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Extraction, Applications, And Future Directions Of Silica Nanoparticles

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Abstract
Background: *Materials of physical size less than approximately 100 nanometres are classified as nanomaterials. They have been of advantage to mankind owing to unique properties significantly different from those of bulk materials. Nanoparticles can be composed of various materials including metals or silica like silica nano particles which are of interest in this study having at least one dimension less than 100 nanometres and exhibit unique optical, magnetic, and chemical properties. Nanomaterials have unique properties that have allowed their utilization in drug delivery, environmental remediation, energy storage, agriculture, and electronics among other applications. Despite their numerous applications, silica nanoparticles present a challenge of toxicity associated with because they are stable and non-biodegradable. Beach sand is locally available in abundance along the coastal regions of Kenya, and occurs as a result of weathering and rocks pulverization, hence, consist of various minerals.*
Materials and Methods: *This study used Sol-gel method of extraction involving hydrolysis and condensation of 100g of silica precursor in the presence of water and an acid or base catalyst where the precursor is hydrolysed to form silanol groups which condense to a silica network and finally the silica nanoparticles.*
Results: *This study gave a yield of 1% which is low and may have been contributed by the raw sand silica content. IR spectrophotometry was used to characterize the functional groups present in the raw sand and the extracted silica and the spectra obtained exhibited a peak between 1100cm-1 and 1000 cm-1 associated with Stretching vibrations of Si-O-Si and another peak at 800cm-1 associated with Si-O-Si bending vibrations however they are more pronounced and very broad in the extracted silica indicating a higher concentration of Si-O-Si in the extract as compared with the raw sand.*
Conclusion: *The leaching method employed in this study was able to extract silica nanoparticles with characteristic IR absorption peaks between 1100cm-1 and 1000 cm-1 and at 800cm-1. The extraction yield was clearly very low at 1% suggesting a low SiO2 content from the Mombasa beach sand.*
Key Word: *Extraction; Infra-Red spectroscopy; Nanomaterials; Nanometres; Nanoparticles: Silica nanoparticles; Toxicity; yield;*

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I. Introduction

Materials of physical size less than approximately 100 nanometres are classified as nanomaterials and have been great to mankind owing to unique properties significantly different from those of bulk materials (Madkour & Madkour, 2019). Nanomaterials take various forms from zero dimensional nanomaterials like quantum dots which are semiconductor particles of nanoscale having unique optical properties. One dimensional nanomaterials like nanotubes which are cylindrical structures with at least one dimension in the nanoscale range (Thakur & Thakur, 2022). Nanoparticles can be composed of various materials including metals or silica like silica nano particles which are of interest in this study having at least one dimension less than 100 nanometres and exhibit unique optical, magnetic, and chemical properties (Joudeh & Linke, 2022). Other nanomaterials include nanostructured films, three-dimensional nanomaterials, nanocomposites, nanocrystals and nanoclusters, and biological nanomaterials like liposomes (Harish et al., 2022; Khan et al., 2022).

II. Nanomaterials Characteristics And Applications

Nanomaterials have unique properties that have allowed their utilization in drug delivery, environmental remediation, energy storage, agriculture, and electronics among other applications (Oluwasanu et al., 2019). Nanomaterials possess a high surface area to volume ratio allowing for increased surface interactions that can be of significance in catalysis, sensors, and drug delivery (Biju, 2014). At the reduced size of nanoscale, quantum mechanics plays a critical role in in influencing how particles behave giving them properties that do not occur in bulk materials like in the properties possessed by quantum dots applied as semiconductors (Bera et al., 2010). They also possess improved mechanical properties, electrical conductivity, optical properties, high hydrophobicity, unique magnetic properties, and thermal conductivity among others (Baig et al., 2021; Joudeh & Linke, 2022).

