

Preliminary Study of Chitosan Coated Silica Derived from Geothermal Solid Waste

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Preliminary Study of Chitosan Coated Silica Derived from Geothermal Solid Waste

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Abstract

Purpose: The purposes of this research are to study the synthesis of chitosan coated silica aerogel made from solid geothermal waste as adsorbent for separating CO₂ and CH₄ and to study CO₂ adsorption kinetics on chitosan coated silica aerogel by Pseudo First Order and Second Order methods.

Methodology: geothermal silica was leached with H₂SO₄ 20% 1: 5 w/v. The chitosan was added with silica and chitosan ratio of 1.3: 10, 1.5: 10, 1.9: 10, 2.2: 10, and 2.4: 10 w/v. IPA was added to silica sol to form hydrogel and gelled. The addition of n-hexane is carried out to occur the solvent exchange process. The gel is dried by Ambient Pressure Drying method. The removal of CO₂ in biogas using 20 g of adsorbent chitosan coated silica aerogel. The experimental adsorption kinetics analyzed by both pseudo first and second order kinetics model.

Results: impurities in geothermal silica need to be purified and it can be synthesized into silica aerogel. The remaining geothermal can act as adsorbents to silica aerogel coated with chitosan by using packed column. The data obtained is kinetic data gained from the pseudo first and second order method. This shows that silica from solid geothermal waste has the potential as CO₂ adsorbent.

Applications/Originality/Value: It is confirmed that silica from solid geothermal waste can be used as CO₂ adsorbent. Therefore, the improvement of innovation in the future of this research is to prepare chitosan coated silica aerogel as CO₂ adsorbent.

Introduction

The availability of oil and gas in Indonesia is getting lower (BPPT, 2017). It is predicted that in 2025 - 2050 Indonesia will become an importer of oil and natural gas (BPPT, 2017). Nowadays, diversification of renewable energy has been strived, such as bioethanol (Melikoglu & Turkmen, 2019), biodiesel (Gozmen Şanlı, Uludamar, & Özcanlı, 2019), and biogas (Khalil, Berawi, Heryanto, & Rizalie, 2019). However, the process of utilizing these fuels still has limitations in the refining process. Both in terms of separation efficiency and costs used, especially for the use of biogas.

Biogas produced from biomass fermentation has been widely used. However, the biogas calorific value is still below the standard (Al Mamun & Torii, 2017) and the carbon dioxide (CO₂) gas content in biogas is still 25-45% so that it can cause corrosion (Kusrini et al., 2017). In addition to reducing the calorific value, the presence of CO₂ gas also makes the biogas operation process uneconomical. Therefore the process of purifying biogas from CO₂ must be carried out to increase and maximize the use of biogas.

Several processes have been developed for biogas purification to achieve high biogas calorific values, such as absorption process using amine solvent (Hairul, Shariff, & Bustam, 2017), membranes (Kusworo, Qudratun, Utomo, Ramadhan, & Indriyanti, 2018), and adsorption using zeolites (Chen et al., 2017). The weaknesses of these processes are that they require high energy, expensive costs for the regeneration process, low adsorption capacity, and are corrosive (Kong, Shen, Cui, & Fan, 2015).

To cover up the existing process, research has been developed on polyethyleneimine (PEI) which has been synthesized and shows largest CO₂ adsorption capacity of 93.4 mg CO₂/g adsorbent at 1 atm pressure & 25-100°C temperature. However, aminated silica synthesis implicates toxic 3-aminopropyltriethoxycylate reagents that can damage human mucous membranes and respiratory tracts, and toluene usage as solvent in an amount 100 times the dissolved silica mass. Exaggerated use of aromatic solvents and toxic reagents have to be evaded (Zhang et al., 2007). Several studies have covered this weakness by replacing amine compounds with chitosan.

The use of chitosan as an adsorbent has been widely researched, one of which is Sneddon et al. (2015) which has coated chitosan into silica gel and has reached an adsorption capacity of 123 m²g⁻¹ with chitosan composites of 19% w. Nevertheless, the low capacity is related to silica gel's surface area, which is only 186m²g⁻¹, too low for notable adsorption. To maximize chitosan's potential as CO₂ adsorbent, a much higher amount of supporting material is needed. Therefore, adsorbents such as silica aerogel can be used to overcome difficulties in terms of biogas purification, non-toxic, easily regenerated, and have higher porosity.

