FABRICATION AND CHARACTERIZATION OF RICE HUSK SILICA WATER FILTER: A SHORT REVIEW

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Abstract. Due to the high demand for water filtration technology in developing countries, various materials have been used for water filter fabrication. However, silica derived from rice husk was believed to be a low-cost agro waste due to the abundant production of the waste material has several benefits needed by industries due to its chemical and physical properties. Researchers were interested in using rice husk-derived materials for water purification in variety forms such as biochar, activated carbon, silica, and hydrogels. In order to fabricate effectively filter water, it is important to consider its morphology, structure, chemical composition, and surface area, which draws scientists to develop new technologies. Therefore, this review is carried out to see how things are currently done to the excellent technique for ceramic filter made up husk-based silica and their characteristics. In this article, two types of manufacturing processes, namely dry pressing and slip casting, and their morphology, porosity and density, and phase analysis were studied. The analysis showed that the sintering temperature and the composition of the raw material significantly improve the morphology and porosity of a silica water filter. However, the technology of silica water filters still needs to be improved and modified so that it can be used to treat various environmental pollutants.

Keywords: Rice husk, silica, ceramic water filter, slip casting, dry pressing

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Introduction

Each year, millions of tonnes of rice are produced worldwide. The literature estimates that each metric tonne of rice, 200 kg rice husk (RH) is generated [1-2]. Due to its huge surface area and high carbon content, the disposal of RH is a significant difficulty in rice production and poses a danger to environmental contamination. There have been attempts to appropriately use RH without harming the environment. While most studies have employed RH as ash to make use of its high silica concentration, others have used it directly to strengthen it with other components [3]. The principal components of RH are cellulose, lignin, and hydrated silicon [4]. To create silica from RH, many techniques have been utilised, including chemical and thermal treatment [5]. However, the most popular kind of treatment is thermal. Due to the highly reactive nature of the silica generated, which could be seen as the technique's primary benefit, little grinding is required. The energy needed for the pyrolysis of the RH is provided by its carbonaceous components, which create extremely porous silica with a substantial surface area [6]. 20 wt% of the RH burned off during the process is left behind as the burnt-out residue, and 95 wt% of it is silica. Prior research conducted by Das et al. [7] has shown that the temperature and duration of the sintering process affect the quality of the silica produced from RH ash. The structural modification of silica is also a result of these sintering conditions [7]. Amorphous silica is produced when RH is sintered at a lower temperature of 500 °C-700 °C, while crystalline silica is obtained at 900 °C [8]. Quartz and cristobalite are the two most well-known types of crystalline silica that may be discovered. Depending on how many contaminants are present in rice husk ash (RHA) on a given occasion, the tridymite phase also could be seen [9].

One of the most frequently used substances in the scientific community is silicon dioxide, which can be found in nature in many different forms. Quartz, tridymite, and cristobalite are the most stable crystalline forms of silica, which also exists in amorphous form [10]. Silica can be used for a variety of things, including excellent adsorbents, semiconductor and insulator manufacturing, and structural refractories [11]. Due to its many inherent qualities, silica is a good option to serve as both a reinforcement material and a matrix for the insertion of other functional components in various matrix phases [12]. Silica has an advantage over other materials when it comes to being used in a variety of applications because of its excellent biocompatibility, thermal stability, chemical inertness, and ease of availability [13]. The mechanical, thermal, magnetic, optical, and electrical characteristics of composites made with the use of silica as a matrix or reinforcing phase are distinctive [14]. In addition to dense silica, porous silica has been extensively used in a variety of applications [15]. The cheapest source of silica is silica sand, which is typically accessible as quartz, tridymite and cristobalite are additional forms of silica that can be found in different rocks. To make silica, however, there are various other standard chemical methods that may be applied. The cheapest source of silica in recent years has been found to be rice husk (RH) and agricultural waste [16]. Under the right circumstances, silica is accessible via RH in both amorphous and crystalline forms [17].

