Enhancing Environmental Sustainability: Harnessing Dune Sand as a Bioresource for Porous Material Production

Tahani-Achouak Chinar[1,2*], Said Benfarhi[3] and Djalila Boudemagh[4,5]

[1]Common core science and technology Mustapha Ben Boulaid University Batna 2, Batna, 05000 , Algeria,

[2]Materials and Living Chemistry Laboratory: Activity & Reactivity (LCMVAR), Batna 1, Batna, 05000 , Algeria,

[3]Chemistry and Environment Chemistry Laboratory, Department of Chemistry, Faculty of Sciences, Elhadj Lakhdhar University Batna 1, Batna, 05000 , Algeria,

[4]Emerging Materials Research Unit, Department of Process Engineering, Faculty of Technology, Ferhat Abbas University, Setif 1, Setif, 19000, Algeria,

[5]Multiphase Polymeric Materials Laboratory(LMPM), Department of Process Engineering, Faculty of Technology, Ferhat Abbas University, Setif 1, Setif, 19000, Algeria,

Corresponding author: email: ta.chinar@univ-batna2.dz

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Abstract

The objective of this study is the preparation and characterization of porous material from dune sand from the Sahara region in Algeria. The first step consists of preparing a sodium silicate by heating at 1200°C a mixture of dune sand and sodium carbonate in a 1/1 mass proportion. The sodium silicate obtained is then dissolved in an aqueous solution and then neutralized with a 2N hydrochloric acid solution. After standing, a gel is formed. The gel is recovered and then washed several times with distilled water until the chloride ions are completely eliminated, then centrifuged and placed in the oven at 900°C until constant weight.

Some preliminary tests were carried out on the obtained material including elemental analysis and scanning electron microscopy, The results of these analyses show that the prepared material is a form of silica. Subsequently, The developed and characterized material is then tested for its capacity to adsorb a cationic dye.

Keywords: Porous material ; dune sand ; freeze ; silica ; adsorption capacity ; cationic dye.

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Introduction

In recent years, the development and characterization of porous materials have attracted growing interest in many areas of research and application. Porous materials are characterized by the presence of pores, which gives them unique properties and makes them particularly attractive for various applications, such as adsorption, gas separation, catalysis and remediation.

The development of porous materials has experienced accelerated development in recent decades. For example, it is estimated that around fifty percent of scientific articles published in journals on catalysis include at least one clay, one aluminate and one silicic material.[1-3].

Porous materials cover a very broad multidisciplinary scientific and technological field. They are implemented in numerous existing or emerging devices and processes.

linked to strong societal issues both in environmental and economic terms. In order to To succeed in respecting the environmental aspect during the process of developing these porous materials, the choice of natural raw materials is imperative.

One of the commonly used materials in the manufacture of porous materials is dune sand. Dune sand, also known as aeolian sand, is a widely available natural material, primarily composed of sand grains from aeolian deposits. Its porous structure and chemical composition make it a promising raw material for the development of porous materials.

The objective of this study is to explore a new approach for the development and characterization of porous materials from dune sand. Using chemical or physical modification techniques, it is possible to control the properties of porous materials obtained from dune sand, such as pore size, specific surface area and adsorption capacity.

The production of porous materials from dune sand can be done by different methods. These include chemical modification, which involves treating dune sand with specific chemical reagents to introduce functional groups into the structure of the material, or physical modification, which involves thermal or mechanical treatments to modify the structure. porous of the material.

Once the porous material has been developed, it is essential to characterize it in order to understand its structure, properties and performance. Techniques such as scanning electron microscopy (SEM) and elemental analysis can be used to characterize the porous material obtained from dune sand.

The study of the properties and applications of porous materials produced from dune sand is of great importance. These materials offer promising opportunities in areas such as water and soil remediation, gas purification, and carbon dioxide (CO) capture and storage.2), as well as in industrial applications such as heterogeneous catalysis.

In this study, we will focus on the development and characterization of porous materials from dune sand, exploring different modification methods and evaluating their properties and performances. The aim is to contribute to the fundamental understanding of the structure and properties of porous materials, as well as to exploration. Because in recent years and for economic and environmental considerations, researchers have been interested in highlighting local wealth.

Among these riches, we find desert sand. Sand is a material very rich in silica, a raw material which is used in many industrial fields, road construction, metallurgy, bed for wastewater decontamination, preparation of silicates, materials with high adsorption power, etc.[4,5] .

2. Experimental part

2.1. Presentation of used sand

2.1.1. Origin

The dune sand used in the preparation of porous materials comes from the Sahara region in Algeria.