Silica aerogel is material with a high specific surface area, high porosity, low density, and easily regenerated (de Fátima Júlio, Soares, Ilharco, Flores-Colen, & de Brito, 2016). In the study of Feng et al. (2018), silica aerogel has a surface area of 945.8m²g⁻¹ so it has potential to be an adsorbent for effective purification of CO₂ in biogas. However, the application of silica aerogel as an adsorbent for biogas purification is limited due to the high cost of manufacture so it is necessary to modify the porosity to maximize the use of silica aerogel.

Porosity is an important property for adsorbent. Distribution of pore size, surface area and pore volume can involve the dimensions and interactions of surface and gas. Therefore, porosity can play an important role in gas mixture separation (Yi et al., 2015). Modification of silica aerogel porosity has been carried out using 1N HCl volume variation and Cetyl

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trimethylammonium bromide (CTAB) surfactant to produce mesoporous silica aerogel with porosity of 12 nm and 2.9 nm (Lee et al., 2017; Vazquez, Gonzalez, Ferrari, & Castro, 2017). Silica aerogel's porosity can be engineered so silica aerogel can be more selective when it functions as adsorbent.

Thus, the innovation of this research is the development of chitosan coated silica aerogel adsorbent as an CO₂ purification adsorbent in biogas. Different from previous studies, chitosan coated silica aerogel has high selectivity, good thermal stability, and is easily regenerated. This is expected to increase the kinetics of adsorption on CO₂ so it can be used to reduce the level of CO₂ gas in biogas. In addition, with the modification of porosity and high surface area in silica aerogel coated with chitosan, the capacity to capture CO₂ will increase. This study also utilizes silica aerogel material made from silica from geothermal solid waste in Dieng. Geothermal silica as an effort to create products that have high economic value to waste utilization. It is expected that the coating of chitosan with silica aerogel and modified porosity with HCl can produce sustainable adsorbent for the purification of CO₂ in biogas that is effective, energy efficient, easily regenerated, and preserves the environment.

The purposes of this research are to study the synthesis of chitosan coated silica aerogel made from solid geothermal waste in Dieng as adsorbent for separating CO₂ and CH₄, and to study CO₂ adsorption kinetics on chitosan coated silica aerogel by Pseudo First Order and Pseudo Second Order methods.

Material and Methods

1. Material

Geothermal solid waste from Dieng, Sulfuric Acid (H₂SO₄) p.a Merck, Sodium Hydroxide (NaOH) p.a Merck, Hydrochloric Acid (HCl) p.a Merck, n-Hexane p.a Merck, Chitosan CV Nura Jaya, Methane (CH₄), Carbon Dioxide (CO₂), IPA p.a Merck, and Aquadest.

2. Method

Adsorbent preparation

First, Silica Purification and Washing. Dieng geothermal silica sample was dried at 110°C for 24 hours, followed by leaching process for 1 hour 45 minutes at 100°C with a ratio of silica and H₂SO₄ 20% 1: 5 w/v. This was done to remove organic impurities and metals in Dieng geothermal silica. Second, washing geothermal silica solution using aquadest to pH 7. Drying of sample is carried out at a temperature of 105°C to a constant weight using a vacuum oven to purify silica powder. To make soles, 10 grams of fine granules from geothermal silica were extracted in 100 ml of NaOH 6N for 1 hour under 98°C heating. Then the mixture is cooled down to 30°C. Samples were filtered using filter paper (whatman 41), the results of this filter in the form of residues namely solid impurity and filtrate in the form of sodium silicate (Na₂O.SiO₂). To form gelation, The filtrate that has been obtained is cooled to room temperature and stirred with magnetic stirrer for 30 minutes. The filtrate was titrated with HCl 1N to pH 7 to produce silica gel. The gel is aged for 18 hours at room temperature, then filtered. Then, chitosan was added with silica and chitosan ratio of 1.3: 10, 1.5: 10, 1.9: 10, 2.2: 10, and 2.4: 10 w/v (Sneddon, Ganin, & Yiu, 2015). Samples were washed with distilled water for 5 times and IPA (60 ml) was added to silica sol to form hydrogel and gelled for 10 seconds. After the formation of hydrogels, the addition of n-hexane is carried out to occur the solvent exchange process. This is done for surface modification of the hydrogel with the ratio of hydrogel and n-hexane 0.75 from a base of 60 ml water glass. Then continued with aging for 3-5 hours (Lee et al., 2017). A mixture of solutions containing silane and solvent agents. The gel is dried by Ambient Pressure Drying method to evaporate the liquid in a vacuum oven at a temperature of 70°C for 1 hour and 150°C for 1 hour until dry to evaporate the liquid to produce chitosan coated silica aerogel (Lee et al., 2017).