In developing nations, ceramic water filters are thought to be the most effective technology for treating household water [18]. Among point-of-use technologies, they also offer the most potential for broad usage due to their ease of manufacture, ease of use, and relatively high efficacy at eliminating bacterial pollutants from drinking water [19]. When incoming water passes through the porous structure of ceramic water filters, microorganisms are often trapped in the nano- and microscale pores [20]. Studies conducted in the past shown that ceramic water filters can eliminate more than 99.9% of bacterial pollutants from water, including E. coli [21]. The World Health Organization (WHO) estimates that infectious diarrhoea brought on by the presence of such toxins in water results in the death of three million people annually, therefore this constitutes a substantial advancement in the quality of drinking water [22]. Despite this, drinking water may still be dangerous owing to the presence of chemical pollutants. Chemical pollutants, such as heavy metals and pesticides, may affect how well important organs operate [23]. This led to various investigations on the silica from rice husks being added to ceramic water filters. Silica from RH is used in porous ceramic structures to filter out chemical pollutants from drinking water. It has been shown that silica derived from rice husk able to eliminate the contaminated water.

Fabrication of Ceramic Water Filter

Ceramic membranes are widely recognised for creating porous and thick pore structures, where the presence of pores may be formed based on the kind of manufacturing procedure employed. Nevertheless, porous ceramic membranes have attracted a lot of interest due to developments in ceramic membrane separation application technologies and the technical and scientific need for porous structures, such as water treatment. Fabrication of ceramic water filter from RH silica could be performed in several methods such as slip casting method [24] and dry pressing method [25]. Depending on the method of shaping, ceramic membranes can be configured as flat sheets, tubular structures, or multichannel structures.

Slip Casting

The slip casting technique is often employed to create ceramics with complicated shapes that are irregular and non-concentric, as shown in Figure 1. In combination with creating porcelain, Monsieur Tendelle utilised this technique for the first time in France in 1790. Slip casting is a popular process for making ceramic membranes because it is easy to use and less expensive than other methods [26]. A slip casting slurry is placed over a microporous plaster of Paris (POP) mould throughout the procedure. According to Darcy's law, the fluid from the slurry is drawn into the mould by a capillary suction pressure caused by the porous nature of the mould. The walls of the mould become a cast, which is a solid coating that has condensed. Excess slip is poured out when the required cast thickness has been achieved, and the mould and cast are then let to dry. The cast typically shrinks as it removes itself from the mold, and it is simple to remove. After the cast has fully dried, it is heated to burn off the binder and sintered to create the final product [27]. To create a slurry, however, in order to produce the desired end result, the precise composition of the powder combination and water employed should be used. Due to the slow drying process involved in this method, casting times are frequently prolonged. Additionally, the wall thickness, which is typically substantial, is difficult to manage throughout the consolidation and drying step. According to Iwata et al. [28], casting time and slurry conditions affected the thickness of the ceramic membrane produced by the slip casting method.

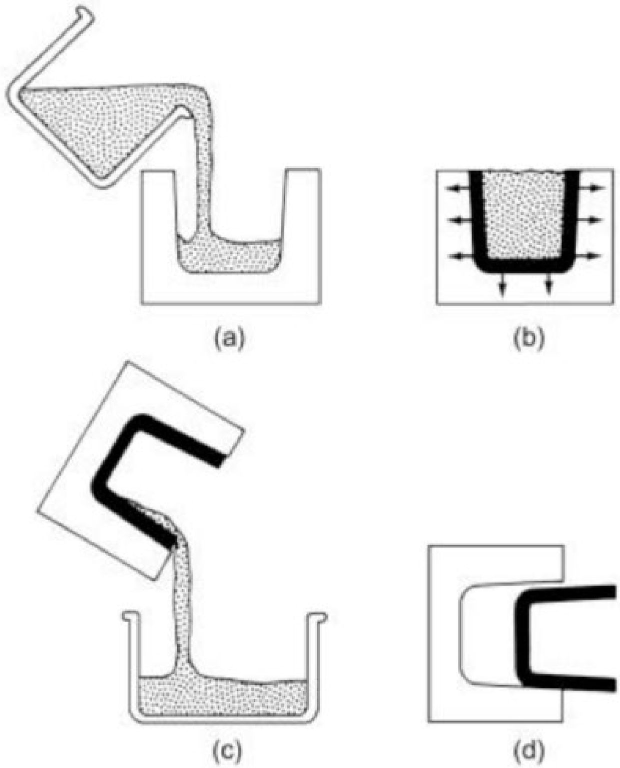

Figure 1: Schematic diagram of the slip casting process [26]

