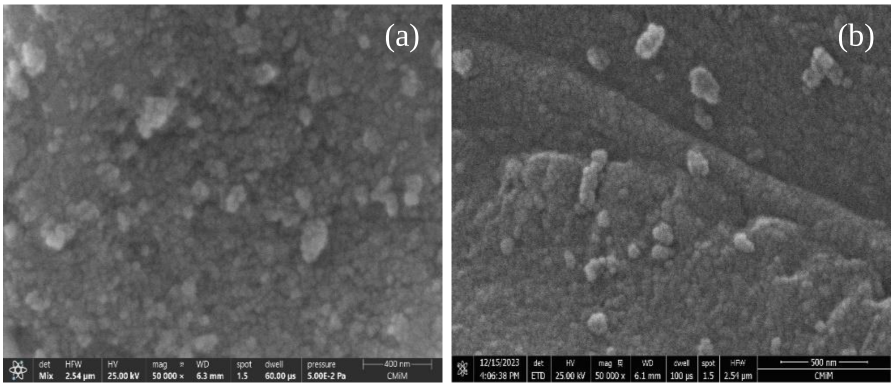

Figure 4 SEM of SiNP aged at (a) 12 h and (b) 18 h.

The scanning electron microscope (SEM) was used to observe the surface morphology of SiNP aged at 12 h and 18 h, as shown in Figure 4. The morphology of SiNP aged at 12 h (Figure 4(a)) looks to be an equiaxed structure with a size of 5-20 nm, while the morphology of SiNP aged at 18 h (Figure 4(b)) is a spherical structure with an average size of 40 nm. This morphology observation is confirmed by the TEM micrograph shown in Figure 5.

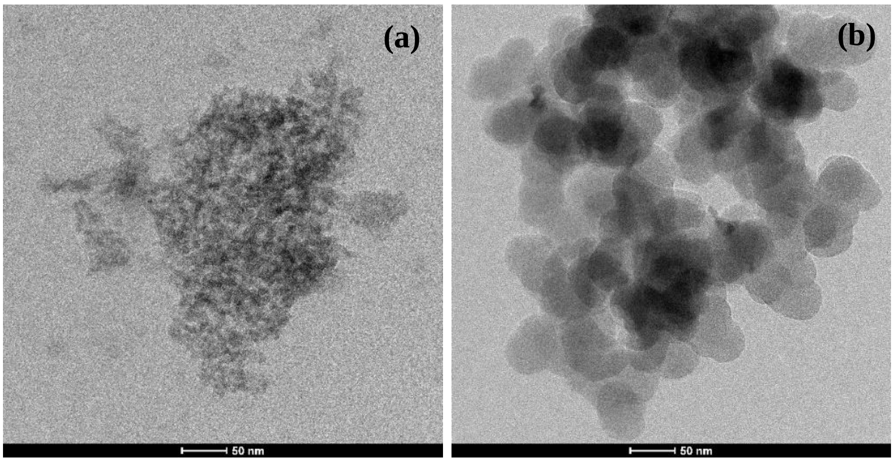

Figure 5 TEM of SiNP aged at (a) 12 h and (b) 18 h.

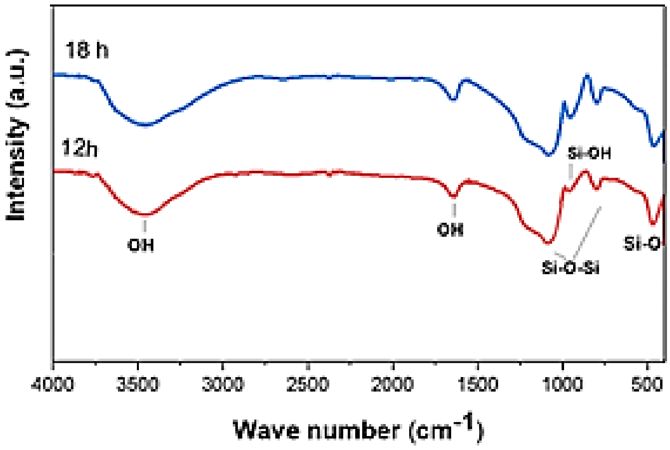

Figure 6 FTIR of SiNP aged at (a) 12 h and (b) 18 h.

Figure 6 shows the chemical bonding of SiNP at aging times of 12 and 18 hours shows a consistent absorption pattern across all spectra, indicating that the silica bonds remain intact despite the chemical aging duration. The FTIR spectra for SiNP exhibit characteristic peaks around 3400, 1600, 1100, 960, 700, and 470 cm^{-1}, corresponding to the absorption bands of -OH, Si-O-Si, Si-OH, and Si-O, respectively. Specifically, the bands at 3400 and 1618.93 cm^{-1} are associated with the bending vibrations of OH groups. The broad absorption band between 1300 and 1000 cm^{-1}, peaking at 1096.97 cm^{-1}, is linked to the asymmetric stretching vibrations of siloxane bonds (Si-O-Si bridges). The band at 962.93 cm^{-1} corresponds to the symmetric stretching vibration of free silanol groups on the surface of amorphous solid Si-OH. Meanwhile, the band at 797.07 cm^{-1} indicates the symmetric stretching vibration of Si-O-Si bonds, and the 469.47 cm^{-1} band is related to the asymmetric deformation vibration of O-Si-O bonds. It is also noted that an increase in the aging time enhances the intensity of the Si-OH peak at 962.93 cm^{-1}.

The specific surface area, total pore volume, and average pore diameter of SiNP were analyzed using the BET method. For the sample aged for 12 hours, the total pore volume was found to be 0.579 cm^3/g, the average pore diameter was 5.625 nm, and the specific surface area was 205.99 m^2/g. When the aging time was extended to 18 hours, the total pore volume decreased to 0.446 cm^3/g, the average pore diameter reduced to 1.499 nm, and the specific surface area significantly increased to 594.55 m^2/g. This suggests that a longer aging time reduces the pore diameter, attributed to an increase in particle size, as confirmed by TEM measurements. The enhancement in specific surface area is primarily due to the increased disorder of the SiNP.

5 Conclusion

The synthesis and characterization of silica nanoparticles (SiNP) derived from geothermal waste rich in silica have been successfully conducted. This study aimed to produce SiNP with a high specific surface area using the sol-gel method and to examine how aging time influences the microstructure and properties of the SiNP. Notably, aging the gel for 18 hours yielded amorphous SiNP with characteristics suitable for nanofluid applications.

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