

FABRICATION OF SILICA WATER FILTER FROM RICE HUSK WASTE PRODUCT VIA SLIP CASTING METHOD

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Abstract. This research focuses on utilizing amorphous silica for silica water filters from rice husk waste products that can be obtained from the area of Pasir Puteh, Kelantan. This research aims to fabricate silica water filters by using the slip casting method and investigate their physical properties. Amorphous silica with very low residual carbon content (approximately 1.0 wt.% residual carbon) was successfully produced by burning silica rice husk in a furnace at 500 °C. The compositions of silica used to fabricate water filter are 50 wt.%, 60 wt.% and 70 wt.%. The bentonite was used as the binder. The fabricated silica water filters were then sintered at 1100 °C. Various characterization such as X-ray diffraction (XRD), scanning electron microscope (SEM), energy dispersive X-ray (EDX) and water absorption analysis were carried out. The findings suggest that the slip casting technique is viable for manufacturing silica water filters, as evidenced by the energy dispersive X-ray (EDX) analysis. This analysis reveals the presence of silicon (Si) and oxygen (O) in all the composition. In conclusion, by utilizing amorphous silica gathered from burning rice husk waste not only promotes sustainability but also results in filters with notable physical properties. 50 wt.% silica is the best composition for fabricating the silica water filter based on the highest rate of water absorption analysis. This approach offers a promising avenue for producing eco-friendly and efficient water filtration systems.

Keywords: Morphology, amorphous, sintering, green technology, water absorption

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1. INTRODUCTION

The current abundance of rice husk has spurred researchers to investigate its benefits and find ways to boost its utilization while decreasing waste from paddy agriculture. However, farmers' aversion to its low market value results in unused waste, perpetuating the surplus [1]. As a result, the waste created by paddy crops contributes to abundance and prevents this waste from being used. The outer layer of a rice seed or grain is called the rice husk. The seed is constructed of hard materials, such as silica, to protect it during the growing season. In the semiconductor, ceramic, polymer, and materials industries, silica is a fundamental raw element that is utilized extensively [2]. Heat-treating of the raw rice husk waste product at 700 °C for 6 hours could result in a 95% silica powder [3]. Rice husk ash contains both amorphous and crystalline silica. Rice husk ash can create both amorphous and crystalline silica when burned at 550 °C to 800 °C and 900 °C to 1300 °C, respectively, according to Fernandes et al. [4]. Finding strategies to make the most of the rice husk ash is crucial. This produces rice husk ash, which is quite high in amorphous silica (85–95%) [5,6]. Furthermore, rice husk is a cheap and sustainable resource that shows promise as an adsorbent for the removal of a variety of contaminants. As a result, amorphous silica is the preferred type of water filter due to its low energy consumption during production and high absorption capacity of impurities.

The technique of filtering water using a porous ceramic medium to remove impurities or microorganisms is known as ceramic water filtration [7]. The ability of slip casting to reproduce complex forms makes it a perfect process for fabricating water filters since it allows for exact control over porosity to ensure consistent performance and customized designs for individual filtration requirements. This method works well with a wide variety of materials, including ceramics and polymers, which are frequently used in filter designs, making it ideal for use in water filtration applications. Its great precision and accuracy make it economical for large-scale manufacturing. Slip casting is a flexible and sensible option for producing water filters because of its capacity for batch production and low material waste, which highlight its effectiveness and environmental friendliness. Over many generations, the necessity to lessen disagreeable tastes, effectively eliminate contaminants that could spread illness, and eventually get rid of things that detract from appearance has led to the development of water filters. The pore size of a water filter is such that it can capture anything larger than a water molecule, including bacteria. Rice husk silica is often considered to be a mesoporous material, meaning it has pore sizes in the range of 2 to 50 nanometers (0.002 to 0.05 micrometers). This pore size range makes it suitable for various filtration applications, including water purification [8].

Green technology, or Greentech, is the abbreviation for ecologically friendly technology. It also alludes to the production of sustainable energy. Because the manufacturing process of the product has a lower environmental impact, using rice husk as a basic material for water filters is considered a green technology [9]. By using the energy-efficient slip casting method in conjunction with a low-energy temperature of 500 °C to produce amorphous silica, we can minimize our carbon footprint while maintaining high-quality output. Through the promotion of environmentally friendly manufacturing practices and the reduction of energy usage, our commitment to green technology reflects our commitment to sustainability. The aim of this research is to examine the process of fabricating a silica filter from through the slip casting technique and to examine the physical properties of silica both prior to and after the production of the silica water filter.