Dry Pressing

One of the most used methods in the ceramics industry is pressing. For dry powder compaction (contains less than 2 wt% water) and semidry powders (holds between 5 and 20 wt% water), uniaxial die pressing and isostatic pressing are often utilized (Figure 2). When using a stiff die, the powder material is compressed and shaped uniaxially at the same time [29]. Cold process and hot process are the two subtypes of uniaxial die compaction process. A powder combination is placed in a die and uniaxially compressed to create a green body (compacted powder) for the cold pressing process. Then take the sample out. The hot process is virtually identical to the cold method, except the green body is heated by induction in a vacuum or inert gas environment [30]. When compared to the slip casting method, the pressing process offered greater coverage for the production of ceramic membrane. The strong mechanical strength of the ceramic membrane produced by the pressing process makes it suitable for use in high-pressure applications. However, the pressing method configuration only produces symmetrical membrane as opposed to asymmetrical membrane because it is typically made in a disc or rectangular shape.

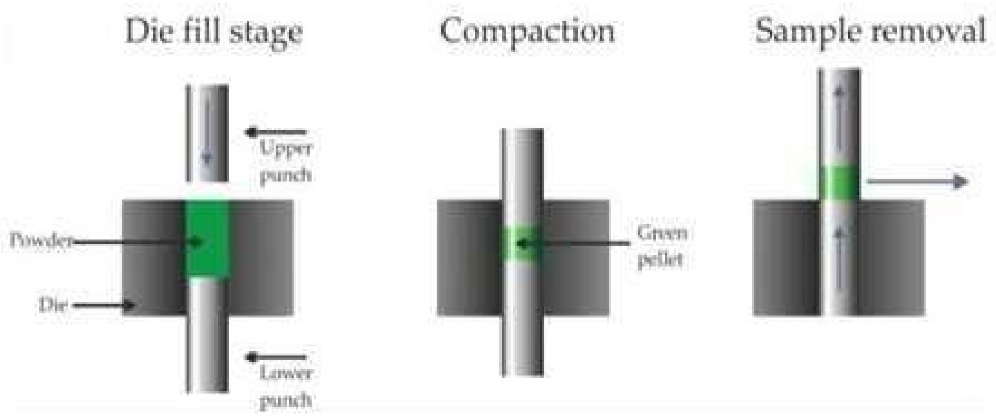

Figure 2: Schematic diagram of uniaxial die compaction for cold process [31]

Characterisation of Ceramic Water Filter Fabricated by Slip Casting and Dry Pressing

SEM Morphology

To learn more about the microstructure of sintered green CWFs, it is necessary to analyse their morphology using FESEM. The samples with 90:10, 70:30 and 80:20 weight ratios of kaolin to RH as shown in Figure 3(b_1), (c_1) and (d_1) respectively. Pore-forming agents (temperature-sensitive components) are often required during heat treatment to create pores in porous ceramic materials [32]. To prevent cracking during sintering, the green CWFs must be pre-dried at room temperature prior to sintering. In order to maintain the bond between the metallic particles and increase the samples' strength and hardness, they were sintered at low temperatures that were gradually raised.

