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Synthesis and Characterization of High-Purity Amorphous Silica from Rice Husk Ash Known as 'Maika' Using the Sol-Gel Method

Rabetafika Heriniaina[1], Rabearisoa Solotiana Rija[1], Rasoloarison Harivony Fanomezana[1], Ranjava Ambinintsoa[1], Raharijaona Hasina Famonjena[1], Raharisoa Soloarilala Claudia[2], Randriana Nambinina Richard Fortuné[1]

[1]*Doctoral School of Industrial Agricultural and Food Process Engineering, University of Antananarivo, Antanarivo, Madagascar*
[2]*Polytechnic School, Doctoral School of Engineering Sciences and Innovation Technologies, University of Antananarivo, Antanarivo, Madagascar*
***Email**: herirabetafika@gmail.com*

A B S T R A C T

The main objective of the present work is the synthesis of high-purity amorphous silica from rice husk ash (RHA), known as "Maika," a widely available waste material generated in artisanal brick kilns. An alkaline treatment followed by acid precipitation was used for silica extraction. The influence of sodium hydroxide concentration on silica yield was investigated. The purity of the synthesized silica was confirmed through XRF analysis.

Keywords: Alkaline treatment, acid precipitation, rice husk ash, amorphous silica, XRF

1. Introduction

In Madagascar, the primary fuel used for firing artisanal bricks is rice husk. Once firing is complete, a small amount of the resulting rice husk ash, known as "Maika," is collected by local people to polish pots and pans; however, most of it is discarded into the environment, contributing to its degradation (Razafitrimo V., 2020).Rice husk ash is mainly composed of silica and traces of metallic impurities (Al_2O_3, Fe_2O_3, K_2O, CaO, and Na_2O) (UMEDA & KONDOH, 2008). Removing these impurities yields high-purity silica, a material widely used in industrial applications (Azat *et al*., 2019; Hamidu *et al*., 2025; Prasetyo *et al*., 2022; Okoronkwo *et al*., 2013).Silica exists in two forms: crystalline and amorphous. Amorphous silica has numerous industrial applications and is used in rubber, plastics, cosmetics, paints, catalysts, lithium batteries, electronics, coatings, optics, refractories, and as an abrasive agent. Crystalline silica is widely used in the glass and ceramics industries (Ajeel et al., 2020; Khushbu et al., 2017; Oulad & Taleb, 2021/2022). Currently, silica is extracted from sand or quartz by melting with sodium carbonate (Na_2CO_3) at 1300°C to produce sodium silicate (Na_2SiO_3), a precursor of silica. Although commercially viable, this method is highly energy-intensive (September *et al*., 2023). For this reason, research efforts are increasingly focused on extracting silica from agricultural waste, which is among the least expensive sources, containing 50–90% SiO_2 (Khushbu *et al*., 2017).The objective of this work is therefore to extract high-purity amorphous silica from rice husk ash generated during artisanal brick firing using a simple process based on alkaline treatment followed by acid precipitation at controlled concentrations.

2. Materials and methods

2.1 Raw material and reagents

Rice husk ash was collected from an artisanal brick kiln in the rural commune of Ambohitrimanjaka. Sodium hydroxide (NaOH) and hydrochloric acid (HCl) solutions were prepared for silica extraction and precipitation.

Photo 1: Rice husk ash “Maika” in an artisanal brick kiln.

Source: Author

2.2 Production of high-purity amorphous silica

Alkaline extraction followed by acid neutralization (precipitation method) is a very efficient and simple technique for extracting amorphous silica from agricultural waste (Khushbu *et al*., 2017). In this procedure, 50 g of ash were added to 200 mL of sodium hydroxide at different concentrations (1, 1.5, and 2 mol/L). Each mixture was heated on a hot plate at 100°C with magnetic stirring for 2 hours.The resulting solution was allowed to stand for 18–24 hours and filtered using Whatman No. 41 filter paper. The filtrate obtained, referred to as sodium silicate solution (Na_2SiO_3), was slowly titrated with 2 mol/L hydrochloric acid under constant stirring until a white gel formed (pH ≈ 7). This white gel, also called hydrogel, was aged overnight. It was then repeatedly washed with hot demineralized water, filtered, and dried in an oven at 105°C for 12 hours. The dried gel, known as xerogel, was ground into powder and used as a source of pure amorphous silica (Dahliyanti *et al*., 2022; Ligom *et al*., 2024; Ibtissem, 2021/2022).The reaction mechanism between rice husk ash and sodium hydroxide solution is represented by the equation (Azat *et al*., 2019; Benlin *et al*., 2022; Megawatia *et al*., 2018):

SiO_2 (rice husk ash) + 2NaOH → $Na_2SiO_3 + H_2O$ (1)

Silica was precipitated by acid neutralization of sodium silicate according to the equation (Khushbu *et al*., 2017):

Na_2SiO_3 + 2HCl → SiO_2 (pure amorphous silica) + 2NaCl + H_2O (2)

The percentage of amorphous silica relative to ash was determined using (Ramasamy *et al*., 2023):

Amorphous silica (%) = (Mass of dried gel × 100) / (Mass of ash) (3)