2. MATERIALS AND METHODS

The production of silica-based water filter consists of amorphous silica from rice husk waste, water, and bentonite as binder. The silica water filter was fabricated with different compositions of silica: 50 wt.%, 60 wt.%, and 70 wt.% with 10 wt.% of bentonites as shown in Table 1.

Table 1: Composition for the silica, water and bentonite for silica water filter

Sample	Composition		
	Silica	Water	Binder (Bentonite)
50 wt.%	50 wt.%	40 wt.%	10 wt.%
60 wt.%	60 wt.%	30 wt.%	10 wt.%
70 wt.%	70 wt.%	20 wt.%	10 wt.%

Prior to commencing the slip casting process, the beaker is initially weighed to determine the weight of silica added. Once the predetermined weight is established, silica is added into the beaker. Subsequently, water is added to the silica in the beaker containing the silica, ensuring the appropriate ratio is maintained according to Table 1. Following the addition of water, the beaker is once again weighed to ensure accuracy before the binder (bentonite) is introduced, adhering to specified weight and ratio parameters, mirroring the meticulous approach employed with the silica. In further fortifying the structural integrity of the sample, the inclusion of binder (bentonite), a naturally occurring clay mineral predominated by montmorillonite, is pivotal. Acting as a binding agent, bentonite finds widespread application in the slip casting process for water filter manufacture. Its addition imbues the resulting material with requisite filtration attributes, a characteristic imperative for optimal filter performance. This addition enhances the constructed water filter's overall functionality and performance. The mixture of silica, water, and binder (bentonite) within the beaker is then gently swirled until thoroughly combined, resulting in the formation of a homogeneous slurry.

Finally, this well-prepared slurry mixture is poured into a POP mould, ready to undergo the slip casting process. Through the pores of the Plaster of Paris (POP) mould, the water content in the slurry is absorbed and eliminated. A layer of silica water filter has been carefully formed on the surface of the POP mould. The excess slurry is fully removed from the mould to create the right shape for the water filter once the silica layer of the filter reaches the desired thickness. After being entirely removed from the POP mould, the sample silica water filter is subjected to the sintering process at a temperature of 1100 °C. The selection of the sintering temperature was based on its alignment within the optimal range, typically spanning from 70% to 80% of the melting point of amorphous silica [10]. Figure 1 shows the schematic diagram of the slip casting process for this research study.

Figure 2(a) shows the slip casting mould for producing the silica water filter. The slurry was poured and held for a certain period of time to gain the green body of the silica water filter. Figure 2(b) shows the green body that was produced by using the slip casting process.