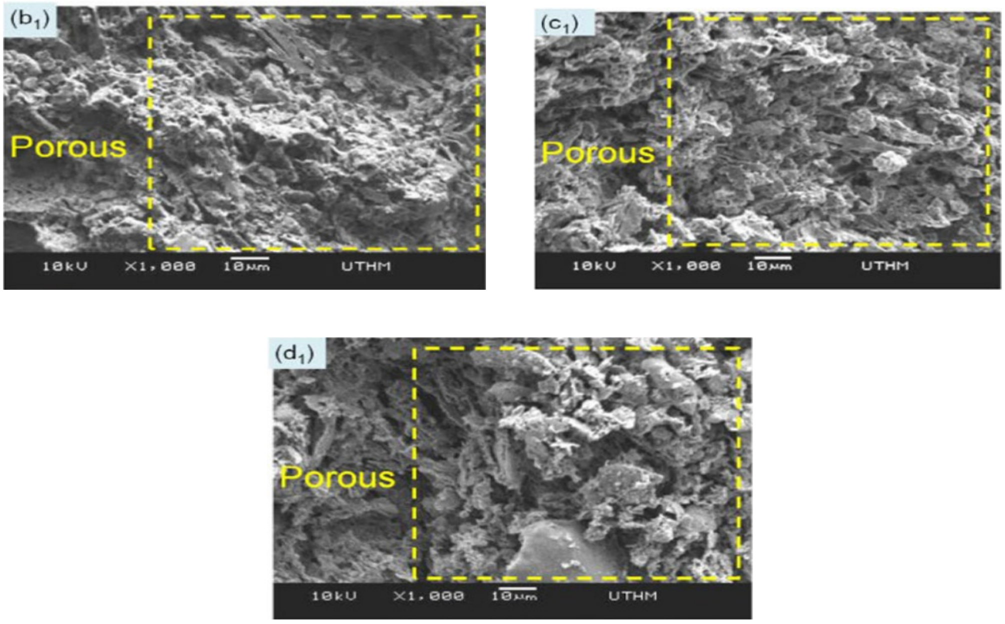

Figure 3: Cross-sectional microstructure of (b_1) Kaolin:RH = 90:10, (c_1) Kaolin:RH = 70:30 and (d_1) Kaolin:RH = 80:20 [24]

Figure 4 displays SEM images of polished and silica compacts made with amorphous and crystalline RHA and sintered at 1450 °C. SEM microstructure reveals that samples made with amorphous RHA exhibit improved compaction when sintered at higher temperatures. According to the result obtained, it was possibly be attributed to the lower green density of silica made using amorphous RHA. These less dense samples begin to form crystals when they are sintered at higher temperatures [33]. These crystals reorganise themselves in more compact groupings to take advantage of the extra space created by the low densification, which increases the density of sintered samples. SEM micrographs in Figure 4 shows that the densification improves as the sintering temperature rises.

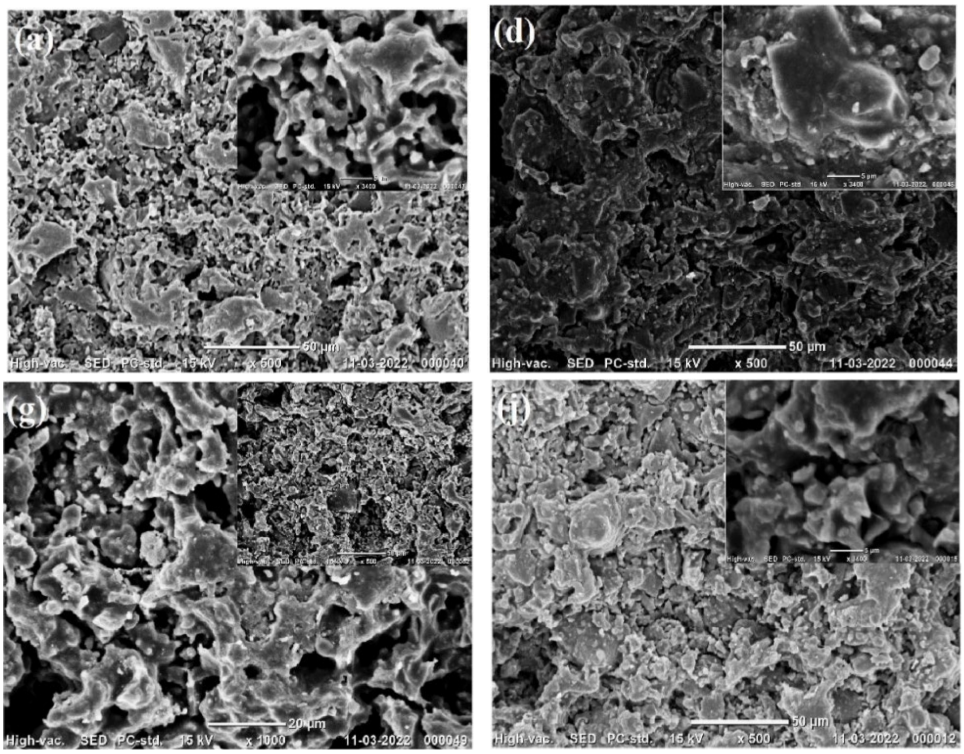

Figure 4: SEM microstructure of sintered silica compacts fabricated at 1450 °C using different heat-treated RHA of (a) 500 °C, (d) 700 °C, (g) 1000 °C and (j) 1200 °C [25]