Nanomaterials toxicity

Despite their numerous applications, silica nanoparticles present a challenge of toxicity associated with it since they are stable and non-biodegradable. Owing to their small size and positive charge, they are able to penetrate biological barriers leading to cytotoxicity, inflammation or even in extreme cases DNA damage (Saifi et al., 2018). They can also induce generation of reactive oxygen species a precursor of oxidative stress that has a lot of harm to biological systems (Samrot & Noel Richard Prakash, 2023).

Carbon nanotubes, silica, copper, clay, titanium dioxide and aluminium oxide are among the many different nanoparticles widely used. This study focuses on silica nanoparticles because of their high surface area, tuneable pore size, modifiability and their large natural deposits (Asefa & Tao, 2012). The production of silica nanoparticles with various pore sizes, particle diameters, and morphologies has been done using a variety of conventional methods and conditions such as liquid crystal templating mechanism which is energy-intensive and expensive. In this study, alkaline treatment method will be used to produce silica nanoparticles since it is simple and cheap, hence, economical.

Beach sand is locally available in abundance along the Coastal regions of Kenya, and occurs as a result of weathering and rocks pulverization, hence, consist of various minerals. The levels of various oxides vary depending on the geographical location, and different types of sand or sand from different region do not affect the characteristics and functions of silica nano particles extracted from it (Meftah et al., 2023). The extraction of silica nanoparticles from locally available beach sand from Kenyan coast has not been extensively researched for use in various possible applications.

Synthesis of Silica Nanoparticles

Silica nanoparticles can be synthesized through various methods including hydrothermal synthesis, flame spray pyrolysis, sol-gel method, stöber Method, micro emulsion, and chemical vapour deposition (Wang et al., 2021). Sol-gel method involves hydrolysis and condensation of the silica precursor in the presence of water and an acid or base catalyst where the precursor is hydrolysed to form silanol groups which condense to a silica network and finally the silica nanoparticles (Singh et al., 2014). It is a simple, low cost method of synthesizing silica nanoparticles that offers control over particle size.

Factors like precursor concentration, type of solvent used, pH of solution, temperature, stirring rate, reaction time, catalyst, and gel aging time influence the synthesis of silica nanoparticles through sol-gel and ultimately the properties of the synthesized silica nanoparticles (Shange et al., 2024).

After the silica nano-particles are synthesiszed, surface modification can be done to functionalize the nano particles to suit the intended application. Functional groups such as amines, thiols, or carboxyl are introduced to Silica nanoparticles to enhance their solubility, stability, and interaction with specific targets like cells, drugs, or pollutants (Cashin et al., 2018; Darwish & Mohammadi, 2018; Rahikkala et al., 2018). Modification can also be achieved through surface charge and size control to influence their interactions in biological or environmental systems. In some instances, coating with polymers or other nanomaterials like polyethylene glycol coatings improve biocompatibility and prevent aggregation in biological environments (Berret & Graillot, 2022).

III. Methodology

The beach sand used in this study was obtained from the Kenyan coast Mtwapa area. Silica content from the beach sand was extracted using alkali fusion method applying the method by (Ishmah et al., 2020). The beach sand was ground to very fine powder using mill to obtain a homogeneous particle size. 100g of the ground sand powder was soaked in 2M HCl solution for 12hours, filtered and the residue washed with distilled water until there is no yellowish colour and dried at 110°C until the water content was reduced. The dried residue was then reacted with 3 M NaOH solution for 4 hours while stirring at 95°C. The obtained suspension was filtered using Whatmann filter paper No. 42 and rinsed with 100 mL of distilled water. The filtrate obtained which was expected to contain sodium silicate was added 6 M HCl solutions while stirring to pH 7 where it formed a gel which was stored for 18 hours. The stored gel was filtered obtaining silica gel as the residue which was rinsed with distilled water. The rinsed Silica gel was then dried at 110°C to obtain silica powder, grown using mortar and pestle, weight and then characterized using an FTIR.

IV. Results And Discussions

Extraction of silica

The beach sand was ground to very fine powder to increase surface area offering a chance of better cleaning. This improves removal of impurities and contact with the extraction reagents.

