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RESEARCH ARTICLE

OPTIMIZING WATER FILTRATION PERFORMANCE: COLD ISOSTATIC PRESSING (CIP) UTILIZATION OF RICE HUSK WASTE WITH SINTERING AT 1100^{0}C

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Abstract. Numerous researchers have shown a keen interest in developing practical methods to maximize the utilization of rice husk (RH) waste. The main objective of this research was to fabricate a water filter using silica derived from RH waste to effectively remove contaminants from well water sources. The amorphous silica-rich black rice husk ash, derived through a fabrication process at 550 °C, serves as an efficient water filtration medium, effectively adsorbing impurities and contaminants to enhance water quality. Furthermore, it is an affordable and sustainable solution for water purification applications since the fabrication process at 550 °C uses less energy and lowers production costs. The silica water filter was manufactured by varying the silica rice husk compositions, which included 78 wt.%, 84 wt.%, and 88 wt.%. The combination of amorphous silica and binders was employed to produce the silica water filter, utilizing the cold isostatic pressing (CIP) method. Subsequently, the compacted samples were sintered at a temperature of 1100 °C. The results obtained from the analysis conducted using Scanning electron microscopy (SEM) provided valuable visual insights into the pore structure of the examined samples and energy dispersive x-ray (EDX) analysis that reveals the presence of silicon (Si) and oxygen (O). Furthermore, measurements for apparent porosity and bulk density were recorded for each sample. For the three different compositions of 78 wt.%, 84 wt.%, and 88 wt.%, the bulk density values were found to be 0.34 g/cm³, 0.27 g/cm³, and 0.25 g/cm³, respectively. Regarding apparent porosity, the results for the respective compositions of 78 wt.%, 84 wt.%, and 88 wt.% were 51%, 55%, and 58%, illustrating that the 78 wt.% silica composition yielded the most effective silica water filter. In conclusion, the outcomes of this research present a promising approach for repurposing rice husk waste, offering a sustainable and efficient solution for water filtration.

Keywords: Amorphous, density, pore, porosity, and sintering.

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1. INTRODUCTION

The growing emphasis on waste reuse and cost reduction in industrial processes has prompted exploration into the potential value of rice husk (RH). RH and its byproduct, black RH ash, are deemed suitable for various residential and industrial applications. This comprehensive study investigates the characteristics and industrial uses of RH, highlighting its potential in response to increasing demand. Furthermore, previous research state that the problem of removing various pollutants from water and wastewater has grown with rapid industrialization. [1]. The research findings suggest that RH holds significant promise for future applications, potentially expanding its utilization to new locations and a broader range of uses.

Researchers are increasingly interested in unlocking the potential benefits of abundant rice husk (RH) and devising methods to enhance its utilization while mitigating waste generated from paddy agriculture. RH can be efficiently converted into fuel and fertilizer, offering numerous advantages. However, farmers often undervalue RH due to its low market value, leading to the underutilization of this waste material. As a result, the waste generated by paddy crops remains abundant and largely untapped [2]. The aim of RH recycling is to conserve limited resources by reusing materials or finding sustainable substitutes, particularly in the study of water filter fundamentals.

The silica content significantly increases after subjecting RH to different times and temperatures during combustion. Heat treatment at 700 ºC for 6 hours produces a 95% silica powder [3]. The combustion of rice husk (RH) results in ash containing both amorphous and crystalline forms of silica, with the form depending on the temperature of the burning process. Amorphous silica is produced at temperatures ranging from 550 ºC to 880 ºC, while higher temperatures (780 ºC to 1300 ºC) lead to the production of crystalline silica [4]. Proper disposal of RH ash is essential to avoid environmental and health hazards associated with indiscriminate dumping. RH ash, predominantly white but also including shades of grey and black, is rich in amorphous silica, constituting a significant proportion (84%-95%) of its composition [5]. As a low-cost and renewable resource, RH proves to be an effective adsorbent material for eliminating various pollutants. In this research, amorphous silica from RH is chosen to produce a water filter due to its low energy consumption during production.