Adsorbent Test

The chitosan coated silica aerogel was measured by weight before being put into the column. After that, put in 20 gram chitosan coated silica to packed column. Then, the flow of methane and carbon dioxide gas each flowed at a rate of 600ml/min. Then the gas that has been mixed is regulated its flow velocity with variations of 100 and 500 ml/min seen through a flow meter. The gas mixture is flowed into the adsorption column containing chitosan coated silica aerogel as an adsorbent of CO₂. After the gas is flowed, the chitosan coated silica aerogel is measured by weight until there is no change in the weight of chitosan coated silica aerogel and the equilibrium time is obtained. This shows that the adsorption has reached saturation so that the adsorption equilibrium time is obtained (Kusrini et al., 2017).

Analysis of CO₂ Adsorption Kinetics

Pseudo first and second order models can be utilized to evaluate the kinetics of gas adsorption on silica aerogel (Loganathan et al., 2014).

A. Pseudo first order

Based on equation (1), q_t (mmol/g) and q_e (mmol/g) indicate the amount of the adsorbed CO₂. q_e can be obtained when the equilibrium of the weight of silica aerogel after CO₂ gas flowed under conditions of constant temperature and pressure. Whereas q_t is obtained when silica aerogel absorbs CO₂ gas at a certain time by measuring its weight. Weight difference (ΔW) will get the value of q_e and q_t . k_f (s⁻¹) indicates first order constants (Loganathan, et al., 2014)

$$\frac{dq}{dt} = k_f(q_e - q_t) \quad (1)$$

To get the k_f value, boundary condition (namely $t=0, q_t=0$, and $t=t_e, q_t=q_e$) is integrated to equation (1), so k_f is obtained (Ghrab et al., 2017).

$$q_t = q_e(1 - e^{-k_f t}) \quad (2)$$

B. Pseudo second order

The pseudo-second order model is based on the hypothesis that the rate of adsorption is related to the square of the number of vacant adsorption sites linearly (Kamal et al., 2017), therefore the rate of kinetic can be showed as:

$$\frac{dq_t}{dt} = k_s(q_e - q_t)^2 \quad (3)$$

q_e can be obtained when the equilibrium of the weight of silica aerogel after CO_2 gas flowed under conditions of constant temperature and pressure. Whereas q_t is obtained when silica aerogel absorbs CO_2 gas at certain time by measuring its weight. Weight difference (ΔW) will get the value q_e and q_t . The value of k_s ($\text{g mmol}^{-1} \text{s}^{-1}$) is the constant of second order rate. To get k_s value by applying and integrating the boundary conditions $t=0, q_t=0$, and $t=t_e, q_t=q_e$ in equation (3) turns into:

$$q_t = \frac{q_e^2 k_s t}{1 + q_e k_s t} \quad (4)$$

The values of k_s for all analyzed temperature and pressure conditions are gained from equation (4).

An error function from the assigned standard deviation is determined by a method expressed in the literature to assume the exactness of the fit of the kinetic models (Loganathan et al., 2014),

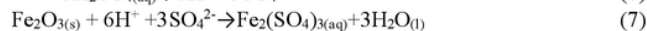
$$\Delta q (\%) = \sqrt{\frac{\sum[(q_{\text{exp}} - q_{\text{model}})/q_{\text{model}}]^2}{N-1}} \times 100\% \quad (5)$$

Δq (%) is the defined standard deviation, q_{exp} & q_{model} are the calculated and experimental number of the adsorbed CO_2 , and number of available data points in each isotherm is described as N (Loganathan et al., 2014).