Porosity and Density

Porosity and density are significant factors that affect how well green CWFs separate heavy metals. A porous region and porosity are related. Porosity rises as the weight ratio of RH additions to kaolin increases, but the inverse is true for density revealed in Figure 5. S2 has the lowest density (1.79 g cm^3) and the highest porosity (45.10%), which can be attributed to the slip-casting of uncompacted particles and the expansion of the pores network. The consistency between porosity and density in the porous region in this research, which is affected by the sintering temperature and silica content, is comparable to that discovered in other studies [34].

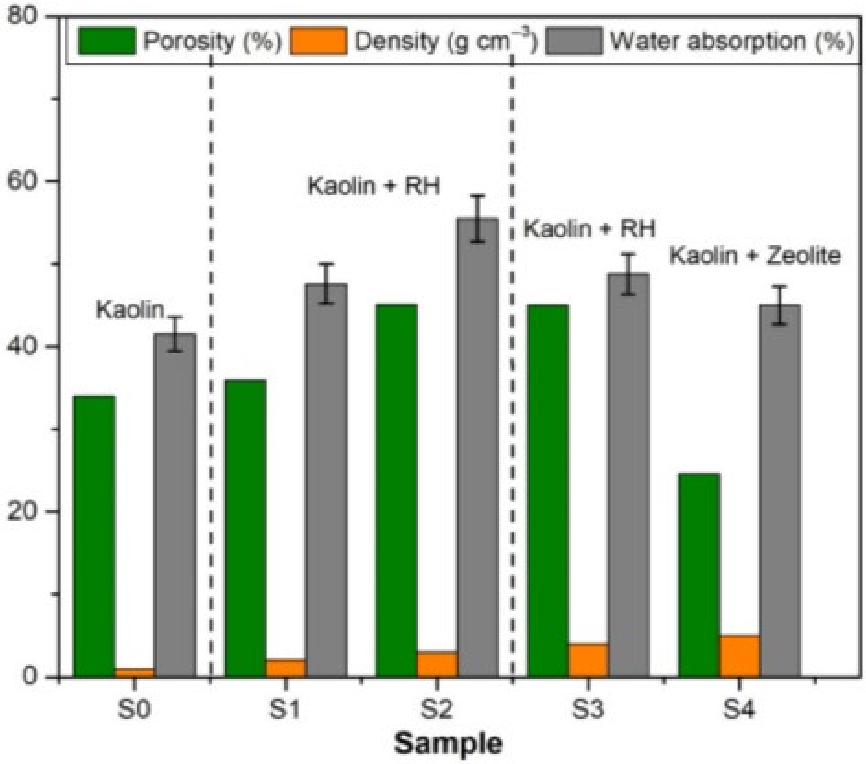

Figure 5: Porosity, density and water absorption of porous CWFs with different composition additives [24]

Utilizing several types of heat-treated amorphous and crystalline RHA and an ideal concentration of sucrose binder solution, silica compacts are effectively manufactured. Further sintered at three temperatures (1450 °C, 1500 °C, and 1550 °C), these samples are then finally consolidated. The collected samples had a bulk density of between 1.59 g/cm^3 and 1.97 g/cm^3 as shown in Figure 6(a). For all types of RHA, samples that were sintered at a higher temperature display greater bulk density [33]. This could be explained by samples consolidating more effectively at higher temperatures. In silica compacts treated at higher temperatures, a trend toward lessening bulk density is seen. Surprisingly, the densification and mechanical strength of the manufactured samples are trending in the opposite direction from those of the green samples. Despite the fact that amorphous samples' green densities are lower than those of samples made using crystalline RHA, sintered materials made utilising amorphous RHA have superior bulk densities. This tendency is related to the conversion rate and percentage concentration of silica phases.