2.1.2. Chemical composition of dune sand

The chemical composition of dune sand used in this study was determined using an XRF spectrometer at the Ain Touta cement plant (w.batna), and also carried out at the research and development center in Boumerdes (for give intelligent quantitative results), the analysis results are gathered in tables 1 and 2 and figure 1.

Table 1: Chemical composition of dune sand.

elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Cl
Mass %	92.58	1.58	1.35	4.12	0.55	0.08	0.54	0.10	0.01

Table 2: Intelligent quantitative results.

Element	Mass percentage	Atomic percentage	Total Intensity	Error (%)
O K	53.74	67.86	766.76	7.95
MgK	1.16	0.96	23.48	10.29

AlK	2.97	2.22	63.26	6.71
SiK	37.94	27.29	805.77	4.02
CaK	1.02	0.51	8.19	19.61
FeK	3.18	1.15	8.30	15.91

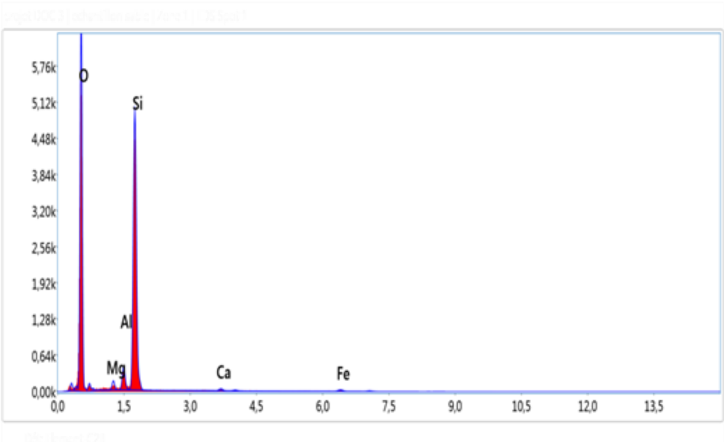

Figure 1. EDX (energy dispersive rays) spectra of elements present on the outer surface of dune sand.

The results of the quantitative and qualitative elemental analysis show that the dune sand used in this work is very rich in silica.

2.2. Preparation of the porous material

2.2.1. Preparation of sand samples

The dune sand used in this study is sieved on a 0.5mm aperture cloth.

2.2.2. Preparation of porous material by sol-gel method

The preparation of the porous material from dune sand by the sol-gel method involves two essential stages:

1. Preparation of sodium silicate;

2. Preparation of the porous material.

2.2.3. Preparation of sodium silicate

Sodium silicate is prepared by calcination in a muffle furnace of a mixture of dune sand and sodium carbonate in a 1/1 mass ratio at 900°C for 4 hours. The reaction is schematized by the following equation:

$SiO_2 + Na_2CO_3 \rightarrow Na_2O.SiO_2 + CO_2$

The product obtained is in the form of a transparent solid.

2.2.4. Preparation of porous material

5 g of sodium silicate are ground in a mortar, then dissolved in 40 ml of distilled water at a temperature of 50°C for 30 minutes with stirring in order to accelerate the solubilization. The solution obtained is basic (pH= 12). A solution of hydrochloric acid with a concentration of 2N is added with stirring to the previous solution. The pH of the final solutions varies between 3 and 9. The solutions are left to stand until a soft gel appears. In this work, only the solution at pH=7 gave a gel after resting for 18 hours. The gel is recovered then washed several times with distilled water until the chlorides ions are completely eliminated, then centrifuged for 10 minutes at 3000 rpm in a Heraeus – Christ GMBH brand centrifuge. The material obtained is introduced into the oven at 110°C until constant weight, then left to cool, weighed and stored in the desiccator for analyzes [6,7].

3. Results

3.1. Characterization of the starting and prepared porous material

3.1.1. Analysis by electron microscopy

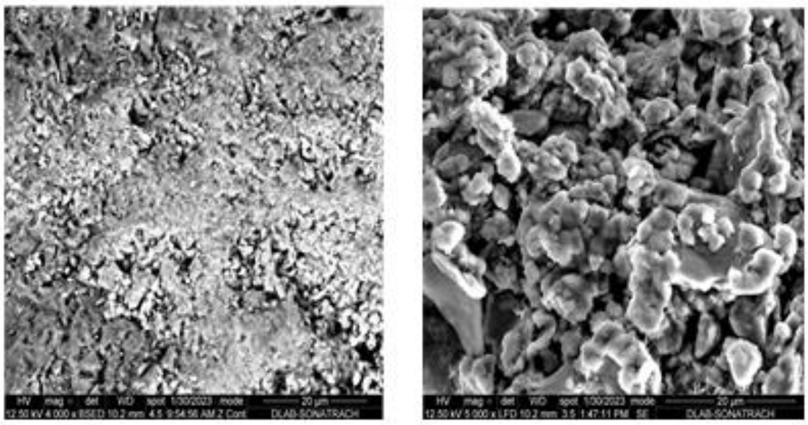

Figure 2 : (a): SEM of sand. (b): SEM of the prepared material.