Result and Discussion

3.1. Preparation of Silica Purification

Silica waste geothermal has a high metal oxide content as can be seen in Fig. 1. This must be removed because it will decrease the quality of pure silica and reduce the metal impurity content. One of the standard specifications required in Na_2SiO_4 is to contain silica of approximately 97% (Ranawat, 2000). Purification of metal oxide particles contained in geothermal silica can be reduced using acid solution (Anas Boussaa, Kheloufi, Boutarek Zaourar, & Bouachma, 2017; Purnomo, Dalanta, Oktaviani, & Silviana, 2018). Research using silica purification with acid has been investigated (Boussaa et al., 2017). The purification of geothermal silica using H_2SO_4 solution can be seen in Fig. 1, the results showed that the optimum silica product was produced from purification using 20% v/v H_2SO_4 with silica content of 98.2% in table 1. The reaction between H_2SO_4 and metal oxide caused damage to ionic bonds in metal compounds with oxygen. SiO_4^{2-} ions are highly reactive to metals, especially alkali metals and from transition groups such as Fe, Ni, Cu, Pb and others. These ions will bind the impurities found in the sample to form sulfate salts from metals. SO_4^{2-} ions bind to metal compounds to form sulfate metal compounds when the H^+ ion bonds with oxygen to produce H_2O compounds. The characteristics of these two ions are interrelated so that they can reduce the metal content in silica. (Fraenkel, 2015). The reactions that occur in metal oxides can be seen in these following equations:



Silica produced with purification using H_2SO_4 20% has silica content of 98.2%. Impurity compounds and metal oxides are very low with Mn, Fe, and Ca levels respectively 0.066, 0.531, 0.95%. This shows that silica from geothermal solid waste can be synthesized to be developed as a material for making silica adsorbent.

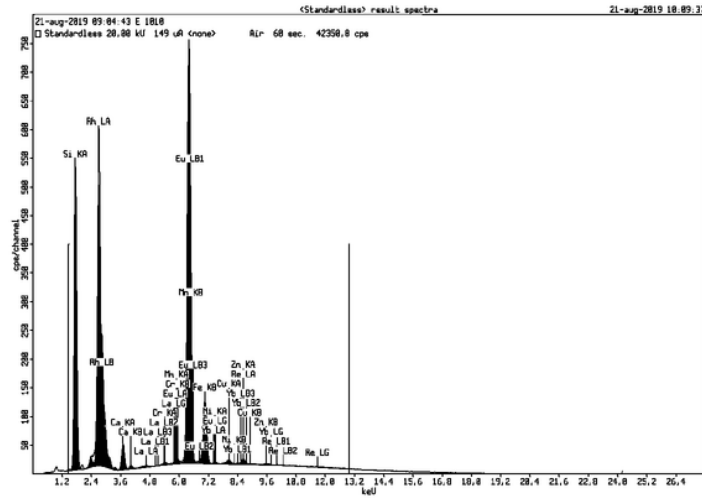


Fig. 1. XRF spectra of geothermal silica prior to leaching process

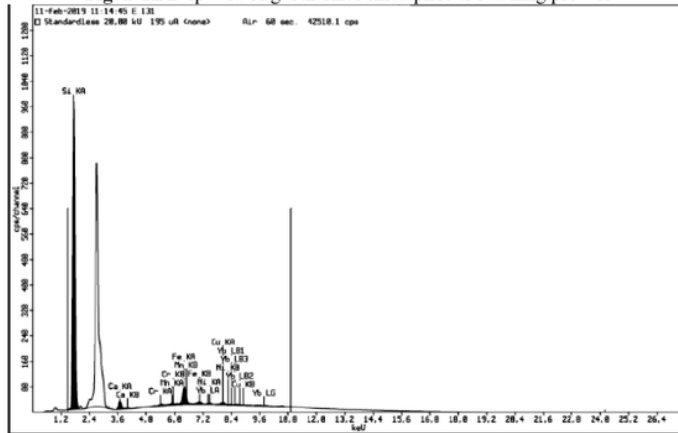


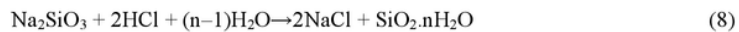
Fig. 2. XRF spectra of geothermal silica post to leaching process

Table 1. XRF Analysis of Scaling Silica

Element	Before Purification (%)	After Purification (%)
Si	86.9	98.2
Mn	0.11	0.066
Fe	10.2	0.531
Ca	1.96	0.95

