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Research paper

Preliminary study on upgrading silica sand from the Elwadi Elgedid, Western Desert, Egypt for compatibility with various industrial applications

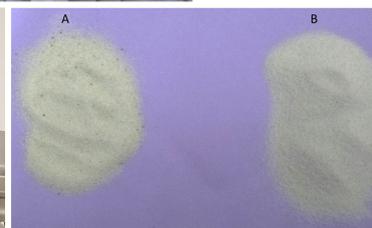
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HIGHLIGHTS

- Silica sand is an economical raw highly silica.
- Purification from contaminations (refractory minerals).
- Physical and chemical techniques are using in regard with low coastline.
- Using rare earth roll, magnetic separator to decrease the iron and titanium oxides.
- Applications that concentrate silica sand can be used.

GRAPHICAL ABSTRACT



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ABSTRACT

The silica sand from the vast Elwadi Elgedid desert is an important potential resource. However, before it can be used industrially, its quality needs to be improved by reducing the ratios of iron and titanium oxides. The current study investigated several different methods of this silica's beneficiation process with regard to the cost of beginning a possible metal-silicon industry. Foremost, looked at autogenesis disintegration, dry screening, and dry-high intensity magnetic separation using Eriez rare earth rolls belt speed 114 rpm, splitting angle 95°. Then moved on to acid leaching via oxalic and sulfuric acids. The analysis of silica sand concentrate reveals 98.80% SiO₂ with 0.40% Al₂O₃, 0.06% Fe₂O₃, 0.03% TiO₂, and 0.38 LOI. This processed silicon sand is currently unsuitable for the metallurgical silicon, solar silicon, and even semi-conductor industries. However, it is suitable for grade F uses, including colored glass containers according to British standards (B.S.) and sheet and plate glass according to the American Ceramic Society and National Bureau of Standard. It is considered medium-grade according to Indian standards specifications (I.S.), making it suitable for pale-coloured glass wares. Moreover, it is suitable for foundry paints, plastics, polymer compounds, rubber, sealants, resins, adhesives, and ceramics industries.

1. Introduction

Silica sand is essential as it is used in manufacturing by more than 300 industries. This includes glass industries such as glassware, crystal glass, plate glass, fiberglass, and optical glass, as well as other industries such as plumbing templates; ceramic strippers; bricks; filters for water purification plants, wastewater, and swimming pools; and as an extensor or a filler in the rubber, plastics, paper, paints industry. It can also be used in a special type of cement in various chemical industries and as a discount factor for the degree of melting of oxides in basal melting [1]. Silica sand is also used in silicon industries to produce computer chips and solar cells, Portland cement, fire bricks, many mold release agents and molding compounds, semiconductor in transistors, several waterproofing systems, and as a component of ferrosilicon - an alloy widely used in the steel industry [2].

The study area was located on the south Dakhla oasis road about 45 km south of the oasis in the Governorate of Elwadi Elgedid, Western desert of Egypt at (25° 07' 37" N, 29° 05' 36" E) (Fig. 1). This figure illustrates the primary topographic features. The raw silica sand has been briefly investigated in a previous study [3,4]. This type of silica sand is a large untapped resource that has not yet undergone upgrading studies on its potential to provide feedstocks acceptable to the silicon industry. One obvious advantage of this sand is its low cost of transportation. In Egypt, huge resources of silica sands (SiO₂ content >98%) exist in the Sinai, Elzafrana in the Eastern Desert, and Elwadi Elgedid in the West Desert. However, despite previous studies that have assessed silica sands resources in different locations in Egypt for exploitation in industrial applications, there is no silicon industry in Egypt [3,5-9].

Before this silica sand can be used, it is vital to upgrade the raw sand by partially removing the iron and undesirable minerals that affect its end-use value at a low cost. Some of these techniques, such as size separation screening and magnetic separation, involve many of the liberated impurities and can reduce or remove unwanted oxides or impurities through physical operations. Chemical leaching is another effective method that has been closely associated with the removal of the often superficial mineral iron oxide. Proposed flow sheets and layouts are necessary to upgrade the impure sand to a higher quality grade acceptable for different industries.



Fig. 1. Location of the study silica sand sample at Elwadi Elgedid, Western Desert, Egypt.

Minimizing the iron oxide content in silica sand ores to add value has been the target of many researchers [10-18]. Ali *et al.* [19] and Boulos *et al.* [20] also investigated utilizing a local quartz resource to produce MG-Si by studying the factors affecting the production process, e.g., the carbon/silica ratio, reduction time, power input, and weight ratio of the carbon sources.