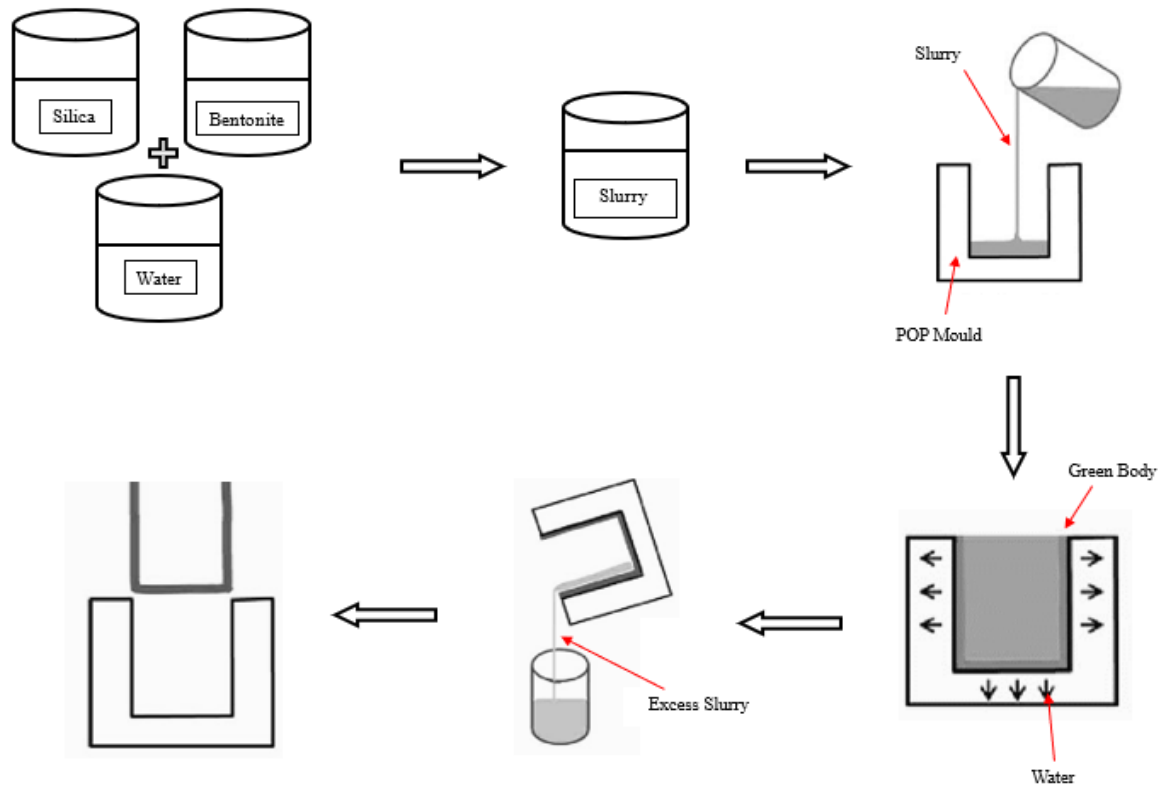


Figure 1: Schematic diagram for slip casting process for fabricating the silica water

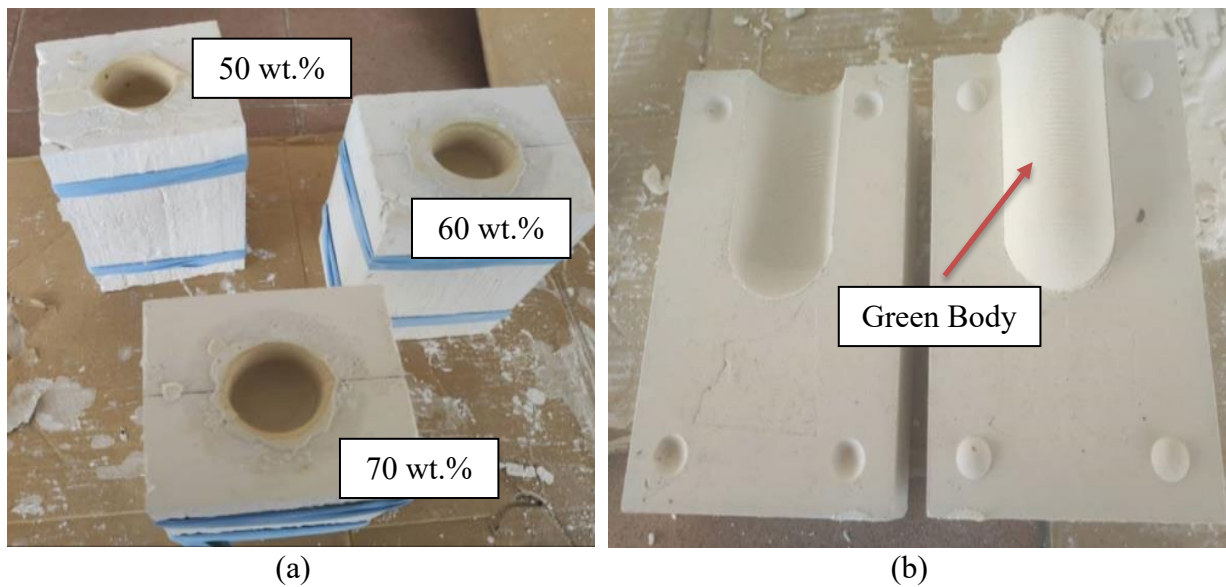


Figure 2: Slip casting process for fabricating the silica water filter, (a) Slip casting mould and (b) Green body

Phase identification of amorphous silica (SiO_2) was characterized using X-ray diffraction (XRD) machine (Brucker D8 Advance, Germany) using a scanning of 2θ in the angle range between (20° to 90°). Morphological analysis and elemental analysis of the samples were examined using scanning electron microscopy (SEM) (Hitachi Tabletop 3030, Japan) connected with energy dispersive X-ray (EDX) (EDX Oxford Instruments).

3. RESULTS AND DISCUSSION

3.1 Phase Analysis by XRD

The amorphous silica used was obtained from rice husk waste product, which had been fired at 500 °C, and the purity of the amorphous silica was confirmed by X-ray diffraction (XRD) analysis as displayed in Figure 3. The higher broad peak was observed at about $2\theta = 22^\circ$. This result highlights the presence of a broad peak, indicating the characteristic structural features of amorphous silica in the XRD analysis. According to Fernandes et al. [10], this amorphism halo profile depicts the amorphous structure of amorphous silica (SiO_2).