Ceramic water filtration involves purifying water from contaminants or germs using a porous ceramic material [6]. The evolution of water filters, from improving taste to eliminating disease-causing materials and enhancing appearance, underscores the importance of this technology. There are several methods to fabricate water filtration which is slip casting and cold isostatic pressure (CIP). Slip casting is an additional efficient way of production that involves pouring a ceramic slurry into a mold to create complicated designs and consistent thickness. Larger, hollow constructions can be easily created with slip casting, which is also easily adaptable to various ceramic compositions [7-8]. On the other hand, cold isostatic pressure (CIP) is a manufacturing technique that applies uniform pressure from all directions to shape and consolidate powders or particulate materials. This versatile method reduces porosity while maintaining the material's composition and structure, enabling the creation of precise, complex parts with enhanced density and improved properties. The objective of this study is to manufacture a silica water filter using CIP and analyze the resulting physical properties of silica. Overall, CIP facilitates high-quality production with improved properties.

2. MATERIAL AND METHODS

2.1 Materials

The primary material used in this study is Raw Rice Husk (RH), sourced from Pasir Puteh, Kelantan. For every 1 kg of raw RH burned, 100 g of silica is produced. The RH is subsequently transformed into powder form through a burning process at a temperature of 550 °C in a box furnace. Porcelain and Polyvinyl alcohol (PVA) were supplied by Maju Saintifik Sdn. Bhd. This PVA serves as a binder, keeping the porcelain particles together, structuring the filter, maintaining its strength, and enabling control over filtration efficiency by altering the binder-to-porcelain ratio.

The process of fabrication of water filters included milling the RH formulation for 30 minutes to break down the rice husk into smaller particles. Following that, the RH particles were sieved through a 90-micrometer mesh size. This sieving procedure, lasting for 30 minutes, is essential to achieve the correct particle size distribution. Afterwards, the screened rice husk underwent the CIP process and produced a densely compacted water filter sample [9].

2.2 Preparation of Rice Husk Water Filter

The variation in silica composition enables the assessment of its impact on sample properties, including porosity and filtration efficiency. Within the CIP method, a rubber plastic mold applies pressure during the molding process. In previous study, CIP's advantages lie in its capacity to ensure uniform powder density for both simple and complex shapes through the application of isostatic pressure and minimal frictional forces [10].

Following the compaction and shaping of the powders, the samples underwent sintering at 1100 °C in a box furnace. The study aimed to achieve optimal material densification, phase transformation, and structural integrity necessary for the desired properties of the fabricated samples by fine-tuning these sintering parameters. The chosen sintering temperature and soaking time were informed by previous experimental observations and theoretical considerations, seeking to strike a balance between achieving the desired material characteristics and avoiding excessive grain growth or thermal degradation.

3. RESULTS AND DISCUSSION

Examining the SEM micrograph in Figure 1 shows silica compositions of 78 wt.%, 84 wt.%, and 88 wt.% from rice husks at a 1000x magnification, allowing for a detailed observation of sample surfaces and their structural characteristics. The micrograph reveals distinct features, showcasing differences in surface morphology, particle densification, and pore arrangement.

Figure 1 illustrates an overview of the microstructure of the sample at a magnification of 1000x, focusing on the analysis of pore distribution and particle densification achieved at a sintering temperature of 1100 °C. The utilization of SEM in this investigation yielded valuable insights into the structural properties of the silica water filter, enhancing the overall comprehension of their suitability for the intended application [11]. On the other hand, the elemental makeup of the sample is revealed by its EDX analysis, which shows that oxygen (O) and silicon (Si) are its main elements. The silica-to-oxygen ratio can be inferred from the strength of the peaks corresponding to these components; a higher oxygen content indicates less silica incorporation in the matrix. Since lower silica content frequently leads to more voids or pores because of weaker particle bonding and reduced densification during sintering, this imbalance may be related to higher porosity [12]. The EDX analysis presented in Figure 1 for 78 wt.%, 84 wt.% and 88 wt.% silica composition illustrates the elemental composition of the samples, revealing critical insights into the silica-to-oxygen ratio. A lower silica-to-oxygen ratio found in the energy-dispersive X-ray (EDX) analysis indicates that the material is less tightly packed, which may promote the creation of larger pores. There are more vacant spaces in the matrix as a result of the decreased silica content, which also causes weaker bonding and poorer structural integrity. Oxide phase formation can be promoted by oxygen-rich compositions, potentially leading to the creation of more pore channels. Consequently, pore formation is encouraged by a decreased silica-to-oxygen ratio, which affects characteristics like fluid permeability, thermal insulation, and mechanical strength [13-14].