Therefore, the aim of this study is to upgrade the characteristics of Elwadi Elgedid silica sand for the broadest possible utilization in industries that require a higher silica percentage and lower iron and titanium percentages. To achieve these purposes, the following investigations were carried out:

- 1- A pilot sample of 0.5 kilograms was taken from the Elwadi Elgedid area.
- 2- Then, a screening analysis was conducted on the sample.
- 3- Followed by magnetic separation investigations.
- 4- Finally, chemical leaching was used to remove the iron oxides.

Several countries' codified standards and specifications were used to evaluate the treated silica sand's quality for industrial applications. Ullmann's Encyclopedia of Industrial Chemistry states high-grade raw materials (quartz) are required to produce metallurgical grade (MG) silicon [21], as shown in Table 1. Iraq's State Company for Mining Industries and Aquatic Insulation, as a part of a project for the production of silicon for solar cell and silicones industries, is shown in Table 2.

Table 1. Chemical composition of the quartz raw materials required for MG silicon [22].

Component	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	TiO ₂	CaO	MgO
wt (%)	≥ 99	≤ 0.1	≤ 0.2	≤ 0.02	≤ 0.1	≤ 0.1

Table 2. The specification for silica sand raw materials required for MG silicon [22].

Component	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	TiO ₂	CaO	MgO	P ₂ O ₅	SO ₃	Na ₂ O	K ₂ O	LOI
wt (%)	99 min	0.03 max	0.5 max	trace	0.1 max	0.006 max	0.4 max	0.5 max	0.25 max	0.05 max	0.2 max

Table 3 summarizes part of the key specification requirement for a range of specialized silicon end-uses [23]. The specification requirements for the highest grades of silica sand are set out in Table 4.

2. Geologic Setting

The geological map (Fig. 2) shows the exposed sedimentary formations [25] range from the Lower Cretaceous to Paleocene period. Pleistocene sediments are widespread and cover the older rock types.

The major formations in the study area are from the Lower Cretaceous, Upper Cretaceous, and Pleistocene periods. The silica sand is restricted to Taref member, a local member of the Nubian Aquifer sandstone which belong to the upper Cretaceous. Field photographs reveal cavities and many cracks in the silica sand strata in the study area (Fig. 3).

3. Analysis techniques and experiments

A pilot sample of Elwadi Elgedid sand was treated to release the iron and titanium oxides and improve the silica content for application in industries with high silica content. Then, a screening analysis similar to that in [3,4] was used to briefly examine the sample's heavy mineral content and geochemical components. Next, the sample underwent magnetic separation at

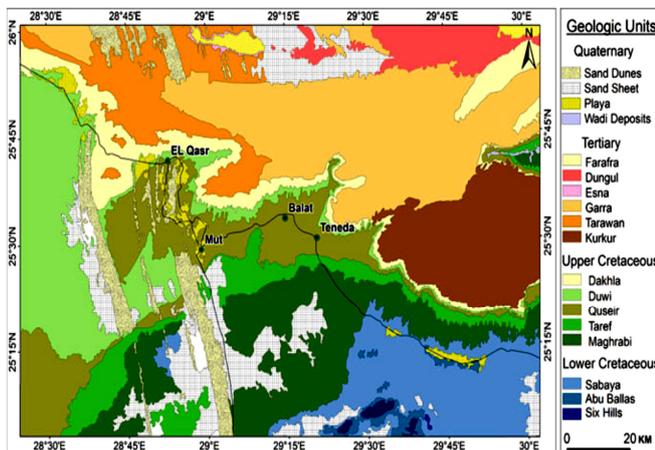


Fig. 2. Geological units of study area at Elwadi Elgedid, Western Desert, Egypt.

Table 3. The key specification requirements for end-uses [23].

End use	Requirements
Coloured glass	SiO ₂ > 97%
	Fe ₂ O ₃ < 0.3%
	Al ₂ O ₃ < 0.5%
	TiO ₂ < 0.03%
	Cr ₂ O ₃ < 0.002%
	Chemical consistency: high < 0.2% coarser than 500 microns < 1% finer than 125 microns
Foundry	SiO ₂ > 95%
	Fe ₂ O ₃ < 0.3%
	CaO < 0.2%
	K ₂ O + Na ₂ O < 0.5%
	Loss of ignition (LOI) 0.5%
	Acid demand to pH4 < 6ml < 2% finer than 200 microns < 0.5% finer than 63 microns
	Sub-rounded to rounded grains Medium to high sphericity grains
Paints, Plastics, Polymer compounds, Rubber, Sealants, Resins and Adhesives	SiO ₂ > 96%
	Fe ₂ O ₃ < 2%
Ceramics	SiO ₂ > 97.5%
	Fe ₂ O ₃ < 0.2%
	Al ₂ O ₃ < 0.55%
The British Standard BS2975	SiO ₂ 97.0
Grade F Coloured container glass	Fe ₂ O ₃ 0.25
	Al ₂ O ₃ 0.1
	Cr ₂ O ₃
Indian Standard for glass making 2 nd Revision (IS 488: 1980)	LOI
	SiO ₂
	Fe ₂ O ₃
	Grade II
American Ceramic Society and the National Bureau Standard (Norton, 1957)	SiO ₂ (min) 98.5
	Al ₂ O ₃ % (max) 0.5
	Fe ₂ O ₃ % (max) 0.06
Quality Sheet and plate glass	CaO + MgO % (max) 0.5

Table 4. Typical chemical analyses of silica sand for the semiconductor industry [24].

