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Synthesis of Silica Gel From Rice Husk Ash for Sustainable Air Conditioning Requirements

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Abstract. An increase in air conditioning demand, driven by global warming and the need for comfort, highlights the importance of energy-efficient systems like desiccant cooling. This research explores using rice husk ash (RHA), an agricultural waste product from Indonesia, to synthesize silica gel for these systems. The study involved synthesizing silica gel from RHA through chemical processes and comparing its sorption capacity to commercial silica gel. Two synthesis methods were tested: a direct reaction of water glass with acid compounds and an impregnation process on honeycomb walls. The results indicate that the direct reaction method produces a silica gel with better pore performance. Ultimately, the study found that RHA from West Java, Indonesia, is a viable raw material for desiccant air conditioning, although its sorption capacity is slightly lower than that of commercial silica gel. This offers a valuable use for agricultural waste.

Keywords: desiccant, rice husk ash, silica gel, adsorption, air conditioning, Sustainable /Renewable

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1. Introduction

Today, the demand for air conditioning (AC) is elevated throughout the world, especially in tropical countries. This issue is mainly caused by two main reasons – the fact of problems in global warming, producing larger cooling loads for the same periods and increasing demand for convenience.

Recent studies of statistical method results estimate that high-quality energy (primary energy) consumed generally for air conditioning, either commercial or domestic, is around 45% of total building energy consumption [1]. A typical example is the Middle East, where AC contributes to 70% of building energy consumption [2].

To lower this energy consumption and reduce the greenhouse effect, alternative methods are required to provide convenient thermal conditions and better room air quality. This alternative system also lowers the consumption of fossil energy, for the most part, through utilisation of some renewable energies – sun, geothermal and low-quality energy [3].

Based on these backgrounds, it is suitable to choose an evaporative air conditioning and desiccant cooling system [4]. The desiccant in this research was selected silica gel that synthesises from RHA. Indonesia was one of the largest rice producers in the world in 2023. Production estimates reach 53.63 million tonnes for milled dry grai [5], and around 22.73 tonnes of rice husks (RH) are agricultural by-products. Rice husk RH can be used as an alternative renewable energy fuel [6]. Burning RH as fuel produces heat energy and rice husk ash (RHA), ranging from 14–15% [7].

All this time, the utilisation of RHA is limited to supplementary fertilizer and rubbing ash. Even in most cases, it becomes waste that produces soil pollution. In this research, it is expected that synthesising RHA into an inexpensive desiccant could improve the by-product benefits of rice production.

The silica gel that will be used as the base material for the honeycomb corrugated paperboard adsorbent wheel is the RHA silica gel that has been extracted. So that the RHA silica gel can stick well to the honeycomb walls, the RHA water glass and an acid compound are impregnated into the honeycomb walls. How to make a desiccant wheel from a corrugated board and the impregnation process is based on references [8]. The basic honeycomb material chosen was WPFP [9], which is in the form of one-sided corrugated cardboard. The process of forming silica gel occurs on honeycomb walls due to the chemical reaction of water glass with acid compounds during impregnation.

Silica gel was first used as the desiccant in the cooling engine in 1920 by EB Miller. However, due to the rapid growth of compressible steam engine research at that time, the development of chiller adsorption engines continued around 1970 [10]. Ng et al. [11]investigated the characteristics of silica gel types A, 3A and RD. This concluded that silica gel types 3A and RD are better options as adsorbent chillers. With regeneration temperatures of 70°C and 90°C, type A could be much lower. Narayanan et al. [12] performed mathematical modelling of silica gel adsorption characteristics and several types of solid desiccants. They concluded that silica gel had the highest absorptivity and the highest relative humidity. Chih-Hao Chen et al. [13] performed research on the production of composite polymer desiccants by combining silica gel with polyacrylate acid and sodium polyacrylate. The results yield that produced a composite polymer desiccant could increase the adsorption capacity 41% higher compared to pure silica gel.

Progress in the development of desiccant materials for air conditioning is currently growing rapidly. Many pure desiccant materials have been replaced with composite materials and polymers due to their advantages. As an example, silica-based composite desiccant SG/LiCl have the adsorption capacity 2–3 times compared to pure silica gel desiccant at high relative humidity. The development of desiccant materials for the latest air conditioning and its characteristics can be seen in the references [14]. Until now, silica gel has been produced from mining quartz sand, which damages the ecosystem and requires considerable energy and escalating global warming. The process uses a conventional method by melting quartz sand with sodium carbon at temperatures 1000oC and 1060°C [15], [16], [17], [18]. Using RHA as silica gel raw material for air conditioning may reduce the greenhouse effect, using renewable energy and increasing the use value of RHA from agricultural products.