The weight 100g was soaked in 2M hydrochloric acid for about 12 hours to remove impurities present in the beach sand besides SiO_2 with vigorous effervescence observed for about 1hour after soaking. Beach sand contains a lot of carbonate in form of calcium carbonate derived from dead marine organisms which reacted with the 2M hydrochloric acid to produce carbon dioxide leading to effervescence and the cations like calcium ions released went into solution. The impurities that dissolved in the 2M hydrochloric acid were separated from the undissolved materials that contained the target SiO_2 through filtration.

The SiO_2 was extracted from the coastal sand through leaching using 3M sodium hydroxide at 95°C for 4hours and continuous stirring conditions which can be regarded as mild and cheap. The sodium hydroxide used in this extraction reacts with SiO_2 in the sand powder to produce sodium silicate and water with heating helping to increase the rate of this reaction.

$SiO_2 + 2NaOH \longrightarrow Na_2SiO_3 + H_2O$ equation 1

Stirring helps to equally distribute this heat and stopping the sand particles from forming solid lumps improving their contact with the extraction solvent. The extraction mixture was then filtered and the filtrate that contained sodium silicate added 6M hydrochloric acid and at a pH 7 the sodium silicate is transformed to tetraortosilicate precipitate (gel).

$Na_2SiO_3+H_2O+HCl \longrightarrow Si(OH)_4 + NaCl$ equation 2

tetraortosilicate precipitate was filtered and cleaned using distilled water and thereafter dried at 110°C to allow the dehydration of tetraortosilicate acid to form SiO_2 powder.

$Si(OH)_4 \longrightarrow SiO_2+H_2O$ equation 3

Silica nanoparticles extraction yield

At the end of an extraction process, the amount of the desired compound that has been obtained is measured against the starting material to measure the efficiency of the employed method and its conditions. Yield of an extraction process is calculated using equation 4.

$\%\ \text{Yield} = \frac{\text{weight of obtained extract}}{\text{weight of the starting material}} \text{X}100$ equation 4

Using equation 1, the % yield was calculated for the triplicate extraction done and the data was as shown in table 1.

Table1: weight of sand used, silica extracted and % yield

	Weight of starting material(g)	weight of obtained extract (g)	% Yield
1.	100.951	0.6079	1%
2.	100.902	0.6062	1%
3.	100.042	0.6024	1%

From the data in table 1, the yield of this extraction is 1% which is clearly very low.

Characterization of the raw sand and the extracted silica nanoparticles

FTIR was used to scan the beach sand and the extracted silica nanoparticles for functional groups and the spectra are as shown in figure 1 for the beach sand and figure 2 for the extracted silica nanoparticles.