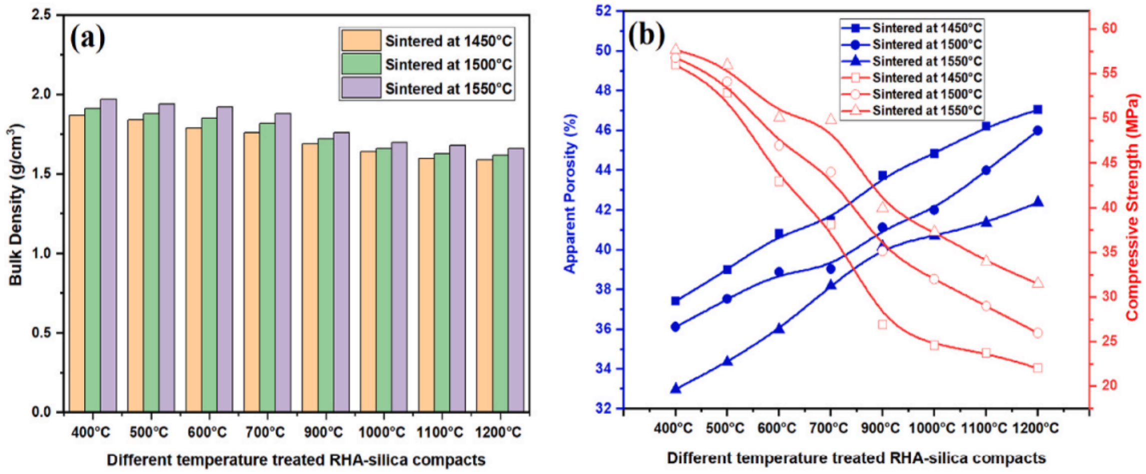

Figure 6: Physical and mechanical properties of sintered silica compacts fabricated using different heat-treated RHA [25]

Phase Analysis

The structural characteristics of raw materials (kaolin, RH, and zeolite) and the structural changes of all green CWFs following fabrication and sintering were examined using XRD analysis. The presence of sharp peaks in the minerals kaolinite (JCPDS Card no. 06-0221), gibbsite (JCPDS Card no. 01-0263), and quartz (JCPDS Card no. 46-1045) demonstrates that the mineral kaolin was primarily composed of silica and alumina with a highly crystalline structure as shown in Figure 7. RH has an amorphous form and includes silica, as seen by the wide peak of quartz (JCPDS Card no. 56-0512) [35]. While the well-crystalline RH ash utilised as the starting material for the synthesis of zeolite is what is responsible for the extremely crystalline zeolite peaks (JCPDS Card no. 38-0241) [36]. It is evident that the structure of samples is altered by the production and sintering of CWFs at high temperatures (1200 °C). Bond angles are modified and interatomic distances are somewhat altered as a result of the cooling process's transition from high to low temperatures. Quartz, tridymite, and cristobalite are three polymorphic forms of silica, and at low and high temperatures, each one has a distinct structure [34].

Figure 8 displays silica compacts made with various heat-treated RHA and sintered at various temperatures, as seen by their XRD patterns. Since there is more cristobalite in the amorphous RHA used to prepare the silica compacts, they have a higher bulk density. The amorphous silica compacts instantly transform to the cristobalite phase at higher sintering temperatures, exceeding the tridymite phase. Due to impurities, the creation of the tridymite phase is also visible, although the quantity of this conversion is minimal. However, when silica compacts made with crystalline phase are sintered at higher temperatures, silica transitions from tridymite to cristobalite. Tridymite is already the predominant phase in crystalline RHA, hence the transition to cristobalite at higher temperatures takes a bit longer. Because of this, silica compacts made with crystalline RHA are less dense at higher temperatures due to a smaller cristobalite phase. For all samples, whether produced using amorphous RHA or crystalline RHA, the silica compacts exhibit greater bulk density when sintered at higher temperatures. The greater conversion of the tridymite phase to the cristobalite phase at higher temperatures may be responsible for this phenomena. The XRD pattern shows in Figure 8 provides strong support for the aforementioned assertion and clearly illustrates how the tridymite phase loses intensity as temperature increases [25].

