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Research Article

Investigation into Sudanese Sand as an Attractive Raw Material for Sodium Silicate Production

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ABSTRACT

Sudan is an African country that is located in northeast Africa it borders the countries of central African republic, Chad, Egypt, Eritrea, Ethiopia, Libya, South Sudan, and the Red Sea. However, like the other African countries Sudan is rich with minerals. White quartz is one of these very abundant minerals in Sudan. Moreover, the purity of the Sudanese sand is extremely high and it can be used as raw material in many industries directly without treatment. One of these big industries is the production of sodium silicate. Sudanese quartz was examined as a raw material in sodium silicate production, in which different sample from the most well-known sand areas in Sudan (*i.e.* Bara, Elmatama, Nile beach, and concrete sand in Omdurman). Sieve analysis and chemical analysis were done for the sample to measure the particle size and the chemical purity of the sand respectively. The results showed that sand from Bara has the highest quality with 98.56% silica content and 100% fine particles. The quartz was mixed with standard soda ash and fused at different temperature, but sodium silicate was produced at a minimum temperature of 1100°C and it failed to be produced at lower temperatures. The solubility in water of the final produced sodium silicate was measured, and it was found 29 gm/100 gm water at the standard condition (*i.e.* 1 at and 25°C) and it increases with increasing the temperature since it was measured 116 gm/100 gm water. The results shows that Sudanese quartz from Bara is extremely attractive commercially as raw material for sodium silicate manufacturing due to its high quality and it is availabity.

Keywords: Sudan; Quartz sand; Sodium silicate; Sieve analysis; Bara

INTRODUCTION

Mineral in Sudan

Sudan is a country that is located in the Northern Eastern of Africa, Sudan is bordered by Egypt to the north, Libya to the northwest, Chad to the west, the republic of central African to the southwest, South Sudan to the south, Ethiopia to the southeast, Eritrea to the east, and the Red Sea to the northeast. It is the third largest country in Africa [1], however, it has a great potential and production of minerals; about 50 to 70 tones/year gold, about 100,000 tones/year of chromite. more than 50 tones /year copper. about 70,000/year Iron, more than 100,000 tones/year gypsum, more than 100,000 tones/year salt, about 100,000 tones/year marble, more than 50,000 tones/year of dimension stones, and more variable amounts of talc, kaoline, flourite, feldspar, white sand and building materials [2].

Sudanese silica sand

Silica sand is one of the most abundant materials on earth. However, MENA region (Middle East and North Africa) is known by its desert climate, and so it has the biggest potential in the world [3]. In Sudan there are some region in which silica sand is found raw with high purity (*i.e.* 98% purity and diameter less than 0,075 and fine particles, therefore, the cost of the purification and the pretreatment.

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Physical and chemical properties

Sodium silicate is a fine white powder without taste or odor. Able to dissolve well in water. It turns out a very viscous liquid, the surface of which appears glassy. That is why the second name of sodium silicate is liquid glass. If you remove the water from this solution, you will get small, amorphous crystals that look like pieces of glass, polished by the waves of the sea on the shore. Outwardly, they are very beautiful. Crystals have a specific system with four atoms per cell [4]. When a solution of sodium silicate is heated to 300°C, it begins to boil and significantly increase in volume. Under the influence of air, natural sodium silicate gradually decomposes. This forms clay and sand. Liquid glass can react with strong acids. The result is stable silicic acid [5].

Production

Sodium silicate is often found in natural minerals. To obtain this salt, use a solution of sodium hydroxide, which must react with silicon dioxide at a temperature of about 1000°C. To obtain nearly all of the silicate salts, a very high temperature is required. There are other methods that are successfully used in laboratories: crystallization of dissolved bottles or precipitation from the gas phase and solutions containing sodium silicate [6].

Industrial application

In soaps and detergents: Sodium silicate is among the first compounds used in detergent formulations. Sodium silicate is a calcium buffer. Calcium ions 2^{+} and magnesium Mg_2^{+} eliminate the so called hardness of water, *i.e.*, softening it. By doing this, an insoluble precipitate is formed, so it is used in small quantities. The action of the sodium silicate allows the cleaner to work without the said ions affecting the cleaning process.