Element	Unit	Metallurgical grade silicon	Solar grade silicon	Polycrystalline solar grade silicon	Electronic grade
Si	wt%	99	99.999 9	99.999 99	99.999 99
Fe	ppm	2000-3000	< 0.3		99.999 99
Al	ppm	1500-4000	< 0.1		99.999 99
Ca	ppm	500-600	< 0.1		99.999 99
B	ppm	40-80	< 0.3		99.999 99
P	ppm	20-50	< 0.1		99.999 99
C	ppm	600	< 3		99.999 99
O	ppm	3000	< 10		99.999 99
Ti	ppm	160-200	< 0.01		99.999 99
Cr	ppm	50-200	< 0.1		
Mg					

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A high-intensity rare earth roll, magnetic separator is normally used to remove the ferrous, para, and weakly magnetic minerals from dry nonmetallic minerals such as silica [26]. In this study, an Eriez high-strength rare-earth roll (RER) magnetic separator was applied for dry magnetic separation (DHIMS) of the refractory minerals in the silica sand (Fig. 4). The main advantages of using DHIMS are as follows:

- Reducing the operating costs, often in a range of 30-50% compared to induced roll magnets and even lower compared to cross belt separators.
- Enhancing product quality
- Optimizing product yields



Fig. 3. Field photographs showing silica sand strata at Elwadi Elgedid, Western Desert, Egypt.

- Augmenting economic recovery of valuable minerals from waste materials.

- Potentially eliminating the need for WHIMS (Wet High Intensity Magnetic Separators) when combined with more efficient mineral sands gravity circuits. This further reduces the process complexity and costs while, at the same time, producing final grade products often after only one stage of magnetic separation. In other words, they often produce a far purer product at a relatively early stage.

- Increasing overall dry processing efficiency.
- Decreasing plant size and lower capital costs.
- Reducing the need for operators and their associated skill levels.
- Enhancing ore reserves due to overall greater efficiencies, resulting in a greater pit to product yield.
- Reducing equipment footprints of up to 90% over electromagnets.



Fig. 4. Eriez rare earth roll, magnetic separator in Central Metallurgical Research and Development Institute.

- Optimizing capacity - Larger diameter rare-earth roll magnets allow mineral processors over 300% more capacity than other prior-art rare-earth magnetic separators.

An ESEM instrument was used to investigate the heavy minerals and quartz grains in the silica sand concentrate. It was supported by an energy-dispersive spectrometer unit (model Philips XL 30). The applied analytical conditions involved 30 kV as the accelerating voltage, 1–2 mm beam diameter during 60 to 120 s as the counting time, and a minimum detectable weight concentration ranging from 0.1 to 1 wt% housed in the Nuclear Materials Authority in Qattamiya, Cairo, Egypt. The major chemical elements in the concentrate silica sand were determined using X-ray fluorescence spectrometry. The resulting major oxides included SiO₂, TiO₂, CaO, MgO, Na₂O, K₂O, Fe₂O₃, P₂O₅, Al₂O₃, Cl, SO₃, and loss on ignition (LOI), as well as the trace elements Zn, Mn, Ni, Cr, Sr, Y, and Zr.

These oxides were determined using AXIOS and WD-X-ray fluorescence (XRF). In addition, sequential spectrometry was used to determine the chemical composition of major and trace elements in the whole sample. The sample preparation and analyses were professionally undertaken in the National Research Center in Egypt (NRC) laboratory. In the NRC XRF lab, the studied silica sand was crushed and then ground in a Herzog mill into a rich fine powder. The sample under investigation was divided into two portions. One was a pressed powder sample prepared to measure the trace elements, and the other was a fused bead sample prepared to measure the major elements.

3.1. Fused bead sample

In a Pt crucible, 1 g of fine powder of the study concentrate sample was mixed with 1 g of flux composed of Li tetraborate/Li metaborate (66.6/33.3) and NH₄NO₃ and 5 ml (solution of 0.5 g per 2 ml distilled water) was added as an oxidizing agent. In an automatic fusion machine Perlx I, the mixture was heated to 550 °C for 3 min to oxidize the sample, then agitated the crucible while increasing the heat to 1150 °C for 10 min. When complete fusion was achieved, the mixture was put in a 37 mm internal diameter Pt dish and cooled naturally for 4 min; afterward, it was further cooled with forced air for 2 min. The yielded fused bead was used in the qualitative analysis of the elements.