2. Methods

2.1 Material

The RHA sample was obtained from Sumedang, West Java. Commercial waterglass, HCL and NaOH were obtained from the Bratachem Chemical Store in Bandung. The experiments were performed at the Chemical Laboratory of Universitas Pasundan Food Technology in Bandung.

The available laboratory equipment was a 250 ml beaker glass, 500 ml Erlenmeyer flask, reflux apparatus (electrothermal), drop pipettes, funnels, Whatman filter paper no. 41, measuring pipettes, plastic mesh strainer, ceramic mortar, pH indicator strips, desiccator (Normax glassware), ceramic cup, thermometer, modified filter apparatus, electronic scale (Mettler Toledo PL202-S, analytical balance uncertainty ±0.5 %), electric oven (Memmert) and electric furnace.

1.1.1 Sodium Silicate Preparation

Synthesis of silica gel was performed based on Kalapathy's method [19], [20]. RHA was calcinated using a slow burning process without the addition of fuel and using an operating temperature of 400–500°C. RHA that contained charcoal were then recalcinated in the furnace at a temperature of 600°C for 4 hours. The obtained RHA were then smoothed, sifted and measured 10 gr for each sample of producing sodium silicate. Samples of RHA were then combined with 300 ml NaOH 2N and heated in a reflux apparatus at 85°C for 4 hours. After 4 hours, the reflux apparatus was then turned off and the solution of RHA and NaOH cooled for 1 hour. The result of this reflux process contains brown sediment, which is a carbon residue and is then filtered with Whatman paper number 41.

2.1.2. Silica Gel Synthesis

In this phase, silica gel was formed by the titration process of liquid sodium silicate with liquid HCL. After forming, the gel went through the ageing process, and then the formed silica gel was washed and dried to the desired silica gel. The purpose of sodium silicate titration with HCL was to form hydrogel, which then underwent the ageing process until the structure was firm. The hydrogels formed were then washed to purify the silica gel from impurities and contaminants in the form of salts and other minerals, and the drying stage aimed to remove water from the silica gel.

2.2 Performance testing and testing of silica gel characteristics

The performance parameters and characteristics of bulk silica gel as the chosen desiccant were adsorption capacity, pore parameters (specific surface area, pore volume, pore size and pore size distribution) and adsorption/desorption performance. The higher the sorption capacity of silica gel, the better it was used as a base material for desiccant wheels or desiccant silica beds [21].

The sorption capacity measured was silica gel resulting from the reaction of water glass and acid compounds with pH variations. Sorption capacity used two test samples – silica gel water glass from RHA and commercial water glass – as a comparison. This test aimed to determine the pH of the chemical reaction of water glass and acid compounds, which produced the highest sorption capacity. The pH of the chemical reaction with the highest sorption capacity was used to make silica gel for desiccant wheels and then to carry out characterization tests.

3. Results and Discussion

3.1 Performance of silica gel

The test was carried out using the air oven method [22]; five samples were prepared to test air humidity adsorption. The test was performed until the silica gel samples reached saturated conditions because the mass of water absorbed no longer increased. The adsorption ability of these samples could be seen from the mass of water absorbed after the silica gel sample was tested. This testing used a desiccator in which 50 ml of distilled water was placed. Five test samples were heated in the oven and then placed inside the desiccator. The adsorption capacity of silica gel to adsorb air humidity could be measured from the mass of absorbed water per gram of silica gel using the following formula:

$$Silica \quad Gel \quad Adsorptivity(\%) = \left[\frac{adsorbed \quad water \quad mass}{silica \quad gel \quad mass}\right] x100\% \qquad (1)$$

Table 1 shows the results of the adsorption capacity of RHA silica gel and commercially made silica gel with waterglass titration with hydrochloric acid having varied pH levels. pH affects the adsorptivity of the silica gel produced. Silica gel that came from RHA had the maximum adsorptivity at pH 12, while silica gel made from commercial waterglass had the maximum adsorption capacity at pH 3. The characteristic adsorptivity of silica gel with a function of pH level can be observed in Figure 1.

Table 1 Data from the test results of the adsorption capacity of silica gel RHA and silica gel from commercial sodium silicate.