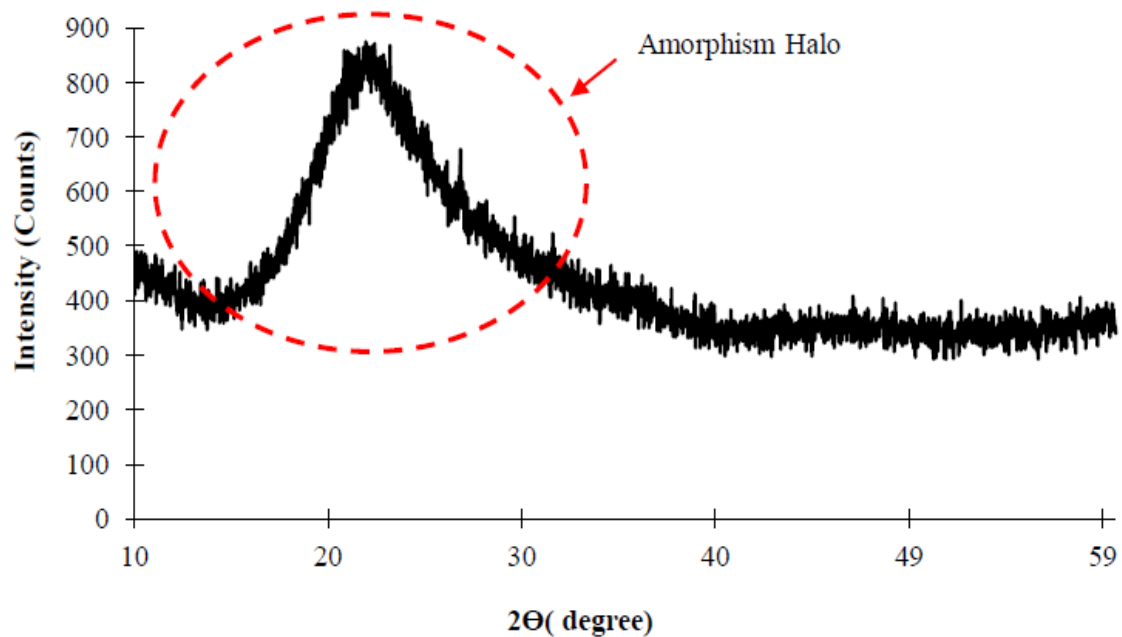


Figure 3: X-Ray Diffraction (XRD) analysis pattern of amorphous silica (SiO_2) as-derived from rice husk waste product

Table 2 shows the comparison of intense peak position of amorphous silica (SiO_2) produced and the previous research [11]. The intense peak location of amorphous silica (SiO_2) is in line with the observations made in previous studies, which is 2θ at 22° . Their amorphism halo pattern confirmed the produced silica (SiO_2) is amorphous.

Table 2: Peak of XRD for amorphous silica (SiO_2) as-derived from rice husk waste product

Sample	Silica Phases	Intense Peak 2θ (°)	Reference
Amorphous Silica (SiO_2)	Amorphous	22	Current Study
	Amorphous	22	Fernandes et al., 2016
	Amorphous	22	Fernandes et al., 2017

3.2 Morphological Analysis by SEM and Elemental Analysis by EDX

After the sintering process, the silica water filter was thoroughly examined for its properties during the production process. Scanning electron microscope (SEM) was used to observe the microstructure of the silica water filter while energy dispersive X-ray (EDX) is used to demonstrate the present of silica in the water filter sample.

SEM micrographs of the compositional sample with 50 wt.% silica is depicted in Figure 4(a). Meanwhile, Figure 4(b) presents the EDX spectrum of the sample with a composition of 50 wt.% silica. As can be seen from the diagram, the pores type that formed are open pores and interconnected pores. The low silica composition causes a wider pore size which is from 10 micrometers to 20 micrometers. In materials with low silica composition, there are fewer silica particles available to form a dense network, resulting in a higher proportion of void spaces or pores within the material's structure. When silica content is low, the matrix formed by binder materials can result by more open and less densely packed structure. Lower silica composition results in increased pore visibility within the sample, reflecting the inverse relationship between silica content and the number of observable pores. As the lower silica composition correlates with a greater number of observable open pores and interconnected pores compared to the sample with 60 wt.% and 70 wt.% of silica composition.

