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Sugarcane *(Saccharum Officinarum)* Bagasse Ash Silica Aerogel as Potential Thermal Insulator: An Alternative Material for Construction Industry

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Abstract: **This study explores the extraction of silica from sugarcane (Saccharum Officinarum) bagasse, converted into ash, to synthesize an organic aerogel with promising thermal insulation properties. The aerogel samples were subjected to hygrometric tests, with the results confirming the efficiency of silica-rich sugarcane bagasse ash in producing aerogels capable of functioning as effective thermal insulators. The findings highlight the potential of sugarcane bagasse ash (SCBA)-derived aerogels as a sustainable alternative to synthetic thermal insulators. With potential applications in industries such as construction, these aerogels offer a viable solution for improving energy efficiency and reducing heat transfer in various environments.**

Keywords: **Silica Aerogel, Sugarcane Bagasse (SCB), Sugarcane Bagasse Ash (SCBA), Saccharum Officinarum, Sodium Silicate Solution, Organic Insulator, Insulator, Construction.**

I. INTRODUCTION

As population density increases and also the climate change on Earth, rising temperatures are to be expected. In the study of Sander et al., (2018), air-conditioning use at home relieved heat stress mostly for people in low density areas but not where the population density was high. Showing increase of heat in urban places. Additionally, temperatures on the Earth's surface have risen, facing a larger risk of indoor overheating (Vardoulakis et al., 2015). For this reason, thermal insulators are one of the solutions for these problems, where high levels of proper insulation can increase thermal comfort even under heat waves (Calama-González et al., 2023).

To conserve energy and minimize green gas emissions, the demand for free natural organic building materials is rising, especially insulating materials from renewable resources. The application of natural materials has been increasingly important. Bio-based insulation materials can provide good performance just like normal thermal insulators (Cosentino et al., 2023). One of the organic materials possible in making insulation is the sugarcane bagasse waste through the making of silica aerogel. As waste, sugarcane bagasse can still be used as something useful and greatly benefits everyone. Bagasse is the fiber of sugarcanes after the extraction of its sap. It originally meant trash, leftovers, and rubbish. However, the components of nutrients made it useful for various uses such as biofuels, ethanol, cellulosic ethanol, and raw materials. Through systematic processes, it is possible to change waste just like sugarcane bagasse into an important and valuable material especially nowadays, such as thermal insulators.

Sugarcane bagasse is possible to become an organic insulator through making of silica aerogel. Aerogels are an uncommon group of nanoporous materials with properties that differ from other materials. It was founded by S. Kistler, from the College of the Pacific in Stockton, California, in the early 1930's. Any material that was taken from organic, inorganic, or hybrid molecular precursors that are generally put together by sol-gel processing and proper drying technology with three-dimensional and extremely permeable network is preserved generally refers to Aerogels (Maleki & Husing, 2016). Sol-gel processing refers to a coating technique that uses the change from a liquid solution with suspended particles to a gel that resembles a solid. It is a method of creating ceramic materials that involves specifically in this study making a sol, letting it gelatinate, and then draining the solvent. Sol are colloidal particles dispersed within a solution (Lin & Deng, 1999).

Sugarcane bagasse has a high silica content as the sugarcane bagasse turned into ash (Megawati et al., 2018), sugarcane bagasse ash has high silica content of 53.1% w/w. Wherein, silica is one of the main components for making silica aerogel, which is famous among other organic aerogels. Silica aerogels are shown to have low thermal conductivity (0.005-0.1W/(mK)) which is good in the making of thermal insulators (Ahmad et al., 2023).

II. MATERIALS AND METHOD

A. Preparation and Collection of Materials

The material is mainly Sugarcane *Saccharum Officinarum* Bagasse. Bagasse is the fibrous sugarcane leftover stalks that are crushed for juice extraction. It is used as a sustainable natural fiber in the production of composite materials (Faruk et al., 2013). The researchers collected the sugarcane bagasse (SCB) from sugarcane juice vendors located in Tubo Juice Stand in NCCC Victoria Plaza, Davao City, Philippines Additionally, other materials are acquired and can only be accessed within a lab, which is located in Davao Medical School Foundation Inc., Davao City, Philippines.

The researchers collected a total of 4.7 kg of Sugarcane Bagasse (SCB). It was separated per kilo inside a trash bag, to organize and prepare it for experimentation.