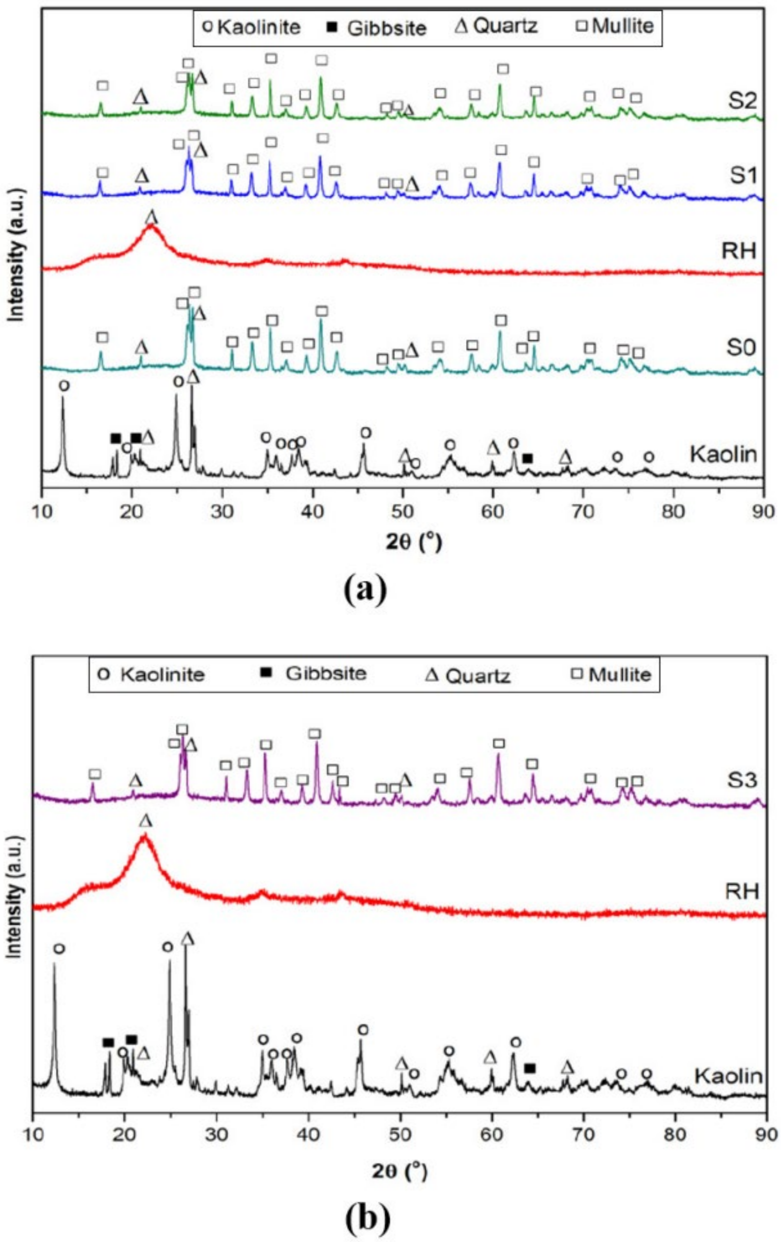

Figure 7: XRD of raw materials including (a) S0 (Kaolin), S1 (Kaolin:RH = 90:10) and S2 (Kaolin:RH = 70:30) and (b) S3 (Kaolin:RH = 80:20) [24]