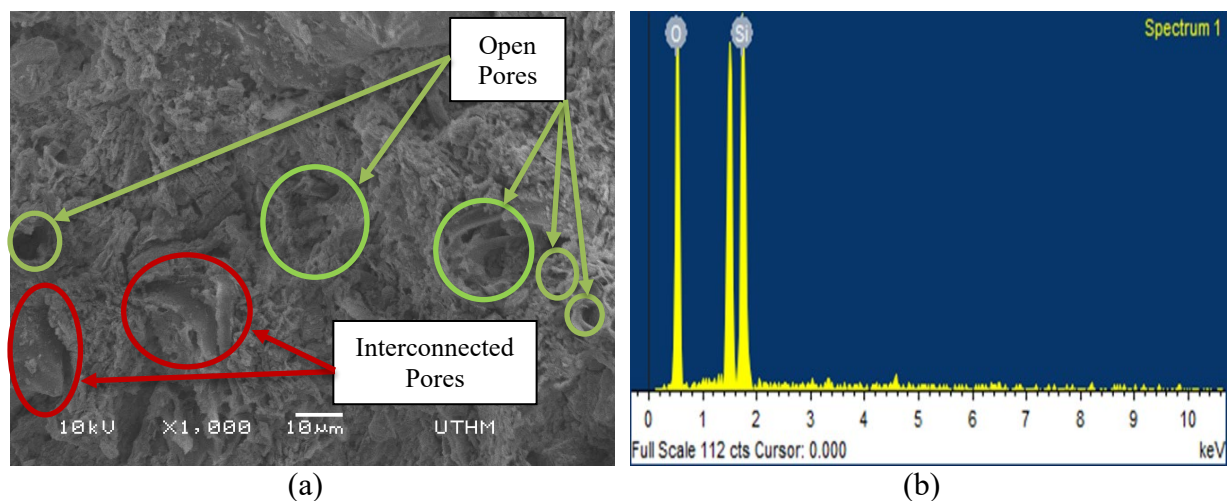


Figure 4: (a) SEM image for 50 wt.% of silica and (b) EDX spectrum of the sample for 50 wt.% of silica

The SEM image of the sample containing 60 wt.% silica is shown in Figure 5(a), offering a detailed view of its structural features and morphology. Concurrently, Figure 5(b) exhibits the EDX spectrum corresponding to the sample with a composition of 60 wt.% silica. The sample's structure appears to have more distinct interconnected pores. Several open pores and interconnected pores are present on the green and red circular, respectively. The composition containing 60 wt.% silica has exhibited noteworthy properties of silica water filter, most notably the ease with which silica has melted and form a solid sintering phase [12]. This property is of paramount importance in the fabrication of silica-based water filters, where controlled heating processes are employed to consolidate silica particles into a porous matrix, essential for efficient filtration. This result emphasizes how important the concentration of silica is in determining how the material will melt and undergo subsequent phase transitions throughout the sintering process. This demonstrates that the water filter

sample, which is composed of 60 wt.% silica, has a higher percentage of water absorption rate than the compositional samples, which are composed of 70 wt.% silica by conducting the water absorption rate analysis. A higher number of visible pores generally mean a higher water absorption rate [13]. When a material has a higher number of visible pores, it will contain more void spaces, which can readily absorb water.