	RHA silica gel				**Commercial water glasses silica gel**			
pH	Dried mass – 24 hour oven at 100°C (gr)	Mass after 24 hour at desiccator (gr)	Adsorbed water mass (gr)	Silica gel adsorption percentage - RHA	Dried mass – 24 hour oven at 100°C (gr)	Mass after 24 hour at desiccator (gr)	Adsorbed water (gr)	Silica gel adsorption percentage – commercial waterglass
3	1,11	1,19	0,08	7,21%	0,83	1,01	0,18	21,69%
5	1,03	1,1	0,07	6,80%	1,14	1,27	0,13	11,40%
7	0,94	1,01	0,07	7,45%	1,75	1,91	0,16	9,14%
8	1,09	1,14	0,05	4,59%	0,85	0,96	0,11	12,94%
12	0,49	0,54	0,05	10,20%	0,81	0,94	0,13	16,05%

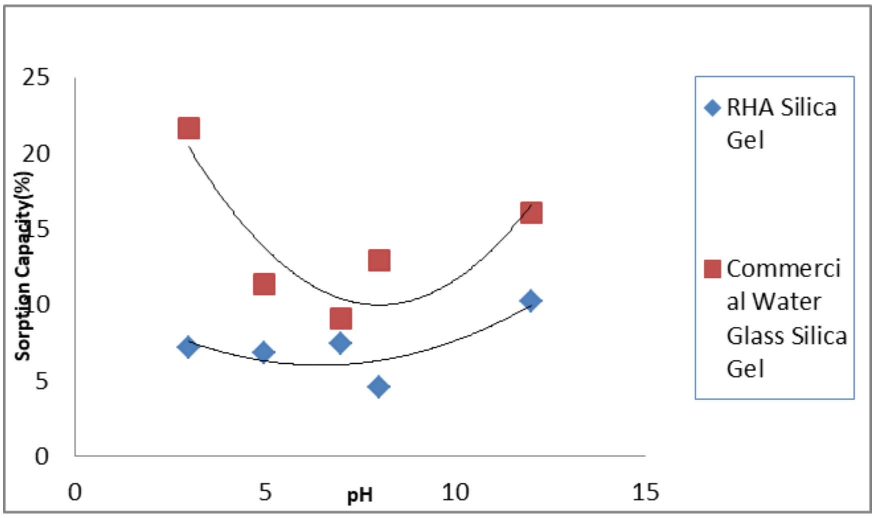

Figure 1. Trendline comparison graph of silica gel sorption capacity to pH function

3.2 Characteristics of Silica Gel

Pore parameters and adsorption/desorption performance were characterised using N_2 adsorption media at 77 K, the Quantachrome Nova version 11.0 gas adsorption instrument, at the ITB Chemical Engineering Laboratory. From this test, the pore characteristics of the husk ash silica gel were obtained, which was the initial data in the design of the desiccant wheel or silica bed desiccant. Silica gel test specimens for testing pore parameters and adsorption/desorption isotherm performance did not need to be activated [23] because silica gel undergoes a cleaning process in which it changes into sodium silicate.

The measurement results are presented in Table 2 and Figure 3.4. This parameter was calculated in the unit mass of all desiccant samples. The surface area and other pore parameters are listed in Table 2.

3.2.1 Pore surface area, pore volume and pore diameter

Based on Table 2, it can be seen that husk ash silica gel has a larger surface area compared to RHA-honeycomb silica gel. Because of the RHA silica gel, the chemical reaction of the water glass with acid compounds was perfect compared to the RHA-honeycomb silica gel. In this way, the volume and pore diameter of the RHA silica gel were greater than those of the RHA-honeycomb silica gel.

Table 2 Results of surface area, pore volume and pore size of testing samples.

Rice hull silica gel	**Surface Area (m^2g^{-1})**	**Pore Volume (cm^3g^{-1})**	**Average Pore Size (nm)**
Rice hull silica gel	130.65	0.26	6.3
Rice hull silica gel–WPFP honey comb	72.76	0.16	6.9

3.2.2 Pore size distribution

Based on Figure 2, it can be seen that RHA silica gel has one highest peak, so the largest diameter in the silica gel pores is 6.9 nm with a total volume of 0.31 cc/g, while RHA-honey comb silica gel has several peaks. The largest diameter in silica particles was 5.8 nm, with a total volume of 0.157 cc/g, and 8 nm, with a total volume of 0.16 cc/g. Thus, the silica gel produced belongs to a group of porous nanomaterials whose function is greater than that of the dehumidification process [24].