3.2. Pressed powder sample

The pressed powder sample was prepared by mixing 6 g of fine powder from study sample with 1.5 g binding wax in a small mill at a speed of 380 cr/mnt for 1 min. Then, the sample was put in an aluminum cup and pressed in an automatic pressing machine under 130 kN. The yielded disk sample was used in quantitative analysis of the elements. The sample was analyzed with an AXIOS, WD-XRF Sequential Spectrometer (PANalytical 2005) controlled from an external computer running the analytical software package (Super Q4) to identify the sand grain morphology. X-ray analysis was conducted using an End Window Rhodium (Rh) Anode X-ray Tube of ceramic construction operated at up to 60 kV and a current up to 160 MA at a maximum power level of 4 kW supplied from a high voltage generator and cooled using deionized water. The tube is designed with a tapered (sharp) nose to give the minimum distance between the anode and the sample surface.

The silica sand sample was first autogenously disintegrated and sieved (dry screen). Any clay and fractions larger than 0.5 mm were removed to minimize the shielding effect of coarse and very fine grains when using the High-Intensity Dry Magnetic Separation (DHIMS) of rare earth rollers. The silica sand sample weighed 500 g after eliminating the unwanted sizes. Following these procedures, the grains of silica sand consisted of –0.5 to +0.25 and –0.25 to +0.125 mm size fractions, with approximately 9.52% of the total sample ranging from –0.5 to +0.25 mm and 90.48% ranging from –0.25 to +0.125 mm (Fig. 5).

The treatment performed on this sample was split into two stages, physical separation and chemical acid

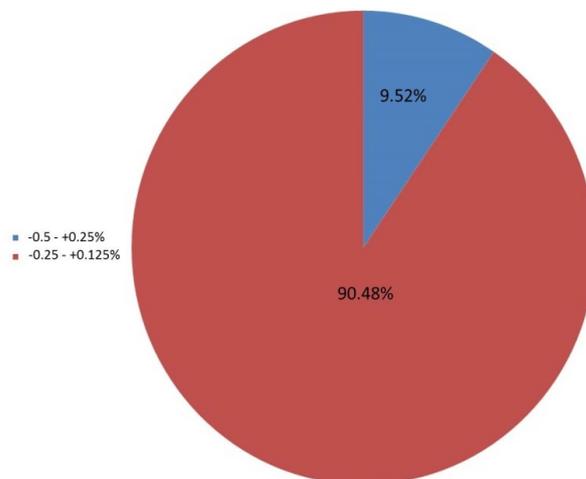


Fig. 5. Pie chart illustrated wt% of feed silica sand sample fractions.

leaching, to remove the iron and other impurities. In the first stage, the prepared sand was fed into an Eriez Rare Earth roll (RER) magnetic separator to remove the iron and titanium minerals contaminating the silica sand by magnetic separation in the 0.5 tesla region. The Eriez Rare Earth roll's belt speed was 114 rpm with a splitting angle of 95°. In the second stage, the acid leaching (using oxalic and sulphuric acids) affected the presence of tiny low soluble barite crystals in the cavities of the quartz grains resulting in an iron oxide film that coated and stained the quartz grains a brown color. Oxalic acid is an environmentally friendly organic acid used to dissolve most iron oxides. It has cheap biological sources and a good complexation ability that can dissolve iron oxide, especially with sulfuric acid.

4. Results and discussion

The data was obtained from experiments carried out on a 500 g silica sand sample after eliminating unwanted grain sizes (to increase silica content) and releasing iron and titanium (impurities) in the raw sample to make it more usable for high silica industries. The amount of concentrate and tail weighed 371.79 and 128.21 g, respectively, making up 74.36% and 25.64% of the feed sample.

The size analysis of silica sand concentrates was classified into two main groups, $-0.5 - +0.25$ and $-0.25 - +0.125$, making up 15.19% and 84.81% of the sample, respectively. Fig. 6 illustrates the size distribution analysis of the concentrate grains.