Figure 1: Collected Sugarcane Bagasse (SCB)

B. Preparation of Sugarcane Bagasse (SCB)

The sugarcane bagasse (SCB) was washed thoroughly with distilled water to remove dirt and soil and then oven-dried at 90 °C, To get uniform drying, the duration of 7 to 8 hours is followed, which were fixed based on preliminary trials (Yusufe et al., 2017). Then, 1N HCl was added to the sample to remove metallic impurities present; leaching takes place in an amount of nominal capacity of 750 mL (Siaw et al., 2020). Moreover, the mixture was soaked in a water bath with a temperature of 75 °C. The effect of contact time was performed at 150 minutes (Ezeonuegbu et al., 2021). Afterwards, the sample was filtered using vacuum filtration, washed with distilled water several times to remove excess metallic ions in the sample (Siaw et al., 2020) and dried again in an oven with a temperature of 90 °C for 7 to 8 hours (Yusufe et al., 2017).

Figure 2: Cleaning of the Sugarcane Bagasse (SCB)

Figure 3: Pouring HCl into the Sugarcane Bagasse (SCB)

Figure 4: Filtering the Sugarcane Bagasse (SCB) treated with HCl

C. Production of Sugarcane Bagasse Ash (SCBA) - Making of Sodium Silicate

The SCB was introduced into a muffle furnace at a temperature of 700 °C and left for 4 hours for the production of sugarcane bagasse ash (SCBA) (Ifijen et al.,2020).

The SCBA was placed inside a beaker containing 1M sodium hydroxide (NaOH) solution. The 1 molar NaOH solution was prepared by dissolving 40 grams in one liter of distilled water. Has higher workability due to the effect of the concentration of NaOH (Rehman et al., 2020).

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Figure 5: Introducing Sugarcane Bagasse (SCB) into the Muffle Furnace

D. Making of Sodium Silicate Solution through Synthesizing Sugarcane *Saccharum Officinarum* Bagasse Ash (SCBA)

To obtain a sodium silicate solution, the sodium silicate (SCBA with NaOH) was heated in a water bath for 1 hour with a temperature of 90 °C. Precipitation of the sodium silicate was performed by adding 1M hydrochloric acid (HCl) solution. In the container with an amount of 50 mL of HCl with concentration of 1 mole (Wang et al., 2017), until the pH of 7 is attained (Ifijen et al., 2020). The mixture was kept for at least 18 hours at room temperature around 20-30°C (Mascolo et al., 2013) for the precipitation to complete, then the slurry was thereafter filtered using vacuum filtration (Siaw et al., 2020).

Figure 6 & 7: Creating of the Sodium Silicate Solution

E. Modifying Silica Gel from Sodium Silicate Solution

Silica gel was prepared by a simple experimental procedure at ambient temperature using sodium silicate solution. First, 5mL sodium silicate solution was added to 50mL deionized water, and then diluted 1 M sulfuric acid was added dropwisely to reach pH value of 6. Furthermore, the strength of the formed silica gel is increased by decreasing the pH value (Katoueizadeh et al., 2020). The slurry was thereafter filtered using vacuum filtration (Siaw et al., 2020) and rinsed with distilled water repeatedly until a neutral pH was achieved (Ifijen et al., 2020).

Figure 8: Creating of the Silica Gel

Figure 9: Silica Wet Gels

F. Silica Gel into Silica Aerogel

The wet gels were freeze-dried step by step. The wet gels were first dried at 243 K (- 30° C) for 1 day, then at 263 K (- 10° C) for 1 day, and finally at 273 K (0° C) for 1 day, using vacuum freeze-drying equipment. Dried gels or the aerogel were finally obtained. This novel drying method was named step-freeze-drying (SF) (Hu et al., 2019). The Freeze Drying method was done in San Pedro Colleges' Laboratory, Davao City, Philippines.

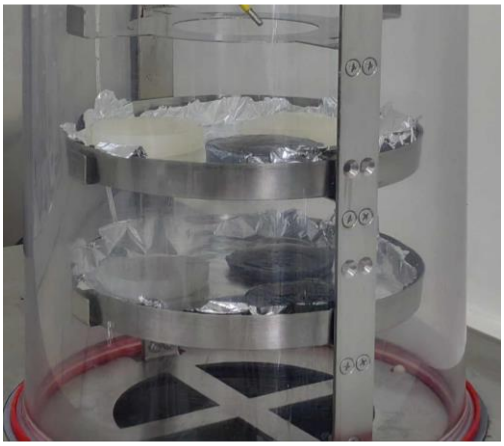

Figure 10: Freeze drying of the Silica Aerogel

G. Testing Silica Aerogel Insulation Capabilities

In testing the insulation capabilities of the Silica Aerogel, utilization of Digital Hygrometer was applied to measure the temperature of the miniature houses. It is a device used as an acoustic thermometer and TDLAS or Tuneable Diode Laser Absorption Spectrometer, it is able to respond immediately to changes in humidity (Underwood et al., 2017). There are 6 miniature houses that are made out of chipboard and popsicles. Additionally a ceiling is made for the miniature to imitate a regular building and where the silica aerogel is placed while testing. In testing the samples, 3 houses have aerogel, while the other 3 have none. Moreover, this testing is done through sunbathing the 6 miniature houses at the same place and time.