In catalysts and silica gel: Silica gel is usually prepared by acidifying a sodium silicate solution to a pH of less than 10 or 11. The time required for gelation varies. Silica can be prepared by mixing sodium silicate with a strong mineral acid. Sodium silicate is used in the manufacture of base catalysts, as it is the source of silica SiO_2.

As an adhesive or glue: Concentrated aqueous solutions of sodium silicate are used as adhesives and sealants. They can withstand temperatures up to 1100°C. The main applications of sodium silicate glue are in sticky paper, corrugated or corrugated board, boxes and cartons. Also for gluing or grooving wood or metal to various types of materials. It is used for gluing glass, porcelain, ceramics, textiles, leather, etc. For bonding fiberglass, optical glass and impact resistant glass containers. It is allowed to prepare refractory cements for the construction of tanks, boilers, furnaces and molds for metal casting, as well as for the manufacture of water resistant or acid resistant mortar or cement. Sodium silicate can react with silicon fluoride to produce acid resistant cement with a low tendency to shrink and thermal expansion similar to that of steel. It is also used to make cement for abrasive discs used in polishing [7].

In oil well drilling fluids: Sodium silicate has been used for many years as chemical slurry during drilling of certain types of formations with very high permeability, such as those consisting of sand. The high permeability means that it allows liquids to pass through easily. It is added with a compound that activates the silicate to form a polymer. This polymer provides strength, rigidity and reduces permeability in granular soils because the soil is less permeable, liquid does not pass through it freely and in this way fluid loss is avoided during the drilling phase of the well.

Other different applications: Sodium silicate has a variety of uses. Some of them are mentioned below.

- In daily care products, for example it is a component of shaving creams.
- In water treatment.
- In bleaching textiles such as wool.
- In bleaching pulp. For example, to whiten ground wood, a mixture containing hydrogen peroxide and sodium silicate, among other components, is used. Sodium silicate is used to isolate metal ions, which tend to accelerate the decomposition of peroxide.
- For the manufacture of fire retardant fabrics. As a fire retardant and as a coating for protective equipment.
- In silica pigments.
- Detection of insect infested corn kernels. A mixture of sodium silicate and water is used as the infected grains float to the surface quickly.
- In electrode position of zinc.
- To clean metal.
- In mineral flotation it is used as a dispersant for sludge and silt and as a conditioner for mineral surfaces.
- Wood impregnation.

METHODOLOGY

The quality of the quartz sand is measured by the softness of the sand's particles and the purity of the sand (*i.e.* the percentage of the SiO_2 in the sand). Therefore, a sieve analysis and chemical composition analysis are done to measure the softness and the purity of the sand respectively. Later on, an IR spectrum test is applied to the final product to affirm that the final product is sodium silicate; moreover, the solubility of the sodium silicate is examined as it is the main property of the product.

Sieve analysis of the sand: Sieve analysis is a technique that used to assess the general size distribution of the particles [8]. However, it was done by passing the 400 gm of washed sand into a chain of sieves of gradually smaller mesh size and then weighing the amount of material that is stopped on each sieve as a fraction of the total mass [9]:

$$\text{Retention percentage on nth sieve} = \frac{\text{Mass retained on the nth sieve } W_n}{\text{total mass } W_n} \times 100\% = R_n$$

$$\text{Cumulative retained percentage on nth sieve} = \sum_1^n R_i$$

$$\text{Cumulative passing percentage through nth sieve} = 100 - \sum_1^n R_i$$

A mechanical shaker from soil laboratory at university of Khartoum was used for implementing the sieve analysis. Four samples of 250 gm were taken from different regions in Sudan: River Nile beach, Regular concrete sand, Elmatama sand, and sand from around bara to choose figure out the best option.

Each sample was treated physically by washing with water to remove the clay and chemically by washing with 5% hydrochloric acid to remove the chemical impurities such as carbonate.

Chemical analysis: As it was mentioned earlier, a chemical analysis was applied to measure the purity of the sand. The samples from Bara and Elmatama had already been analysed by the Geological Research and Authority of Sudan (GRAS) [10]. Therefore, only the samples from Nile River and regular concrete sand were analysed chemically using XRD in GRAS laboratories (Figure 1).