3.2. Silica Aerogel Synthesis

The schematic diagram of silica aerogel preparation is shown in Fig. 3. Synthesis of silica aerogel ensued through the sol-gel stage where contact between silica and NaOH formed a solution of Na_2SiO_3 precursor replacing the Si-OH silanol group into Si-ONa ionic bonds. In this manner, Na_2SiO_3 dissolved in water and later subjected to hydrolysis to transform into silicic acid $\text{Si}(\text{OH})_4$ through the addition of HCl. The polycondensation of $\text{Si}(\text{OH})_4$ caused the formation of colloidal spherical silica with hydroxyl groups. Then, silica hydrogel bonding siloxane (Si-O-Si) groups was formed by inducing polycondensation by adding IPA. After washing and drying at atmospheric pressure, silica aerogel was obtained as the final product. Several studies have succeeded in synthesizing aerogel under atmospheric conditions (Feng et al., 2018; Lee et al., 2017). Therefore ambient pressure drying conditions can be used to produce silica aerogel. The research that has been done obtained surface area and pore volume respectively $819 \text{ m}^2/\text{g}$, 12.00 nm and $945.8 \text{ m}^2/\text{g}$, 3.8 nm (Feng et al., 2018; Lee et al., 2017).



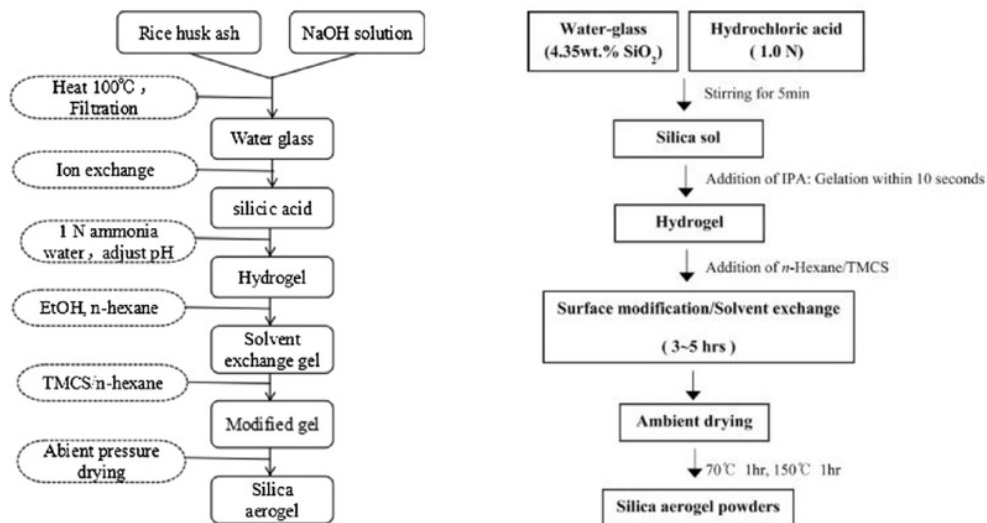


Fig. 3. Flowchart for synthesis of water glass to silica aerogel (Feng et al., 2018; Lee et al., 2017)

3.3. Adsorbent column preparation for biogas purified

Fig. 4. shows an experimental schematic for CO₂ purification with a fixed-bed two columns (Kusrini et al., 2017). The size of the fixed-bed column adsorption is 15 cm in length and 0.8 cm in diameter. Biogas is used from the Palm Oil Mill Effluent (POME). This research uses zeolite (2M) adsorbent coated with 2.5 g chitosan. The formula is shown in table 1. Surface areas are 39.06 and 8.25 m²/g. While the average adsorption capacity is 8.5 nm. The results obtained are zeolite (2M) coated with chitosan that can absorb ~ 83% CO₂ adsorption. This shows that the amine group contained in chitosan is capable in binding CO₂ from biogas from POME.