Figure 11: Testing of Silica Aerogel of its insulation capabilities

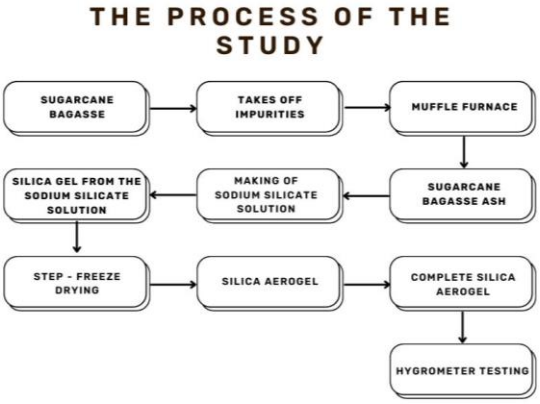

Figure 12: The Semantic Graph of the Study

Risk and Safety

Laboratory safety measures were observed during the conduct of the study. The researcher used aprons and/or lab gowns, surgical gloves, face masks and heat proof gloves. It is to prevent accidents and potential harm in the laboratory. After using the lab materials and equipment, all of it is washed and cleaned accordingly. The proper waste disposal was observed, especially the acidic wastes. Additionally, the researchers are always guided by the professionals inside the laboratory.

Data Analysis

The researchers utilized descriptive statistics, focusing on the mean and standard deviation. This method analyzes the statistical measurements in temperature differences between the samples with aerogel and those without aerogel, which is derived from the hygrometer. In addition, an Independent T-test was employed to evaluate the significance of the observed outcome differences between the samples with aerogel and without aerogel. This analysis shows a comprehensive and thorough construction of the datas.

III. RESULTS AND DISCUSSION

In observing the capabilities of the silica aerogel, a digital hygrometer was used to measure the temperature of the miniature with and without silica aerogel as an insulator.

Table 1. Shows the mean and standard deviation of the first trial temperature measured by the digital hygrometer data analysis

Descriptive Statistics

Descriptive Statistics

	12:40 PM		1:00 PM		1:20 PM		1:40 PM		2:00 PM	
	With Aerogel	Controlled	With Aerogel	Controlled	With Aerogel	Controlled	With Aerogel	Controlled	With Aerogel	Controlled
Mean	40.267	45.333	42.633	46.100	39.300	45.933	40.667	44.800	40.467	44.500
Std. Deviation	0.153	1.069	0.462	1.249	0.529	1.704	0.808	1.345	0.814	1.473

The table above presents descriptive statistics (specifically the mean and standard deviation of the gathered data) comparing the sample group with aerogel to the control group over different time intervals, specifically from 12:20 to 12:40. Both samples are placed in an area where they can catch direct sunlight. However, the control group consistently shows higher mean values compared to the aerogel-treated sample across all 20-minute intervals for 1 hour and 40 minutes. This pattern continues throughout all time points, indicating that the control group maintains higher temperature readings or similar metrics, while the aerogel-treated group demonstrates lower values, suggesting its effectiveness as a thermal insulator. The standard deviation values reflect the variability within each group. The aerogel-treated group generally exhibits lower standard deviation values compared to the control group, indicating that the data for the aerogel-treated samples are more tightly clustered around the mean. This lower variability in the aerogel group could suggest more consistent thermal insulation performance.

Table 2. Shows the mean and standard deviation of the second trial temperature measured by the digital hygrometer data analysis

Descriptive Statistics

Descriptive Statistics

	1:20 PM		1:40 PM		2:00 PM		2:20 PM		2:40 PM	
	With Aerogel	Controlled	With Aerogel	Controlled	With Aerogel	Controlled	With Aerogel	Controlled	With Aerogel	Controlled
Mean	34.900	38.167	35.867	38.067	35.933	38.700	35.867	38.133	35.067	36.867
Std. Deviation	0.400	0.586	0.252	0.451	0.493	0.872	0.473	0.643	0.289	0.306

In trial 2, the table exhibits the mean and standard deviation of the second trial of the silica aerogel insulating capabilities. With a time interval of 20 minutes in a span of 1 hour and 40 minutes, with a total of 5 stages from 1:20 to 2:40 PM. As observed in the data, the mean of the controlled group has a constantly higher value than the aerogel group. It shows that it is significant and evident that the silica aerogel has insulating capabilities. While as what we can observe in the standard deviation, the controlled group also constantly has a higher value than the aerogel group. In general, the aerogel group is lower than the controlled group. Which determines the effectiveness of the silica aerogel as a thermal insulator.