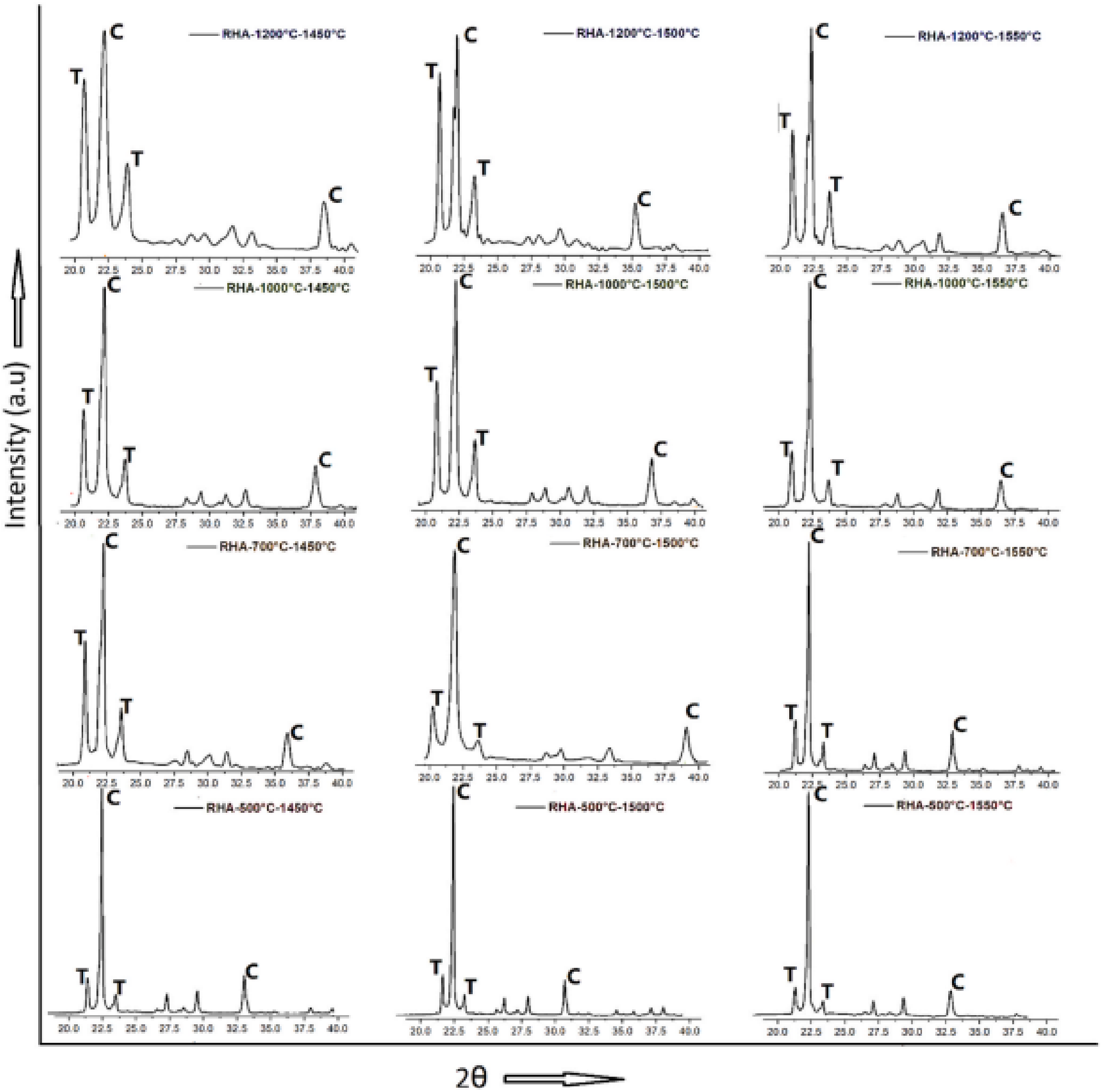

Figure 8: XRD pattern of silica compacts fabricated with different heat-treated RHA and sintered at different temperatures [25]

Conclusions

The performance and price of water filter technology will determine how far the industry can advance with it. Due to its advantages, the ceramic water filter is currently receiving more attention in the scientific community. However, the major drawback is the expensive cost of manufacturing ceramic water filters. Therefore, thorough research into the advantages of ceramic water filters in terms of their long service lives and improved performance will undoubtedly become more concentrated in the future to make up for their high price. On the other hand, attention should also be given to other options, like the price of manufacturing ceramic water filters. It could be accomplished by choosing the right raw materials and techniques. For instance, natural clay, solid waste, or any other inexpensive materials can be used as the primary materials and as the method for creating ceramic water filters. The majority of researchers use the pressing approach. Compared to the alternative technique, this procedure is more costly. The slip casting technique provides an excellent method that is inexpensive, simple to use, and doesn't require the use of sophisticated machinery. However, it was difficult to regulate and dependent on the casting time and slurry condition how thick the ceramic water filter was made utilising the slip casting process. To solve this issue, a modified slip casting process has to be used. Additionally, attention should be paid to the ceramic water filter's performance, which is closely related to the elements influencing the creation of efficient, affordable ceramic water filters. To enhance the development and characteristics of the ceramic water filter, more research is required, such as optimising the composition and size of precursor materials and pore formers via the design of the experiment. Overall, rice husk silica water filters have shown promising results in removing contaminants from water. They are low-cost, environmentally friendly, and have excellent adsorption and filtration properties. Further research is needed to optimize the fabrication process and improve the filtration efficiency of these filters.

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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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