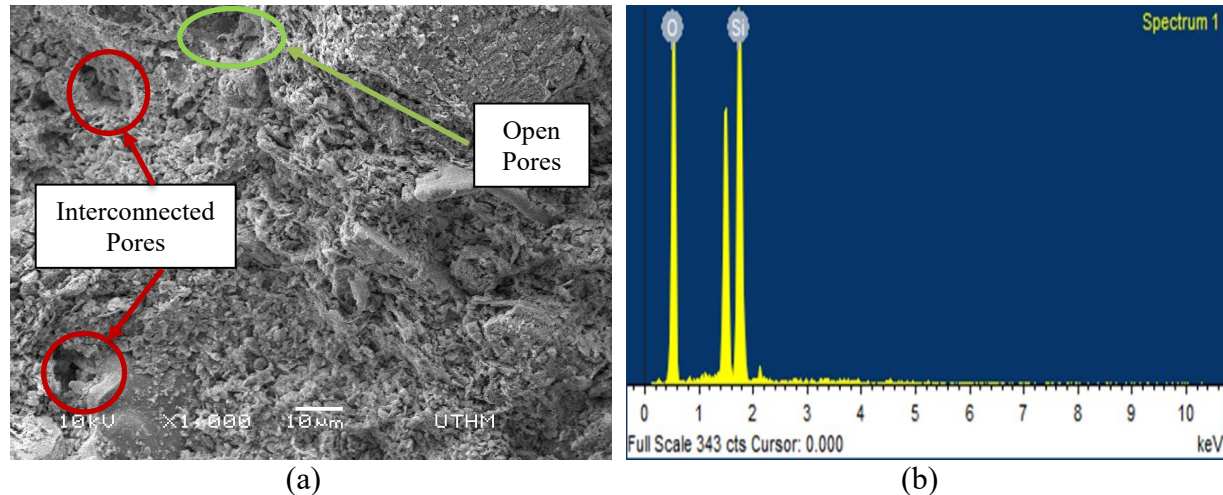


Figure 5: (a). SEM Image for 60 wt.% of silica and (b) EDX Spectrum of the sample for 60 wt.% of silica

The sample comprising 70 wt.% silica water filter is presented in Figure 6(a). In parallel, Figure 6(b) illustrates the EDX spectrum corresponding to the sample with a composition of 70 wt.% silica. Compared to compositions of 50 wt.% and 60 wt.%, the sample's structure exhibits an irregular shape of interconnected pores and the lowest porosity dispersion rate. This remark implies that the sample with the highest silica composition has the lowest porosity dispersion rate and an irregular form when compared to samples with compositions of 50 wt.% and 60 wt.%. The increase in compactness is resulted from the open pores in the material matrix changing into solid silica particles by increasing the composition of silica into the sample. An increase in silica composition reduces the number of visible open pores and serves as filler during consolidation procedures [14]. This phenomenon arises due to the characteristic behavior of silica itself, which tends to densely pack, thereby occupying pore spaces and reducing the visibility of the pores. Consequently, as the proportion of silica increases, the interstitial spaces available for pore formation decrease, resulting in a corresponding reduction in the number of pores discernible within the sample. This improvement in filtering effectiveness implies that the irregular shape and reduced porosity dispersion rate of the filter favorably contribute to its capacity to efficiently remove pollutants from the water, even with the possible disadvantage of slower water flow. Even though higher concentrations of silica enhance filtration efficacy, the implementation of a sample with increased number of visible pores is requisite for optimizing the water filtration system.

Referring to Figures 4(b), 5(b) and 6(b) of energy dispersive X-ray (EDX) spectrum, the EDX analysis indicates the presence of silica in the water filter sample. From the results, it is confirmed that the existence of both elements which are silicon (Si) and oxygen (O) [12,15-16]. The results for elemental analysis of the fabricated silica water filter is presented in Table 3.

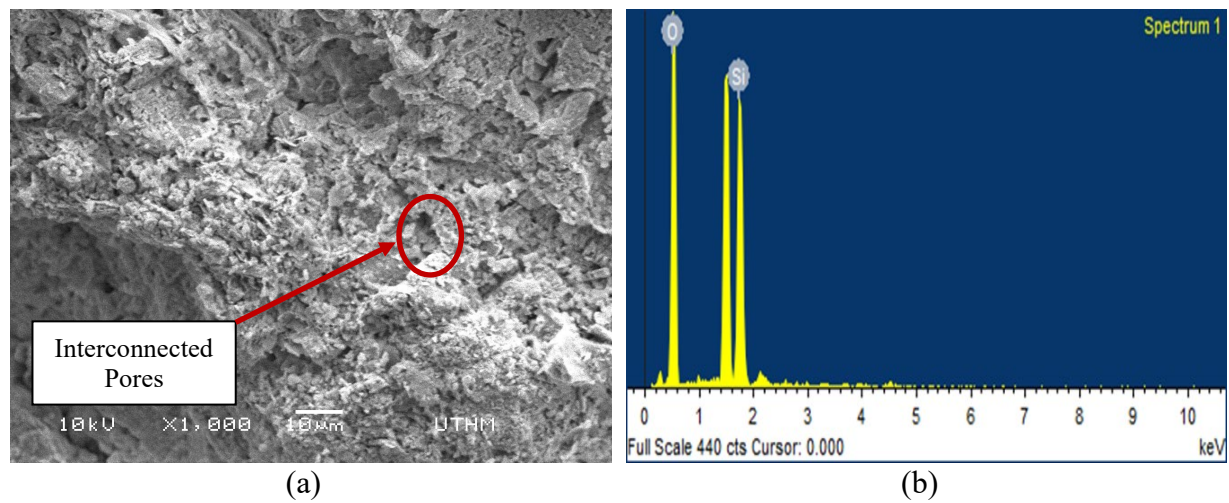


Figure 6: (a) SEM image for 70 wt.% of silica, and (b) EDX spectrum of the sample for 70 wt.% of silica