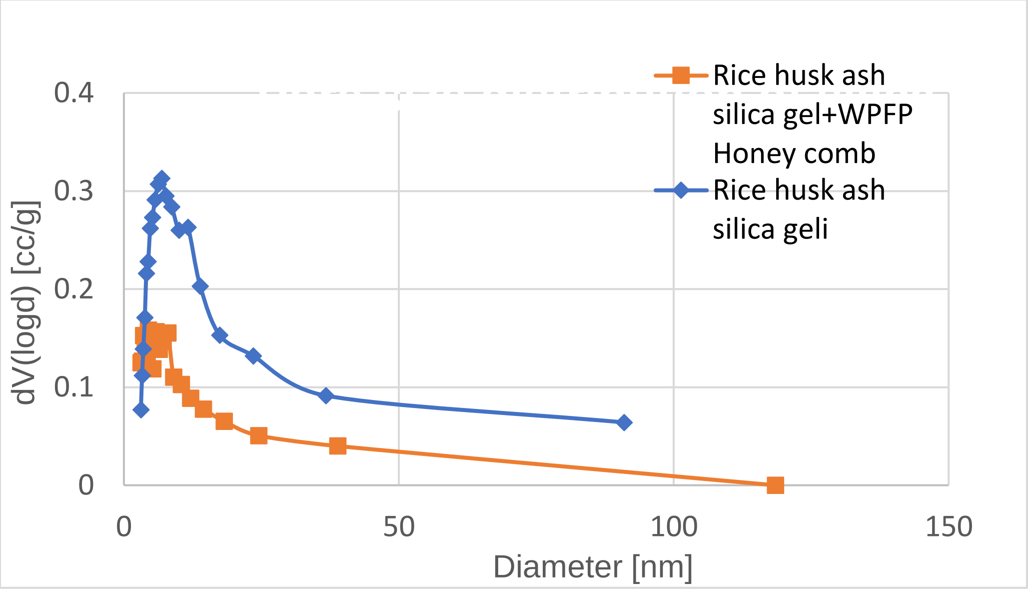

Figure 2. Pore size distribution of silica gel

3.2.3 Adsorption and desorption performance test

Looking at Figure 3, it can be concluded that the curve is included in the IUPAC 2015 [25] standard classification IV and type 2 hysteresis curve. Both curves have the same trend; only the silica gel–honeycomb curve is steeper than the silica gel–honeycomb curve. The ability of an ordinary adsorbent silica gel to absorb water vapour was much higher than that of an adsorbent silica gel-honeycomb. This was because the adsorption/desorption ability of silica gel-honeycomb is low because not all sodium silicate reacts with acid compounds. The silica gel that is formed is only on the surface of the honeycomb wall. Unlike the silica gel formed in the Erlenmeyer flask, the silica gel synthesis process is, according to standard procedures, to make silica gel from sodium silicate RHA and acid compounds.

Figure 3 also shows that there is no micropore filling because the silica gel formed only has mesopores and macropores. Pore filling starts with a single layer of mesopores from a relative pressure of ± 0.03– ± 0.18 followed by multi-layer filling until a relative pressure of ± 1.

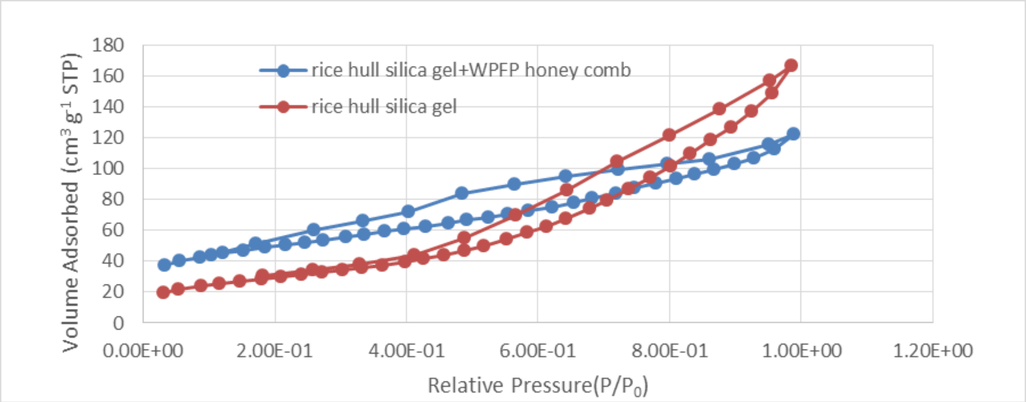

Figure 3 N_2 adsorption isotherms curves

4. Conclusions

The experimental results showed that the overall adsorption capacity of silica gel from commercial water glass performed better compared to silica gel made from RHA water glass. The performance of silica gel based on pore parameters shows that silica gel resulting from the reaction of water glass and acid compounds is directly better than silica gel resulting from the impregnation of water glass and acid compounds.

The maximum adsorption capacity of commercial water glass is 21.7% at polymerisation pH 3. The maximum adsorption capacity of silica gel from RHA water glass is 16.1% at polymerisation pH 12, and rice husk ash from Sumedang Bandung rice fields can be used as a raw material for making a renewable energy AC desiccant.

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