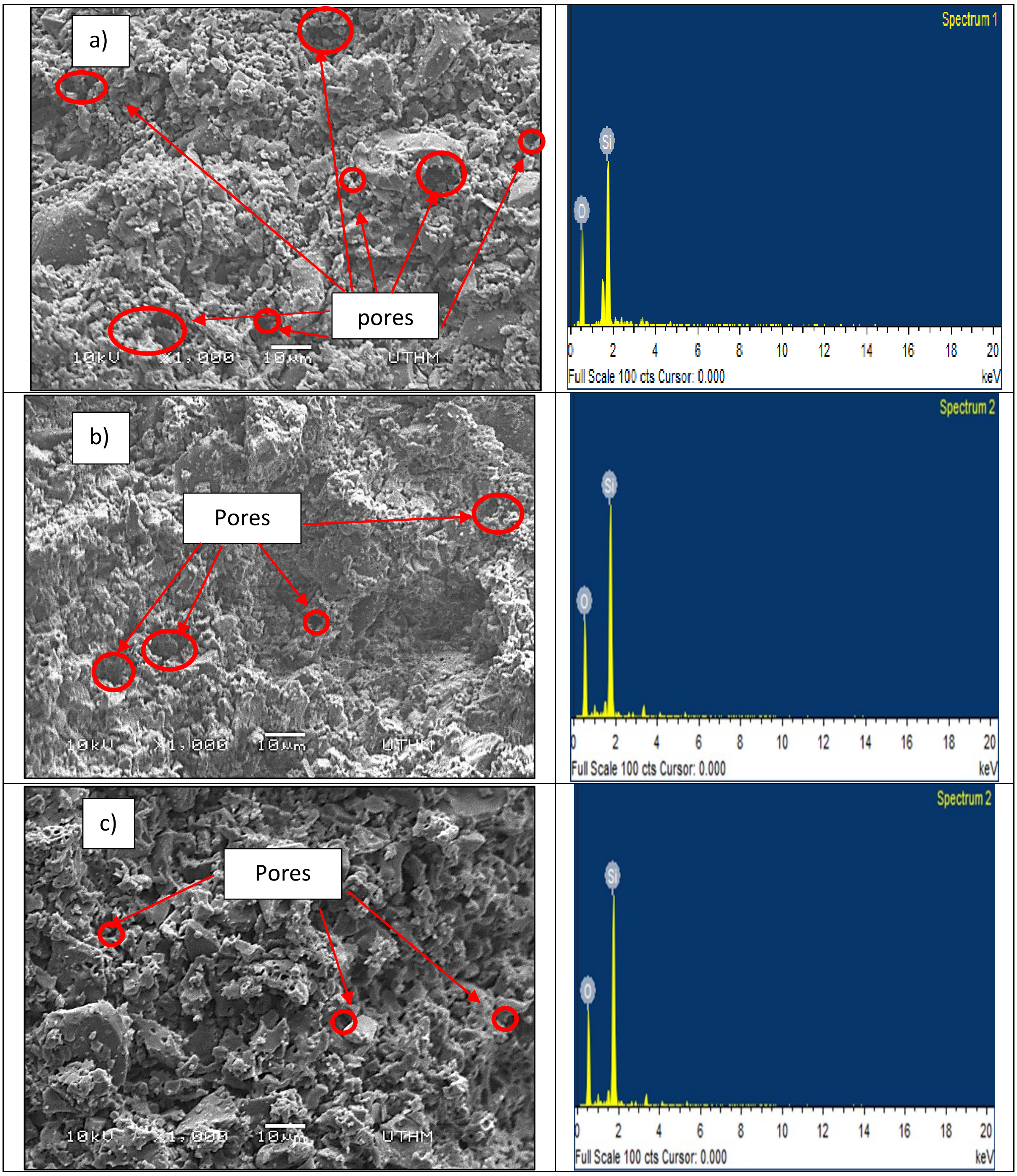

Figure 1: SEM micrographs and EDX Analysis for (a)78 wt.% composition of silica, (b)84 wt.% composition of silica and (c)88 wt.% composition of silica

Upon magnifying Figure 1(a) by 1000 times, the micrograph highlights variations in pore distribution, with the 78 wt.% silica composition displaying a higher number of pores distributed across the sample surface. These pores exhibit varying sizes and shapes, indicating a more porous and interconnected structure in this particular sample. The EDX analysis shows, when correlated with the pore distribution from the micrograph of the 78 wt.% silica composition, reveals an interesting relationship between elemental composition and porosity. The EDX analysis reveals significant peaks for silicon (Si) and oxygen (O), confirming their substantial presence in the sample. These peaks confirm that the regions with a high density of pores correspond to areas where silicon and oxygen are dominant, aligning with findings that suggest a silica framework can create a highly porous and interconnected structure [15].