Table 3. Shows the t and p-value of the first trial

Independent Samples T-Test

Independent Samples T-Test

	t	df	p
12:40 PM	−8.125	4	0.001
1:00 PM	−4.509	4	0.011
1:20 PM	−6.439	4	0.003
1:40 PM	−4.561	4	0.010
2:00 PM	−4.150	4	0.014

Note. Student's t-test.

In Trial 1, the results of the independent T-test confirmed that the organic silica aerogel is a good thermal insulator. As shown in the table, a statistically significant difference exists between the samples with aerogel and without aerogel. Additionally, the p-values are significantly lower or below the significance level of 0.05, which indicates that the results are significant and states that organic silica aerogel is a good thermal insulator. Moreover, the insulating capabilities of the organic silica aerogel is consistent over time in changing temperature, showing that it has significantly lower temperature than the controlled treatments at different time and temperature.

Table 4. Shows the t and p-value of the second trial

Independent Samples T-Test

Independent Samples T-Test

	t	df	p
1:20 PM	−7.975	4	0.001
1:40 PM	−7.379	4	0.002
2:00 PM	−4.784	4	0.009
2:20 PM	−4.920	4	0.008
2:40 PM	−7.417	4	0.002

Note. Student's t-test.

The results of the Trial 2 independent samples t-test revealed significant differences between the two groups at all time points. Specifically, the t-statistic and p-values indicated that the means of the two groups were significantly different at each time point, with p-values ranging from 0.001 to 0.009. This confirms that organic silica aerogel is a good thermal insulator. And at different times, there is a consistent significant value. These findings suggest that the two groups exhibited distinct patterns or trends at each time point.

IV. CONCLUSION AND RECOMMENDATIONS

The present study demonstrates that sugarcane bagasse ash (SCBA) holds significant potential as a precursor for the development of aerogels with promising thermal insulation properties. The experimental data reveals that aerogels derived from SCBA effectively reduce the heat transfer through roofs in prototype housing models, indicating their capacity to serve as efficient thermal insulators. The successful extraction of silica from sugarcane bagasse and its subsequent conversion into aerogels not only highlights the viability of this agricultural byproduct for advanced material applications but also presents an environmentally sustainable alternative to traditional insulation materials. The thermal performance of SCBA-based aerogels, as evidenced in this study, underscores their potential as a cost-effective and eco-friendly solution for energy-efficient construction.

For future research, the use of the supercritical drying method is highly recommended as a precise and controlled procedure for transforming the liquid gel into gas, eliminating surface tension and capillary stress. To ensure accuracy and consistency of results, a thermogravimetric analyzer should be employed for testing samples in subsequent studies. Further investigation is also needed to explore the scalability of this process and to assess the long-term durability of SCBA aerogels in real-world applications. This will help optimize their properties for broader adoption as thermal insulators in the building and construction industry.

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V. APPENDICES

Table 1. Shows the temperatures recorded during the first trial of the insulating capabilities of the aerogel.

SAMPLE	12:40 PM	1:00 PM
S1: WITH AEROGEL	40.3°C	42.1°C
S2: WITH AEROGEL	40.1°C	42.9°C
S3: WITH AEROGEL	40.4°C	42.9°C
S4: WITHOUT AEROGEL	45.9°C	47.1°C
S5: WITHOUT AEROGEL	46°C	46.5°C
S6: WITHOUT AEROGEL	44.1°C	44.7°C

Table 2

1:20 PM	1:40 PM	2:00 PM
39.1°C	39.8°C	40.1°C
36.9°C	41.4°C	41.4°C
39.9°C	40.8°C	39.9°C
47.9°C	46.3°C	43.2°C
44.9°C	43.7°C	44.2°C
44°C	44.4°C	46.1°C

Table 3. Shows the temperature recorded during the second trial of the insulating capabilities of the aerogel.

SAMPLE	1:20 PM	1:40 PM
S1: WITH AEROGEL	36.3°C	37.4°C
S2: WITH AEROGEL	34.5°C	35.2°C
S3: WITH AEROGEL	34.4°C	35.4°C
S4: WITHOUT AEROGEL	38.4°C	38.6°C
S5: WITHOUT AEROGEL	37.5°C	38.1°C
S6: WITHOUT AEROGEL	38.6°C	38.5°C

Table 4

2:00 PM	2:20 PM	2:40 PM
36.5°C	35.5°C	35.4°C
35.6°C	36.4°C	34.4°C
36.7°C	34.7°C	34.5°C
39.1°C	38.4°C	37.2°C
37.7°C	37.4°C	36.6°C
39.3°C	38.6°C	36.8°C