Production of sodium silicate (reaction: Sodium silicate was produced from quartz sand by reacting the quartz sand with soda ash (Sodium carbonate) in a high temperature (down to 1000°C) for six to eight hours depends on the composition of the mixture [11]. The reaction is shows as follow:

$$Na_2CO_3 + nSiO_3 \xrightarrow{heat} Na_2O.nSiO_2 + CO_2$$

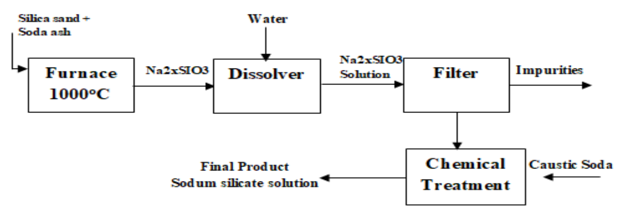

Figure 1: Flow chart of sodium silicate production.

IR spectrum test: To affirm that the reaction has completed and almost all the reactants has converted into the desired products (*i.e.* Sodium silicate) an IR spectrum test was done at the physical and chemical research center, university of Khartoum, Sudan.

Solubility of the product: The solubility of sodium silicate was measured by dissolving 3.5 gm samples of the produced lumps in a 20 ml of distilled water for five minutes using a magnetic bar rotator. The dissolving was done at different temperatures: 150°C, 100°C, 80°C, 40°C, and 25°C.

$$Solubility\left(\frac{gm}{100gm\ solvent}\right) = \frac{weight\ of\ the\ solid}{wieght\ of\ solvent} \times 100$$

RESULTS AND DISCUSSION

Sieve analysis of the sand: Sudan possesses quartz sand with extraordinary high silica content and fine particles in areas such as Elmatama and Bara. However the sand from around Bara was found to be the best raw material in term of particle size, since it doesn't need particles size reduction at all (Tables 1-6).

Table 1: Sieve analysis for Bara's sand.

Mesh No.	Mesh dia mm	Weight retained (gm)	Partial percent (%)	Accumulated (%)	Passing (%)
25	0.6	0	0	0	100
36	0.425	0	0	0	100
44	0.3	1.27	0.00508	0. 51	97.67
72	0.211	27.2	0.1088	11.48	97.18
140	0.15	129.12	0.51648	63.54	34.15
200	0.075	83	0.332	97	0.6855
200>	0.075>	1.7	0.0068	100	0

Table 2: Sieve analysis for Elmatama's sand.

Mesh No.	Mesh dia mm	Weight retained (gm)	Partial percent (%)	Accumulated (%)	Passing (%)
25	0.6	0	0	0	100
36	0.425	0	0	0	100
44	0.3	1.22	0.00488	0. 49	98.1895

72	0.211	25.78	0.10312	10.89	98.6976
140	0.15	124.86	0.49944	61.23	37.9556
200	0.075	92.47	0.36988	99	0.6694
200>	0.075>	1.66	0.00664	100	0

Table 3: Sieve analysis for regular concrete sand.

Mesh No.	Mesh dia mm	Weight retained (gm)	Partial percent (%)	Accumulated (%)	Passing (%)
25	0.6	140	56.7	56.7	43.3
44	0.3	73	29.22	85.92	14.08
140	0.15	33.625	13.45	99.37	0.63
200	0.075	0.275	0.11	99.48	0.34
200>	0.075>	0.85	0.34	100	0

Table 4: Sieve analysis for nile river sand.

Mesh No.	Mesh dia mm	Weight retained (gm)	Partial percent (%)	Accumulated (%)	Passing (%)
25	0.6	0	0	0	100
36	0.425	100	40	40	60
44	0.3	79	31.6	71.6	28.4
72	0.211	28.33	11.33	83	17.13
140	0.15	33.33	13.33	96.33	3.8
200	0.075	0.7	0.4	96.73	3.4
200>	0.075>	1.5667	0.63	97.36	2.64

Table 5: Chemical analysis for Bara's sand.

Component	Composition
SiO	98.56%
Al_2O_3	0.99%
Fe_2O_3	0.26%
CaO	0.01%
Other Component	0.18%

Table 6: Chemical analysis for Elmatama's sand.