Moving to Figure 1(b), the elimination of pores becomes evident, revealing enhanced particle densification in the 84 wt.% silica composition. This densification is supported by EDX analysis, which reveals a higher concentration of silicon (Si) and oxygen (O) in this sample, implying that increased silica content results in a more compact and uniform structure. The reduction in pore size and number is directly related to denser particle packing, which minimizes voids and improves the overall integrity of the material [16]. Figure 1(c) further indicates that the particle size is notably larger in the sample with an 88 wt.% silica composition compared to the other compositions, with fewer pores observed. Moreover, there is a decrease in pore size with an increase in the silica RH composition. Pore size decreases as silica RH composition increases, which is consistent with earlier research showing that increased silica content leads to better particle packing and less porosity. This trend has been extensively established in ceramic materials, where higher silica concentrations improve densification and reduce voids [17]. This finding aligns with the EDX analysis, which shows a higher concentration of silicon (Si) in this composition, indicating a more extensive silica network that contributes to increased particle size.

Figure 2 illustrates the graph representing bulk density at a sintering temperature of 1100 °C. The analysis of apparent porosity is essential in this study due to its significant impact on the physical properties of the silica water filter. The structural fragility of the ceramic body increases with higher porosity values. Upon examination of Figure 2, apparent porosity values for various silica water filter compositions indicate that the 88 wt.% composition exhibits the lowest apparent porosity at 55%. In contrast, the apparent porosity values for the 84 wt.% and 78 wt.% compositions are 60% and 68%, respectively. This finding suggests a considerable decrease in apparent porosity between the 84 wt.% and 88 wt.% compositions.

In Figure 2, the graph depicting bulk density in relation to sintering temperature reveals crucial insights into the material characteristics. The density measurements, conducted using Archimedes' principle, were systematically obtained for various silica compositions. As illustrated in Figure 2, a discernible trend emerges, indicating a positive correlation between bulk density and the silica composition. Specifically, in previous research an increase in silica composition corresponds to a notable elevation in bulk density [9]. This relationship between bulk density and silica composition is further supported by SEM micrograph, which shows a corresponding reduction in pore size and number as the silica content increases. The SEM micrographs reveal that with higher silica compositions, the densification process leads to fewer and smaller pores, resulting in more tightly packed particles and higher overall material density

Moreover, the investigation of silica water filter density at different compositions, it is evident that the 88 wt.% composition stands out by showcasing the highest bulk density among the tested compositions. This finding implies that a higher silica content, represented by the 88 wt.% composition, contributes significantly to the compactness and mass per unit volume of the water filter material. The observed trend underscores the importance of silica composition in influencing the bulk density of the water filter, thereby offering valuable insights for optimizing the fabrication process to achieve desired density characteristics.

In Figure 3 shows that the decrement trendline in apparent porosity occurred within the 88 wt.% to 78 wt.% range. This implies a comparatively smaller decline in apparent porosity between the 84 wt.% and 78 wt.% compositions in comparison to the 88 wt.% and 84 wt.% compositions. In summary, the examination of apparent porosity values yields valuable insights into the silica water filter's effectiveness for various compositions in water filtration applications. The 78 wt.% composition, with a high apparent porosity value, is suitable for scenarios requiring elevated water flow rates. Conversely, the 84 wt.% and 88 wt.% compositions are suitable for applications where a more condensed and dense structure is desired. High porosity indicates a greater number of pores in the silica filters, facilitating water passage through the filter components [18]. The substantial flow rate, reflected in the 63.91% apparent porosity value, is beneficial for reducing water filter clogging, particularly in situations with high turbidity, providing an efficient means for water to flow through the element [19]. This research underscores that the 78 wt% silica sample is approved for water filter production.