Fig. 7 depicts the mineralogical content of the silica sand concentrate, and a complete chemical analysis is

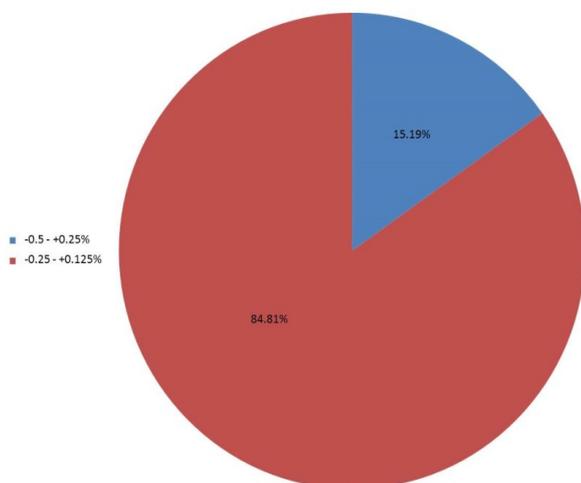


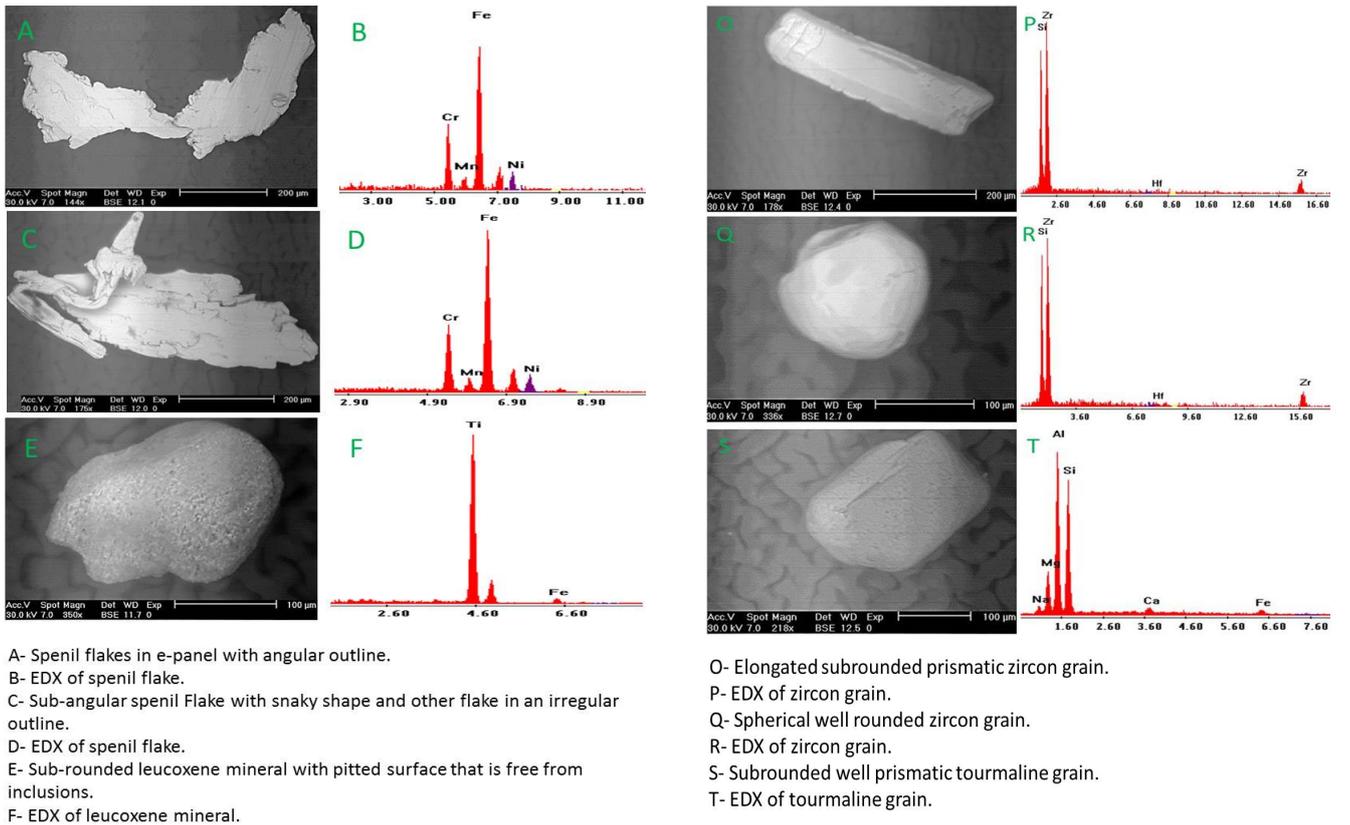
Fig. 6. Pie chart illustrated wt% of concentrate silica sand sample fractions.

shown in Table 5. High-intensity magnetic separation sounds are essential in minimizing the Fe_2O_3 content, and mineral images are used to represent the silica sand sample.