Component	**Composition**
SiO_2	94%
Al_2O_3	3.10%
Fe_2O_3	0.73
CaO	0.18
MgO	0.11%
K_2O	0.81%
Other Component	1.07%

The particles size of Bara sand and Elmatama meets the standards (*i.e.* 46% partial retention on mesh no.140 and 31% weight passing percent (Ash Associates bench scale), so it can be used directly without any reduction in particle size. Nile river sand and the regular concrete sand have relatively big particle size, therefore, it is not preferable to use it as a raw material in sodium silicate production for the costs that follow the mechanical process used to reduce the particle size. The quarts from river sand have a very organized particle sizes, this feature makes it very suitable to be used in water filtration. According to these results Elmatama's sand has the best quality in term of particle size and particle distribution (Figure 2 and Tables 7-10).

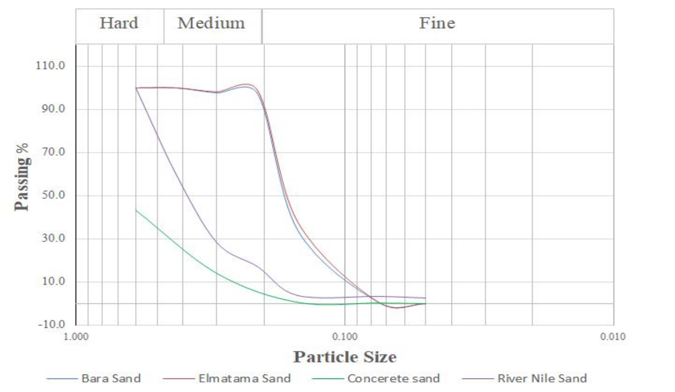

Figure 2: Sieve analysis for all the samples.

Table 7: Chemical analysis for regular concrete sand.

Component	**Composition**
SiO_2	87.74%
Al_2O_3	0.32%
Fe_2O_3	0.43%
CaO	3.20%
SO_3	0.02%
Other component	8.29%

Table 8: Chemical analysis for nile river beach's sand.

Component	Composition
SiO_2	87.91%
Al_2O_3	4.70%
Fe_2O_3	0.94%
CaO	0.14%
SO_3	0.09%
Other component	6.22%

Table 9: Successful runs for producing sodium silicate at two different temperatures.

Run No.	Ratio SiO_2:Na	Reaction temperature (°C)	Time elapsed (hrs)
1	3:01	1100	t>8
2	2,5:1	1200	6

Table 10: Solubility of the produced sodium silicate.

Lumps weight (mg)	Water volume (ml)	Temperature (°C)	Evaporates (ml)	Solubility (g/100 ml water)
3.5	20	150	17	116.6
3.5	20	100	16.5	100
3.5	20	80	16.3	94.5
3.5	20	40	10	43.3
3.5	20	25	7	29

Chemical analysis: Sand from around Bara has the highest purity, the 1% of the aluminum oxide doesn't affect the production of sodium silicate but it affects the solubility of the product adversely since it is insoluble material [12]. The compositions of both Iron oxide and calcium oxide are very low so their existence can be neglected.

Elmatams sand comes after Baras sand with purity of 94% and noticeable existence of Aluminum oxide, moreover, the Magnesium oxide converts into Magnesium hydroxide which is insoluble component, however it may help to neutralize the final product. There is also a noticeable amount of potassium oxide, it is a reactive material that reacts with silicon contents in high temperature producing potassium silicate, and however, potassium silicate has almost the same properties of sodium silicate [13].

The regular concrete sand contains relatively high percentage of carbon oxide and it is the reason behind the dark color of this type of sand, however, carbon oxide is the main component of cement and it is known by its unique properties that make it a perfect material to be used in the constructions. River Nile sand has the highest content of Aluminum oxide.

Production of sodium silicate culets (reaction): Sodium silicate culets was failed to be produced in temperatures less than 1100°C due to the insufficiency of the heat. It might have succeeded if the soda ash (Na_2CO_3) and quartz (SiO_2) was left for two days. Yet the quality of the culets would not be as high as if the reaction took place at 1100°C or higher. However, the cullets were successfully produced at 1100°C and 1200°C in 10 hrs and 6 hrs respectively. Both of the products were the same and barley to be distinguished Figures 3 and 4.