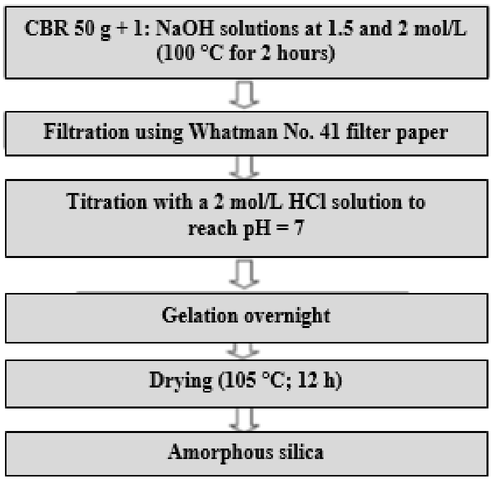
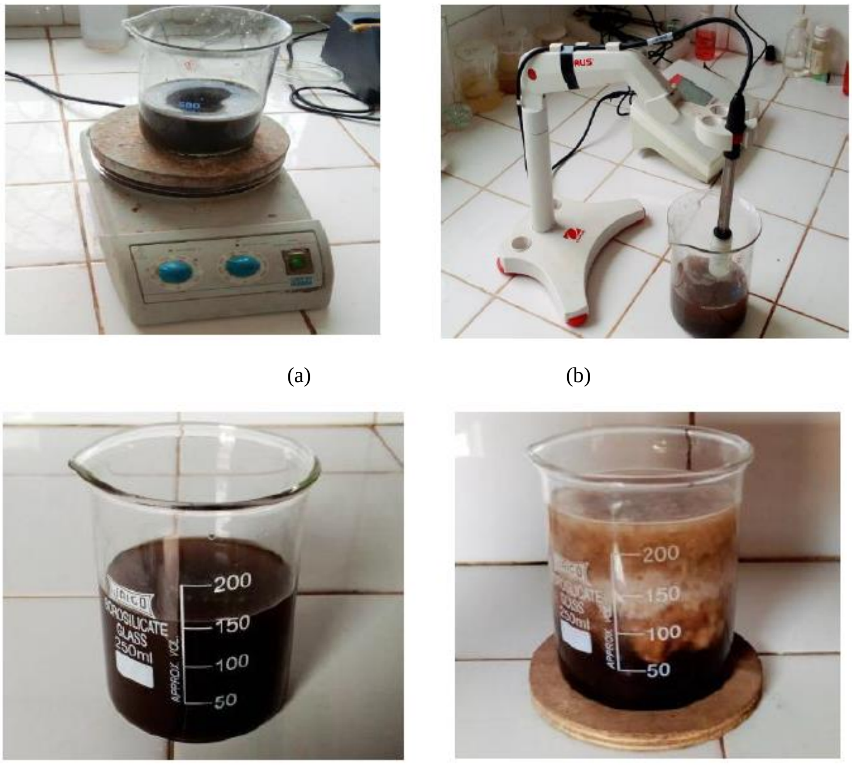


Figure 1: Flowchart of the amorphous silica production process.

Source: Author



(a) (b)

(c) (d)

Photo 2: (a) Heating of the solution on a hot plate; (b) pH measurement; (c) Sodium silicate solution; (d) Progressive formation of white silica gel.**

Source: Author

3. Results and discussion

3.1 Effect of NaOH concentration on silica powder purity

Table 1 presents the oxide composition obtained by pXRF analysis of the ash before and after chemical treatment (alkaline and acidic). The results show that silica production increases with increasing NaOH concentration, and the best result was obtained with 2 mol/L NaOH, yielding a silica content of 96.94%. This behavior can be explained by the stronger alkaline environment created by higher sodium hydroxide concentrations, which enhances silica dissolution and sodium silicate formation, thereby increasing silica content.A significant decrease in metallic impurities (metal oxides) was also observed as NaOH concentration increased. However, alkaline treatment alone could not completely remove these impurities, which explains why silica purity did not exceed 99%.

Table 1: Oxide composition of ash before and after treatment (%)

Oxydes	Before treatment	after treatment		
		1mol/L de NaOH	1,5mol/L de NaOH	2mol/L de NaOH
SiO_2	72,70	94,13	95,49	96,94
Al_2O_3	10,17	2,51	1,94	1,17
Fe_2O_3	2,36	1,04	0,75	0,67
CaO	0,00	0,00	0,00	0,00
MgO	1,14	0,84	0,57	0,31
SO_3	0,00	0,00	0,00	0,00
P_2O_5	0,27	0,30	0,22	0,18
K_2O	0,74	0,00	0,00	0,00

Oxydes	Before treatment	after treatment		
		1mol/L de NaOH	1,5mol/L de NaOH	2mol/L de NaOH
MnO	0,00	0,00	0,00	0,00
others	12,62	1,18	1,03	0,73

Source: Author

Photo 3: pXRF device used for major oxide determination

Source: Author

3.2 Silica yield relative to ash

Table 2 shows the extraction yield of amorphous silica obtained from 50 g of ash.

Table 2: Yield of amorphous silica extracted from ash as a function of NaOH concentration.

Sodium hydroxide concentration	1mol/L	1,5mol/L	2mol/L
Mass of dried silica gel	28,11g	33,54g	35,20g
Yield	56,21%	67,07%	70,39%

According to this table, amorphous silica yield increases with NaOH concentration. Based on the total silica content of the untreated ash (Table 1), more than 78% of this silica was in amorphous form at different NaOH concentrations. This confirms that the rice husk ash used in this work is a high-amorphous-silica ash.

Photo 4: Silica powder.

Source: Author

4. Conclusion

In this study, an experimental investigation was conducted to produce pure silica from rice husk ash sourced from artisanal brick kilns. High-purity amorphous silica powder was successfully extracted through alkaline dissolution using NaOH, followed by acid neutralization with HCl. Silica production increased with NaOH concentration (1–2 mol/L). The alkaline environment created by higher sodium hydroxide concentrations enhanced silica dissolution and sodium silicate (Na_2SiO_3) formation, thereby improving silica yield. The highest silica yield (70.39%) was obtained using 2 mol/L NaOH for a reaction time of 2 hours.This methodology could be applied in the future for large-scale production of pure silica from rice husk ash.

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