Amorphous SiO_2 Nanoparticles from Natural Sands: Structure and Porosity

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https://doi.org/10.12982/CMUJNS.2020.0037

Received: *January 1, 2020*
Revised: *April 4, 2020*
Accepted: *April 10, 2020*

ABSTRACT

Silica (SiO_2) nanoparticles (NPs) generally include mesoporous materials (2–50 nm), having broad application prospects, such as for drug delivery systems. In this study, we report the porosity of amorphous SiO_2 NPs by investigating their crystal structure, morphology, diameter, and volume of pores. Amorphous SiO_2 NPs have been prepared from quartz sand, heated at a temperature range from 500 to 1,200 °C. The identification of the crystal structure was performed using XRD, the morphology and grain growth particles were considered using SEM, and the diameter and volume of pores were investigated using BET. An FTIR analysis was used to analyze the -Si-O and Si-OH functional groups. The results of this study presented that at a calcination temperature range of 500–800 °C, the crystal structure disappeared. However, at a temperature of 1,000 °C, a new crystalline tridymite structure was observed. Furthermore, the structural transformation was observed at a temperature of 1,200 °C from the amorphous phase to the polycrystalline phase consisted of quartz, cristobalite, and tridymite structures. During the calcination process, as the particles' pore size grew more significantly, the number of grain boundaries decreased, influencing the particle porosity sizes. The results of the analysis using BET presented that the pore surface area and pore volume of the samples tended to be smaller, along with increasing calcination temperature.

Keywords: Structural transformation, Amorphous SiO_2, Nanoparticle, Porosity, Calcination temperature

INTRODUCTION

In general, quartz sands from the Bancar-Tuban, Indonesia area contain many oxide elements, including SiO_2, Fe_2O_3, $CaCO_3$, Al_2O_3, and a few other oxides; which are clean brown (Akl et al. 2013; Munasir et al., 2013; Sdiri et al., 2014). Furthermore, the color of the quartz sands is bright white or another, depending on its contaminant compounds. Other physical properties of the quartz sands are given as follows; hardness of 7 Mohs, specific gravity of 2.6–2.7 (g.cm^{-3}), melting point of 1,715 °C, specific thermal of 830 (J.kg^{-1}.°C^{-1}), and thermal conductivity of 7.7–8.4 (W.m^{-1}.K^{-1}). Silica has the crystalline structures of quartz, cristobalite, and tridymite with the temperature stability of 870 °C, from quartz to cristobalite, and 1,470 °C, from cristobalite to tridymite (Guttman, 1990; Marians and Hobbs, 1990; Stevens et al., 1997; Dapiaggi et al., 2015). Interestingly, slica NPs can be prepared from natural quartz sands (Munasir et al., 2013), siliceous sands (Sdiri et al., 2014), and douiret sands (Trabelsi et al., 2009). The synthesis routes can be employed by the alkali fusion by using KOH at a temperature of 350 °C (Mori, 2003), NaOH at a temperature of 500 °C (Mori, 2003; Munasir et al., 2013), and Na_2CO_3 at a temperature of 1,100 °C (Trabelsi et al., 2009). Moreover, the synthesis methods can also be conducted by using hydrothermal method or chemical process (Zulfiqar et al., 2016), such as the precipitation, reverse microemulsion, and flame synthesis, and sol-gel process (Guo et al., 2017).

The natural raw materials as sources of silica are hardcore such as diorite and gabbro (Jang et al., 2008; Trabelsi et al., 2009; Waseem et al., 2009), quartz sands (Munasir et al., 2013, 2015), clays or muds, organic materials such as rice hush ash (Liou, 2004; Nittaya Thuadaij, 2008), and bagasse ash (Affandi et al., 2009). Quartz sand is commonly found in coastal areas of rivers, lakes, beaches, and some in shallow seas. Most of the content of quartz sand is silica (SiO_2), which is 55.30-99.87 wt% (Munasir et al., 2015). Silica is widely used in various applications such as for mixed materials in concrete (Said et al., 2012; Heikal et al., 2013); tire industry, rubber nanocomposites (Chen et al., 2008), emulsion wall-paint (Mizutani et al., 2006), lotions and cosmetics, ingredient cosmetic efficacy (Fruijtier-Pölloth, 2012), ceramics (Said et al., 2012; Heikal, 2013; Obrtlík et al., 2017), heavy metal absorbent material of Cd^{+2} and Pb^{+2} (Saad Al-Farhan, 2016), $Fe_3O_4@SiO_2$ core-shell (Karimi et al., 2016), wrapper drugs (Barbé et al., 2004; Kwon et al., 2013), packaging, and anti-bacterial agents (Wang et al., 2007; Luo et al., 2015). Silica NPs can also be applied for developing renewable energy, such as for material for ion-lithium batteries, electrodes (Favors et al., 2014), electrolytes (He et al., 2005; Park et al., 2007),