The sand grain morphology was evaluated using a scanning electron microscope (SEM). Additionally, a binocular microscope and SEM were used to evaluate the optical and morphological features of the detrital grains. The studied picked light and heavy grain fractions were subjected to investigation after separation by bromoform. Results showed that the heavy mineral contents were zircon, rutile, tourmaline, leucoxene, spinel, and ilmenite. The light mineral content was mainly quartz divided into brownish color grains stained with iron oxides and pure (white, clean glasses) colored grains without any inclusions on their surface. Characteristics of the grains were categorized, and the EDX patterns are shown in Figs. 7A to 7Z. In addition, the SEM images below indicate the presence of different shapes of minerals with irregular morphologies, for instance, Figs. 7A, 7C, and even 7Y show sub-rounded grains. But other grains are sub-rounded or elongated and sub-angular.

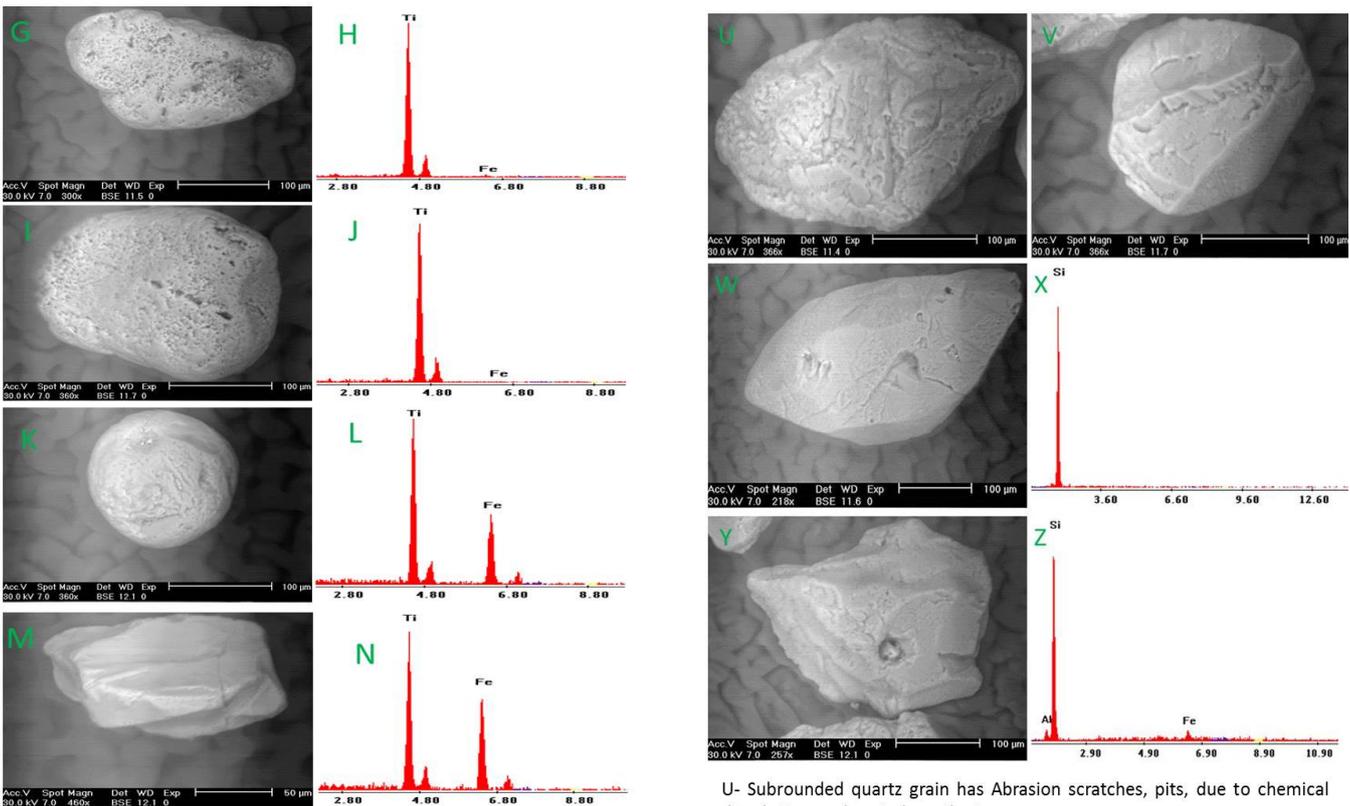
SEM images show that spinel has a flake form and e-panel lamellae cracks with an angular outline (Fig. 7A). The EDX pattern of this crystal is shown in Fig. 7B. Other spinel crystals have a subangular outline snaky shape, and other flakes have an irregular outline (Fig. 7C), with the EDX pattern illustrated in Fig. 7D. Leucoxene grain has a sub-rounded outline, and its surface is pitted and free from inclusions (Fig. 7E); its EDX pattern is shown in (Fig. 7F). Rutile prismatic grain has a sub-rounded outline with a pitted surface (Fig. 7G), and its EDX pattern is shown in Fig. 7H. Sub-rounded prismatic rutile grain is illustrated in Fig. 7I with straight scratches on the surface; its EDX pattern is shown in Fig. 7J. Ilmenite grain has a spherical shape with a rounded outline (Fig. 7K); its EDX pattern is shown in Fig. 7L. Another ilmenite grain is a prismatic shape and has a sub-angular outline (Fig. 7M); its EDX pattern is shown in Fig. 7N. Zircon grains have several shapes, such as elongated sub-rounded prism (Fig. 7O) and spherical well rounded (Fig. 7P); the EDX pattern of these zircon grains is shown in Figs. 7Q and 7R. Tourmaline grain has a well prismatic form and sub-rounded outline (Fig. 7S); its EDX pattern is shown in Fig. 7T.