Table 3: Elemental analysis of the fabricated silica water filter

Element	50 wt.%		60 wt.%		70 wt.%	
	Weight Percentage (%)	Atomic Percentage (%)	Weight Percentage (%)	Atomic Percentage (%)	Weight Percentage (%)	Atomic Percentage (%)
Oxygen (O)	52.05	65.58	51.30	64.90	54.26	67.56
Silicon (Si)	47.95	34.42	48.70	35.10	45.74	32.44

3.3 Water Absorption Analysis

The silica water filter absorption rate analysis for the three compositions is displayed in Figure 7. The significance value of water absorption analysis for silica water filters fabricated using the slip casting method typically falls within a range of 30% to 40% [17]. This optimal range of 30% to 40% of water absorption rate signifies the extent of water uptake by the filter material, providing valuable information about its porosity, permeability, structural integrity, and suitability for water filtration applications. The water absorption analysis was repeated five times for each of the samples. At 39.41%, the highest absorption rate is found in 50 wt.% meanwhile for 60 wt.% silica, the water absorption rate is 38.52%. In the silica water filter sample containing 70% wt. % silica, the water absorption rate percentage showed the lowest water absorption rate (37.65%). The water absorption findings are consistent with the observation from scanning electron microscopy (SEM), which indicate a greater present of visible pores on the sample, the percentage for water absorption rate will be higher [18]. This demonstrates that a higher silica composition in the sample results in a lower rate of absorption for the silica water filter, as seen by the decreasing curve in Figure 7.

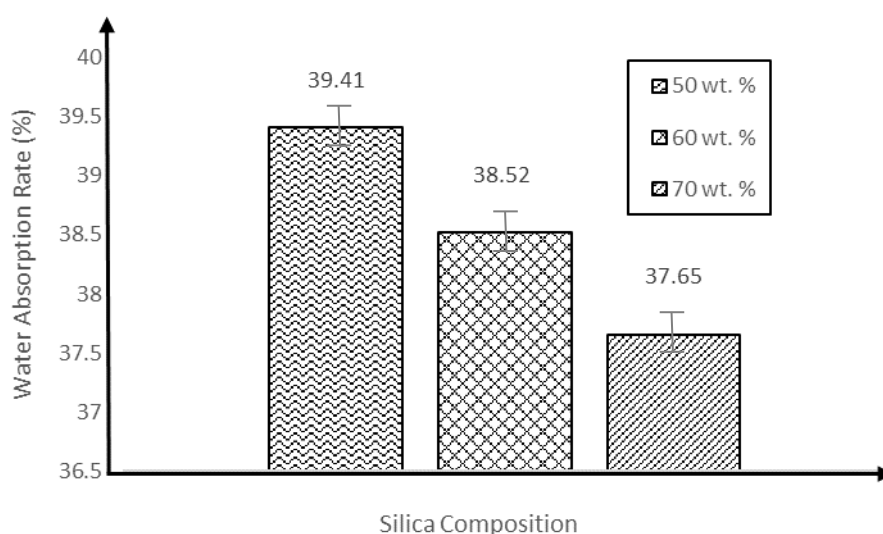


Figure 7: Water absorption analysis for silica water filter

4. CONCLUSIONS

In conclusion, the ceramic water filter has gained significant attention in the scientific community due to its numerous benefits. This study successfully synthesizes amorphous silica at 500 °C using a furnace-based approach, laying groundwork for future filter advancements. Slip casting, despite challenges in thickness control, offers time and material accessibility advantages. Experimentation with rice husk silica compositions (50 wt.% to 70 wt.%) reveals valuable insights into filter fabrication. Performance validation through rigorous testing underscores the impressive filtration capacity and pollutant removal efficacy of the silica water filter, particularly notable for its natural porous surface. Among compositions, 50 wt.% silica stands out for optimal visible pores and water absorption, crucial for effective filtration. Maintaining reasonable pore size enhances efficiency, indicating silica water filters' potential as efficient purification systems. Further research on density and porosity optimization is necessary to maximize utility in water purification, emphasizing the need for ongoing investigation and innovation.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