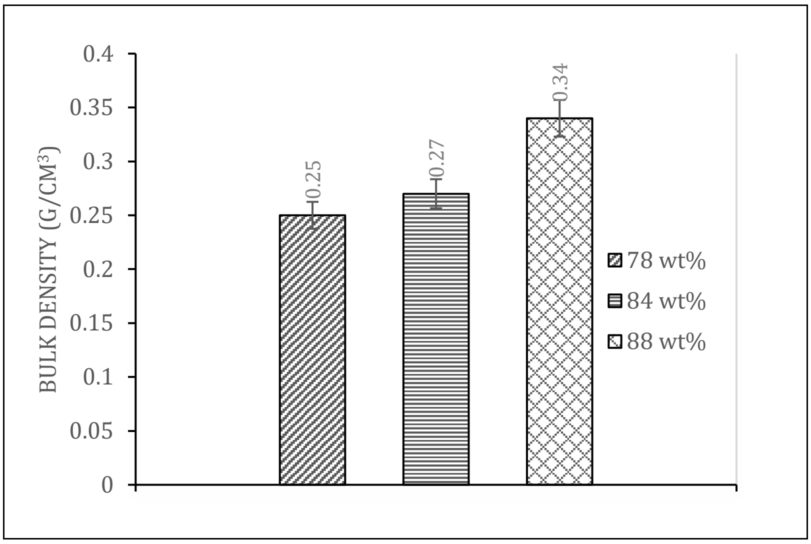

Figure 2: Results of bulk density for silica water filter at 1100 ºC sintering temperature

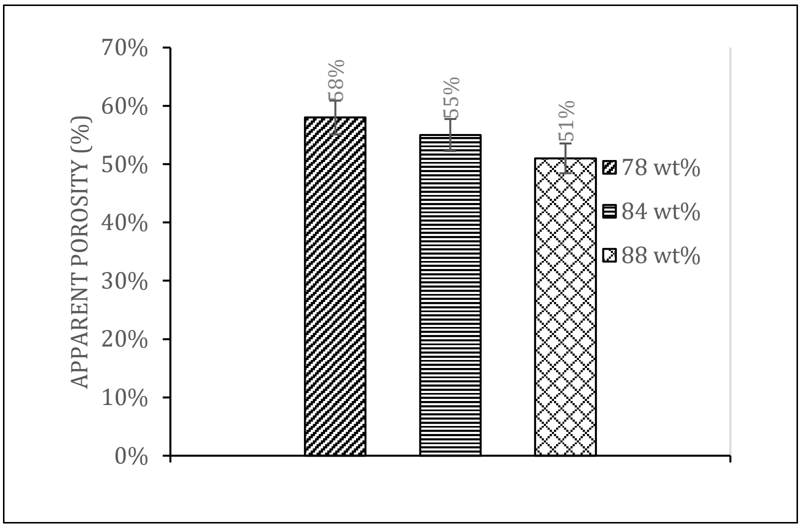

Figure 3: Results of apparent porosity for silica water filter at 1100 ºC sintering temperature

Contrary to the bulk density results, the graph trend observed here is in opposition. Previous research suggests that introducing silica into the composition results in decreased density but simultaneous promotion of increased porosity [20]. Elevating the silica composition yields lower apparent porosity values at 78 wt.%, with apparent porosity decreasing as silica composition increases. Furthermore, the analysis indicates that the apparent porosity of the samples tends to decrease as the sintering temperature rises. A reduction in apparent porosity, attributed to an increase in rice husk content, leads to a decrease in unit weight and an enhancement in thermal insulating properties [20].

This observation suggests that the silica composition significantly influences the porosity and pore density of the samples. The higher pore content in the 78 wt.% silica composition could affect the material's properties, such as increased surface area, enhanced fluid permeability, or improved adsorption capacity. An increase in sintering temperature also reduces the porosity and glassy phase of the ceramic. The elevation of silica composition contributes to an increased presence of the liquid phase derived from fluxes, aiding the merging and arrangement of particles. Consequently, the size of porosity decreases when larger granules are formed [21].

4. CONCLUSIONS

In summary, employing Rice Husk (RH) waste for the production of silica water filters offers a sustainable solution to water filtration while simultaneously repurposing a commonly discarded waste material. From a previous study, the burning of RH waste at 550 °C yields RH ash, containing amorphous silica suitable for fabricating the silica water filter in low cost and save energy. Utilizing the CIP method, filters were created in three compositions: 78 wt.%, 84 wt.%, and 88 wt.%, with the 78 wt.% silica composition yielding the most favorable outcomes in an apparent porosity of 58% and a bulk density of 0.25 g/cm^3. These results showcase a promising avenue for sustainable water filtration, presenting a practical means to maximize the utilization of RH waste.

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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

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