Quartz grains are divided into two groups. The main group has clean quartz grains without any iron



A- Spenil flakes in e-panel with angular outline.
 B- EDX of spenil flake.
 C- Sub-angular spenil Flake with snaky shape and other flake in an irregular outline.
 D- EDX of spenil flake.
 E- Sub-rounded leucoxene mineral with pitted surface that is free from inclusions.
 F- EDX of leucoxene mineral.

O- Elongated subrounded prismatic zircon grain.
 P- EDX of zircon grain.
 Q- Spherical well rounded zircon grain.
 R- EDX of zircon grain.
 S- Subrounded well prismatic tourmaline grain.
 T- EDX of tourmaline grain.



G- Subrounded rutile prismatic grain with pitted surface.
 H- EDX of rutile grain.
 I- Subrounded rutile prismatic grain with straight scratches in surface.
 J- EDX of rutile grain.
 K- Rounded ilmenite with spherical shape.
 L- EDX of ilmenite grain.
 M- Subangular ilmenite prismatic grain.
 N- EDX of ilmenite grain.

U- Subrounded quartz grain has Abrasion scratches, pits, due to chemical dissolution or chemical weathering.
 V- Subrounded quartz sand grain has Abrasion scratches, pits, due to chemical dissolution or chemical weathering.
 W- Rounded quartz grain with v-shape cravks and pits in its surface.
 X- EDX of quartz grain.
 Y- Subrouded quartz grain with irregular outline shape even iron oxide is existed in pits and surface of grain.
 Z- EDX of quartz grain.

Fig. 7. Photomicrograph SEMs and EDXs of mineral content in studied silica sand concentrate.

Table 5. Chemical composition of the concentrate silica sand sample from Elwadi Elgedid.

Main oxides	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	Cl	LOI
Concentrate (wt%)	98.80	0.03	0.40	0.06	0.02	0.09	0.04	0.02	0.02	0.10	0.04	0.38
Raw (wt%)	98.19	0.24	0.57	0.08	0.08	0.10	0.06	0.01	0.03	0.13	0.04	0.30
Traces		Ni		Cr		Cu		Sr		Zr		
ppm		39.29		68.42		39.94		25.37		103.64		

inclusions, including sub-rounded grains with abrasion scratches and pits (Fig. 7U), sub-rounded sand grains with abrasion scratches and pits (Fig. 7V), and rounded grains with v-shape cracks and pits in its surface (Fig. 7W). Fig. 7X shows the EDX pattern that reflects the effect of chemical dissolution or early chemical weathering on the grains of the main group. The other group is made up of quartz grains that still include iron inclusions. The sub-rounded quartz grains with irregular outline shapes have pits filled with iron inclusions and a thin brownish film on their surface (Fig. 7Y); its EDX pattern is shown in Fig. 7Z.

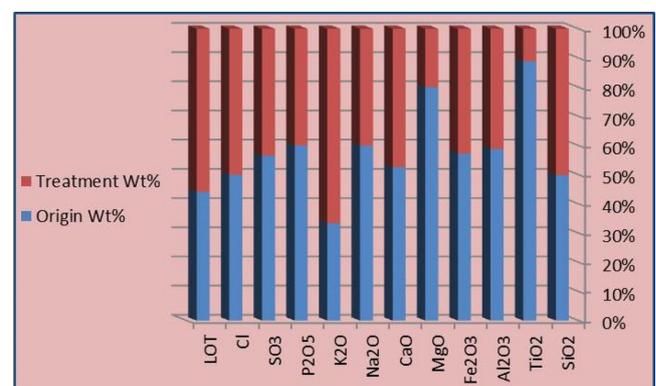
As shown in Table 5 (chemical analysis of the silica sand concentrate), the results revealed that the highest percentage concentration of SiO₂ in the silica sand sample reached 98.80%, minor oxides included (in wt%) Al₂O₃ (0.40), TiO₂ (0.03), MgO (0.02), Fe₂O₃ (0.06), Na₂O (0.04), K₂O (0.02), CaO (0.09), P₂O₅ (0.02), Cl (0.04), and SO₃ (0.10), a loss on ignition (0.38), and trace elements (in ppm) Cr (68.42), Cu (39.94), Sr (25.37), Ni (39.29), and Zr (103.64) were detected.