References

- [1] Abualnoun Ajeel, S., Sukkar, K. A. & Zedin, N. K. (2020). Extraction of high purity amorphous silica from rice husk by chemical process. *IOP Conference Series: Materials Science and Engineering*, 881(1), 012096.
- [2] Alias, S. S., Harun, Z. & Abu Mansor, S. (2020). Characterization and performance of rice husk as additive in green ceramic water filter fabricated by slip-casting. *World Journal of Engineering*, 17(4), 553-562.
- [3] Della, V. P., Kühn, I. & Hotza, D. (2002). Rice husk ash as an alternate source for active silica production. *Materials Letters*, 57(4), 818–821.
- [4] Fernandes, I. J., Calheiro, D., Sánchez, F. A. L., Camacho, A. L. D., De Campos Rocha, T. L. A., Moraes, C. A. M. & De Sousa, V. C. (2017). characterization of silica produced from rice husk ash: comparison of purification and processing methods. *Materials Research*, 20, 519–525.
- [5] Harun, Z., Shohur, M. F., Yunus, M. Z., Jamalludin, M. R. & Ismail, A. F. (2013). The effect of crystalline rice husk silica on polysulfone membrane for wastewater treatment. *Applied Mechanics and Materials*, 328, 798–801.
- [6] Jaidi, Z., Azmi, M. A., Abd Rahman, H., Huai, T. K., Yusop, U. A., Ghani, M. Z. I. A. & Roslan, M. F. (2023). The effect of milling duration to the structural properties of silica from rice husk. *Malaysian Journal of Microscopy*, 19(1), 193-201.
- [7] Mohamed, F. M. & Alfalous, K. A. (2020). The effectiveness of activated silica derived from rice husk in coagulation process compared with inorganic coagulants for wastewater treatment. *Egyptian Journal of Aquatic Research*, 46(2), 131–136.
- [8] Askaruly, K., Azat, S., Sartova, Z., Yeleuov, M., Kerimkulova, A. & Bekseitova, K. (2020). Obtaining and characterization of amorphous silica from rice husk. *Journal of Chemical Technology & Metallurgy*, 55(1).
- [9] Muslem, M. F., Ahmad, S., Shukor, M. S. S. A., Noor, F. M., Azmi, A., Rahman, H. A. & Ismail, A. (2023). Fabrication of water filter from rice husk waste product via cold isostatic pressing (CIP) method. *Malaysian Journal of Microscopy*, 19(2), 42–51.

- [10] Fernandes, I. J., Calheiro, D., Kieling, A. G., Moraes, C. A. M., Rocha, T. L. A. C., Brehm, F. A. & Modolo, R. C. E. (2016). Characterization of rice husk ash produced using different biomass combustion techniques for energy. *Fuel*, 165, 351–359.
- [11] Rahim, P. S. A., Rahman, H. A. & Ahmad, S. (2023). Fabrication and characterization of rice husk silica water filter: A short review. *Malaysian Journal of Microscopy*, 19(2), 234-247.
- [12] Jaidi, Z., Azmi, M. A., Mokhtar, M. A., Rahman, H. A., Mahzan, S., Ismail, A. & Ibrahim, M. H. I. (2024). Study of material characterization of samarium doped ceria-rice husk ash silica (SDC-RHASiO₂). *AIP Conference Proceedings*, 2925 (1), 020041.
- [13] Zhang, J., Zheng, W., Wu, J. M., Yu, K. B., Ye, C. S. & Shi, Y. S. (2022). Effects of particle grading on properties of silica ceramics prepared by selective laser sintering. *Ceramics International*, 48(1), 1173-1180.
- [14] Rajpoot, S., Malik, R. & Kim, Y. W. (2019). Effects of polysiloxane on thermal conductivity and compressive strength of porous silica ceramics. *Ceramics International*, 45(17), 21270-21277.
- [15] Ismail, N. A. A., Azmi, M. A., Ahmad, S. & Taib, H. (2015). Effect of rice husk firing temperature on synthesis of silica (SiO₂). *Advanced Materials Research*, 1087, 470-474.
- [16] Shukor, S. S. A., Ahmad, S., Rosli, S. N., Rahman, H. A., Mahzan, S., Azmi, M. A. & Muslem, F. (2024). The Effect of Sintering Temperature of Silica Water Filter Produced by Slip Casting Method. *AIP Conference Proceedings*. 2925 (1), 020051.
- [17] Abd Aziz, A. E. H. B. & Ahmad, S. (2022). Characterization of silica from pasir puteh, kelantan rice husk for water filter application. *Research Progress in Mechanical and Manufacturing Engineering*, 3(1), 915-920.
- [18] Chahal, N., Siddique, R. & Rajor, A. (2012). Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of concrete incorporating silica fume. *Construction and Building Materials*, 37, 645-651.