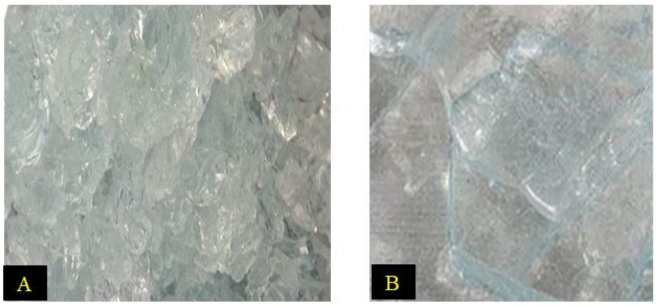

Figure 3: Sodium silicate culets produced at a) 1100°C; b) 1200°C .

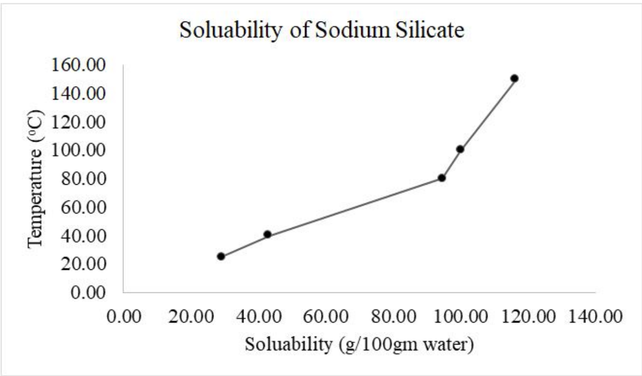

Figure 4: The effect of the temperature on the solubility of the sodium silcicate culets for all the samples.

Solubility of the product: The solubility of the produced sodium silicate was found 29 g/100 gm water at the room temperature. However, it increases up to 116.6 g/100 gm water at 150°C. The commercial sodium silicate has solubility of 160 gm/100 gm water at 100°C and 22 gm/100 gm water at 25°C. The lower solubility is a result of the impurities in the sand and the ratio of the reacted silica to soda ash. The purity can be enhanced by washing the quartz chemically and physically before it is feed into the oven. Nevertheless, the extreme cheap price of Bara and Elmatama quartz is commercially attractive, and the cost of the produced sodium silicate is way cheaper to the commercial one (Figure 5).

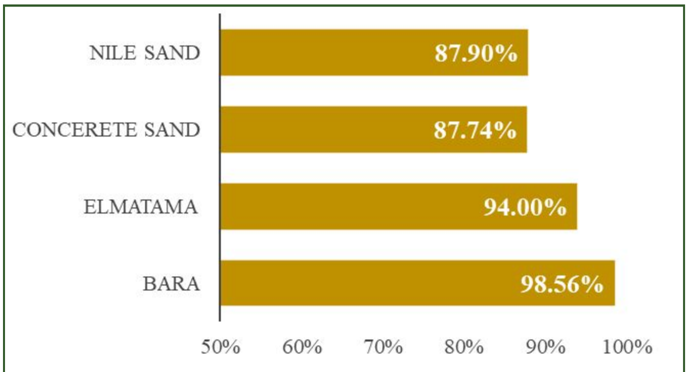

Figure 5: Purity of the quartz (silica content) for all the samples.

CONCLUSION

Sudan has a high potential of pure silica quartz. However, most of this quartz is not exploited. Bara sand has shown the highest purity of 98% of silica content, that purity is acceptable as a direct raw material for sodium silicate manufacturing. Moreover, the sieve analysis shows that sand from Bara and Elmatama has an extremely fine particle size unlike beach sand and concrete sand.

Sodium silicate can be produced from Sudanese sand at minimum temperature of 1100°C in which the reaction time is about five hours. The produced sodium silicate has very good solubility at room temperature and almost similar to the commercial sodium silicate. Thus, Sudanese quartz has very fine particle and extremely high purity makes it very attractive raw material for producing of sodium silicate. However, this valuable resource can be exploiting locally by constructing number of sodium silicate factories in Sudan, or externally by treating it and exporting it.

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