Observation of raw sand using SEM shows that the grains are mostly rounded to sub-rounded, and we observe the existence of small particles in the form of fragments which appear in a white color.

SEM observation of the porous material shows the existence of a porous structure, this porosity is confirmed by the observation of pores and irregular cavities of different dimensions.

3.1.2. Elemental analysis

The results of the XRF analyzes of the produced material obtained are shown in Table 3. From these results, we note that the mass ratio SiO_2/Na_2O equal to 1.55.

Table 3: Chemical composition of the porous material.

elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Cl
Mass %	61.45	0.75	0.10	3.32	0.55	0.08	39.66	0.08	0.01

3.2. Study of the adsorption of the dye on the porous material

This study consists of highlighting the prepared material and making it more competitive in the treatment, for example of waste water for the removal of dyes. We have chosen in this work a dye, methylene blue, a widely used cationic dye in the textile industry. The results obtained are compared to those obtained in the case of dune sand.

The determination of the concentration of the dye in aqueous solution is carried out by dosing.

UV/visible spectrophotometric. The absorption of radiation by a solution of concentration C is obeyed by the Beer-Lambert law [8,9].

The UV/visible spectrophotometry assay requires the creation of a calibration curve for the dye.

The methylene blue used in this study is manufactured by LABOSI. To make the curve calibration, we prepared from a stock solution of MB of concentration C0= 10 mg/l a series of solutions of known concentrations. Absorbance measurements were carried out on a UV-Visible spectrophotometer.

The absorption maximum for MB is located at 665 nm. The results of the analyzes at this wavelength are summarized in Table 4. The variation in absorbance as a function of concentration is shown in Figure 3.

Table 4: Results of measurements in the case of methylene blue.

Test Number	V_{BM}(ml)	V_{H_2O}(ml)	C(mg/l)	A
1	1	19	0.5	0.17
2	2	18	1	0.24

3	3	17	1.5	0.33
4	4	16	2	0.37
5	5	15	2.5	0.40
6	6	14	3	0.43
7	7	13	3.5	0.47
8	8	12	4	0.52

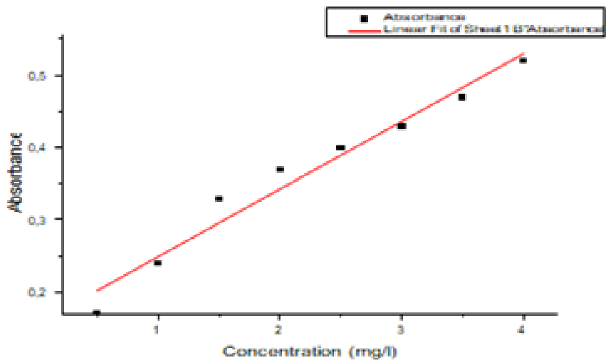

Figure 3: MB calibration curve (10mg/l).

3.3. Study of the adsorption of methylene blue on dune sand

In a 250 ml flask, 20 ml of a solution of methylene blue of concentration C are introduced.0 = 10 mg/l. The flask is kept in a water bath and stirred (200 rpm) at 20°C for 10 min so that the thermodynamic equilibrium stabilizes between the methylene blue solution and the bath liquid. A specific quantity of dune sand is added. The mixture is stirred for 2 hours then centrifuged for 5 min at 3000 rpm in a Heraeus – Christ GMBH type centrifuge. The supernatant is immediately analyzed by UV-Visible spectroscopy at λBM = 665 nm. The results obtained are summarized in table 5.

Table 5: Calculation results in the case of methylene blue/sand.

Test Number	1	2	3	4
Mass of sand (mg)	5	10	15	20
A	0.31	0.27	0.21	0.16
C_e (mg/l)	1,9	1,5	0,98	0,47

Elimination (%)	81	85	90.2	95.3

The results of table 5 are shown in figure 4:

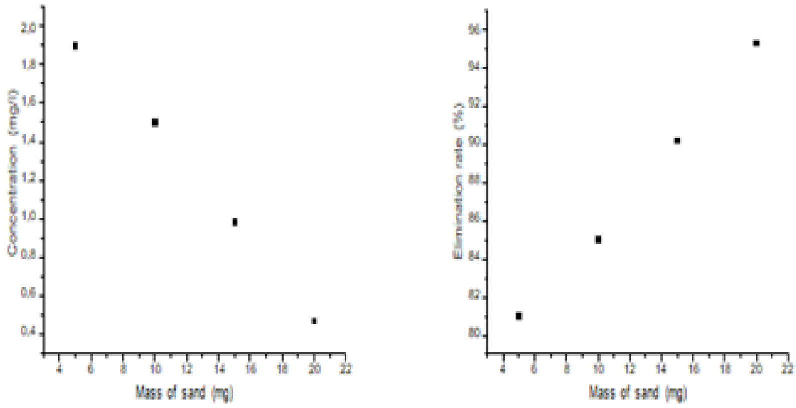

Figure 4: Variation of the : (a): concentration ,

(b): percentage depending on the mass of the sand.

The results obtained show that the concentration of the dye in the aqueous solution decreases with the increase in the mass of sand. This phenomenon can be explained by the presence of a negative surface charge on the dune sand surface. This charge is at the origin of the forces of attraction with methylene blue, a cationic dye. These forces are stronger as the mass of sand is larger.

3.4. Study of the adsorption of methylene blue on the prepared material

The previous experimental protocol was applied in the case of the adsorption of methylene blue on the prepared material. The results obtained are brought together in table 6, then shown in figure 5.

Table 6: Calculation results in the case of methylene blue/porous material.

Test Number	1	2	3	4
Mass of porous material (mg)	5	10	15	20
A	0.15	0.1	0.054	0.049
C_e (mg/l)	0.9	0.55	0.15	0.10
Elimination (%)	91	94.5	98.5	99

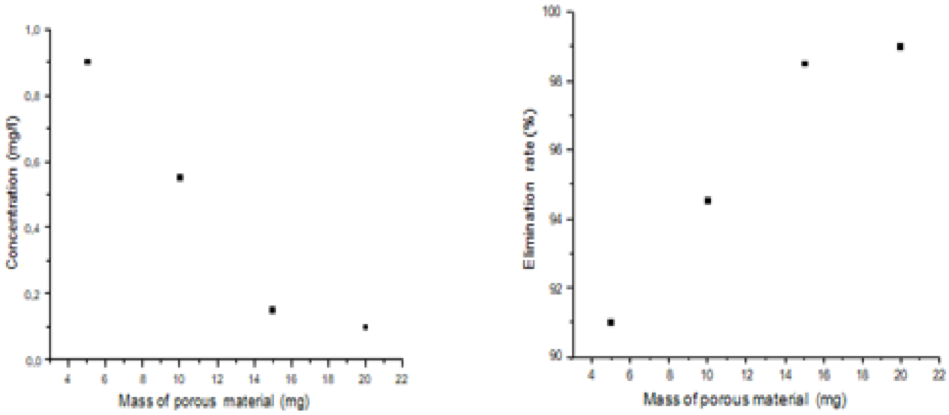

Figure 5 : Variation of the : (a): concentration ,

(b): of the percentage depending on the mass of the porous material.

The phenomenon observed in the case of the adsorption of methylene blue on dune sand was observed in the case of the adsorption of this dye on the prepared material. The only difference is that in this case the forces of attraction are very strong.

4. Conclusion

In conclusion, the development and characterization of a porous material from dune sand offers numerous opportunities and advantages. This approach makes it possible to develop an abundant natural resource, while meeting the growing needs for porous materials in various fields.

XRF spectrometry analyzes show that the dune sand used in this study is rich in silica. This material is used in a wide variety of fields, glass manufacturing, decontamination of polluted water and the synthesis of silicate materials, etc. The silicate obtained by fusion of dune sand with sodium carbonate is a sodium silicate with a ratio of SiO2/ Na2O=1.55. Treatment of this silicate with hydrochloric acid (2N) gives a soft gel. After washing and drying, a solid material is obtained.

SEM analysis and observation of the porous material shows the existence of a porous structure, this porosity is confirmed by the observation of pores and irregular cavities of different dimensions.

The results obtained by the study of the adsorption of the cationic dye: methylene blue (MB) shows that the prepared material has a great adsorption power.

The reaction of dune sand with sodium carbonate produces a water-soluble sodium silicate. Carbonates and other elements (except alkalis) are insoluble in phase aqueous and subsequently they are separated by filtration.

This work has made it possible to deepen knowledge on natural resources (dune sand) and the derived product (porous material) and their characterizations and highlights several ideas on the future creation of other more specific and more efficient structures.

The processes for producing porous materials from these raw materials represent only a small part of a very vast field of study in constant development.

The future challenge, concerning the development of porous materials from natural raw materials must be based on achieving a balance between the three elements: the durability of natural materials, preservation of the environment and cheaper cost [10,11] .

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