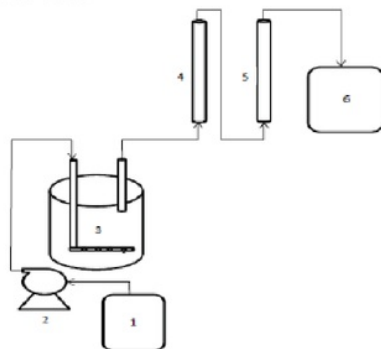


Fig. 4. Schematic process for purification of biogas with zeolite/chitosan (Kusrini et al., 2017)

Table 2. Elemental analysis of zeolite coated chitosan (Kusrini et al., 2017)

Element	%weight composition
C	4.23
O	50.68
Na	2.41
Al	6.93
Si	30.94
K	1.85
Ca	1.24
Fe	1.71
Si/Al Ratio	4.31

According to (Kusrini et al., 2017; Lee et al., 2017), the required silica weigh are 30.94% wt and 4.35% wt. Whereas the geothermal solid waste silica shows a relatively high Si content of 98.2% as shown in Figure 5. This shows that geothermal solid waste has the potential to be developed as a source of silica as a material for making CO₂ adsorbent.

Therefore, the next innovation is to use silica sources from geothermal waste. Adsorbent used is chitosan coated to silica aerogel. The schematic process for further research is shown in Fig. 5. The height of the packed column adsorption with the length is 15 cm and the diameter is 5 cm. The biogas used is artificial biogas.

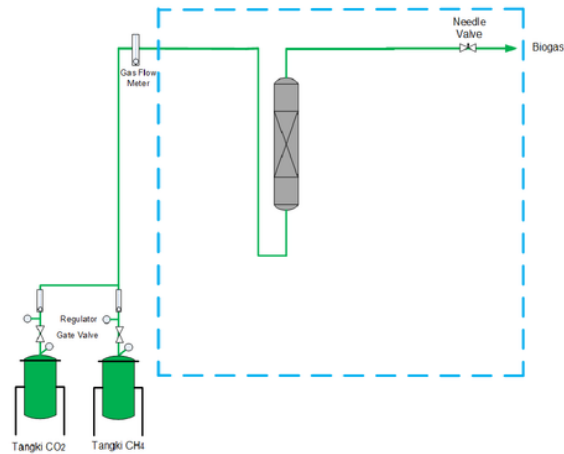


Fig. 5. Proposed schematic process for purification biogas with silica aerogel coating chitosan

3.4. Response data of kinetics study

The gas adsorption kinetics in silica aerogel can be calculated by the pseudo first and second order (Loganathan et al., 2014).

A. Pseudo First Order

The Calculation of adsorption kinetics with equations (9):

$$2 \quad \frac{dq}{dt} = k_f(q_e - q_t) \quad (9)$$

q_e (mmol/g) and q_t (mmol/g) represent the number of the adsorbed CO_2 . q_e can be obtained when the equilibrium of the weight of silica aerogel after CO_2 gas flowed under conditions of constant temperature and pressure after silica aerogel adsorbing CO_2 gas at a certain time. k_f (s^{-1}) indicates the constant of first order (Loganathan et al., 2014). After equation (9) is integrated with boundary conditions ($t=0$, $q_t=0$, $t=t\infty$, and $q_t=q_e$), equation (10) is gained.

$$q_t = q_e(1 - e^{-k_f t}) \quad (10)$$

The value of k_f for adsorption of CO_2 on silica aerogel under various temperature and pressure is obtained from equation (10) (Loganathan et al., 2014).

B. Pseudo second order

Adsorption kinetic rate can be showed as equation (11) :

$$\frac{dq_t}{dt} = k_s(q_e - q_t)^2 \quad (11)$$

The value of q_e and q_t will be determined by weight difference (ΔW). k_s ($\text{g mmol}^{-1} \text{s}^{-1}$) indicates the constant of second order rate. After equation (11) is integrated with boundary conditions ($t=0$, $q_t=0$, $t=t\infty$, and $q_t=q_e$), equation (12) is gained.

$$q_t = \frac{q_e^2 k_s t}{1 + q_e k_s t} \quad (12)$$

the values of k_s for entire evaluated temperature and pressure conditions are gained based on equation (12) (Loganathan et al., 2014).

Conclusions

The content of geothermal silica waste still contains a lot of impurities, it needs to be purified and it can be synthesized into silica aerogel. The remaining geothermal can act as adsorbents to silica aerogel coated with chitosan by using packed column. The data obtained is the equation of kinetic data from the differences in the weight of silica that has adsorbed CO_2 . This shows that silica from geothermal waste has the potential as a CO_2 capture. Therefore, the improvement of innovation in the future of this research is to prepare chitosan coated silica aerogel to adsorbent .

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