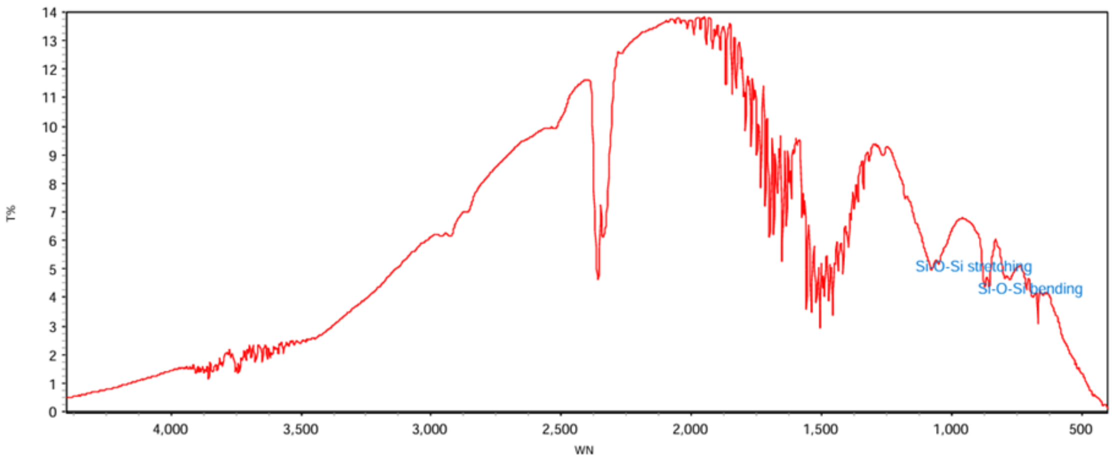

Figure 1: IR spectrum of beach sand

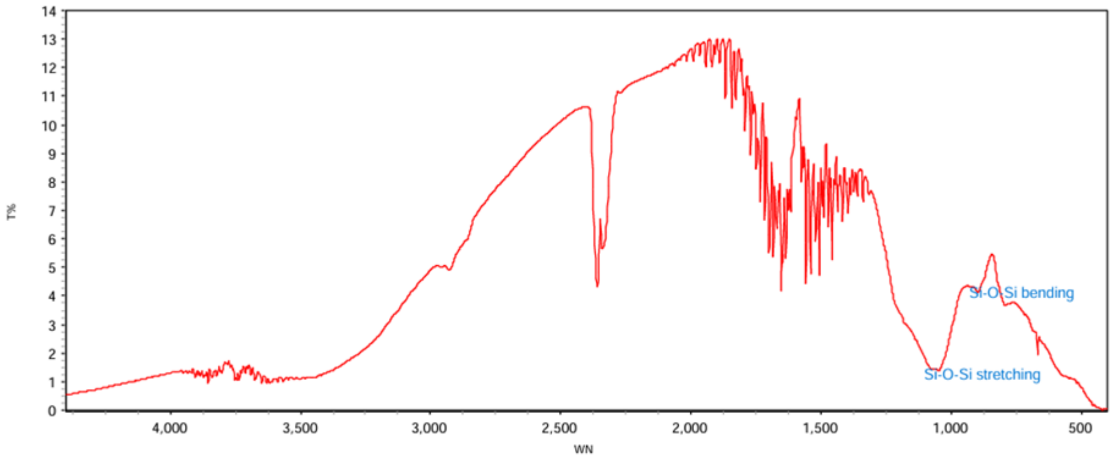

Figure 2: IR Spectrum of extracted silica nanoparticles

IR spectrophotometry was carried out the raw saw and the extracted silica particles to check on the functional groups related to silica and the spectra obtained are as shown in figure 1 and figure 2. The spectrum of the raw sand exhibits a peak between 1100cm^{-1} and 1000 cm^{-1} associated with Stretching vibrations of Si-O-Si and another peak at 800cm^{-1} associated with Si-O-Si bending vibrations (Yusuf, 2023). These two peaks were very evident in the spectrum of the extracted silica nanoparticles as shown in figure 2 however they are more pronounced and Si-O-Si stretching vibrations is very broad as compared with the raw sand Si-O-Si peak indicating a higher concentration of Si-O-Si in the extract as compared with the raw sand.

Table 2: Peak position interpretation table (Ellerbrock et al., 2022)

Wavenumber(cm-1)	Interpretation
3400-3550	OH stretch
Around 1650	OH bend
11100-1000	Stretching vibrations of Si-O-Si
around 800	Bending vibrations of Si-O-Si
450 -470	Out of plane deformation vibrations of Si-O-Si

V. Conclusion

The leaching method employed in this study was able to extract silica nanoparticles with characteristic IR absorption peaks between 1100cm^{-1} and 1000 cm^{-1} and at 800cm^{-1}. The extraction yield was clearly very low at 1% suggesting a low SiO_2 content from the Mombasa beach sand. Despite the relatively low yield, the study has demonstrated the potential of utilizing locally available raw materials to obtain silica nanoparticles that can be utilized in various fields including agriculture, medicine, environment, and electronics.

Recommendations

The researchers are recommending a comparative extraction of silica nanoparticles from Kenyan coastal sand and inland sand to confirm which of the two natural sources would give a better yield of silica nanoparticles to be applied in any of the application fields.

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