It should be noted that the high SiO₂ content of the treatment sample revealed that silica sand is mostly composed of high quartz crystal content. The concentration of SiO₂ in this study's silica sand sample is similar to the silica sand in other research [16]. Similar to the results of Osman *et al.* [4], there was no significant difference in the chemical composition of the treatment sample and the raw sample (Table 5). A slight decrease in Fe₂O₃ content in the treated silica sand compared to the Fe₂O₃ in the raw sample (a 25% reduction in iron content) was achieved; however, the iron oxide content never exceeded 0.005%. Moreover, a 97.5% reduction of TiO₂ content was achieved (Fig. 8), as well as a 75% reduction in MgO content. Also, 75.15% of Zr (417 ppm) content was reduced compared to the Zr (103.64 ppm) content in the raw sample. A substantial decrease in TiO₂%, MgO%, and Zr (in ppm) revealed that titanium minerals (ilmenite,

leucosene, and rutile), tourmaline (which contains MgO in its chemical structure), and zircon (which contains Zr in its chemical structure) were removed. These minerals are considered contaminants [27] or refractory minerals.

Based on the laboratory processing studies conducted on the pilot silica sand sample from the Elwadi Elgedid, Western desert, Egypt, a proposed beneficiation flow sheet (Fig. 9) is explained in the following paragraph.

To begin, the pilot sample of silica sand can be either blended in any proportion or taken individually. The sample is first dry-screened using a single deck vibrating screen with a 500 g screen, and the oversize (> 0.5) and undersize (< 0.125) grains are discarded. In the first stage of the treatment process, the modified desired fractioned sample is passed through dry rare earth magnetic separators to remove iron and titanium impurities. During the process, the non-magnetic part of the magnetic separator is sent to be washed twice with tap water and then dewatered. In the second stage, the acid leaching process is carried out by a sulfuric acid concentration and oxalic acid concentration. Then, the sample is washed with hot water for one hour. Finally, the sample is decanted, washed with tap water several times, and dewatered and dried in a drying oven at 90 to 100 °C for 6-8 h.

**Fig. 8.** Stacked column wt% of raw silica sand and concentrate after treatment chemical compositions.

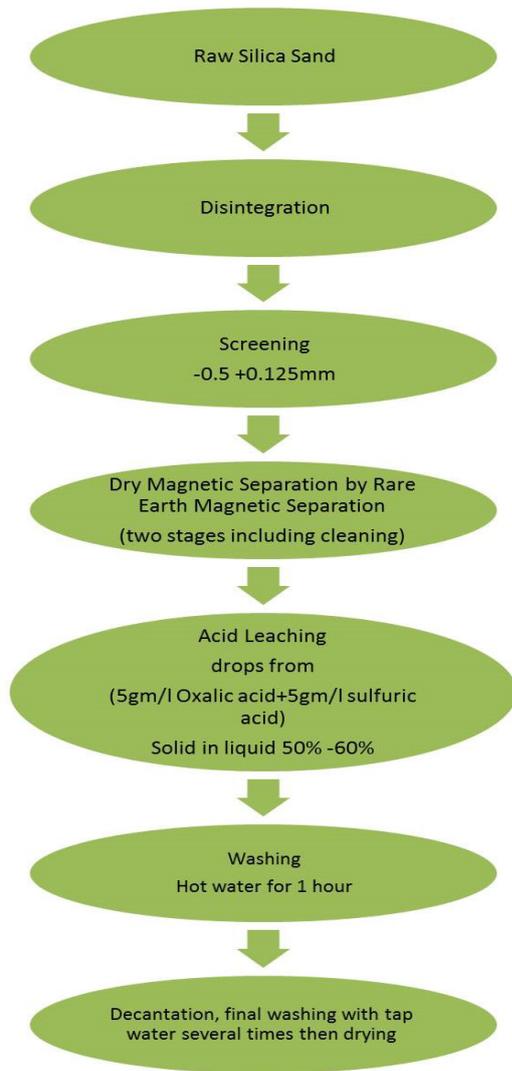


Fig. 9. Integrated flow sheet for the processing of silica sand for special silica grade.

Fig. 10 shows an image of the raw and processed samples from the Elwadi Elgedid, Western desert. As can be observed, the treated samples reflected more brightness (matte, vitreous) and color due to the quartz (the silica) in the sample. The treated sand concentrate demonstrated a notable enrichment in the bright minerals and a reduction in refractory minerals compared to the raw silica sand (white) of the Elwadi Elgedid (see Fig. 10). This image is a visual indicator (difference in whiteness) of the purification of this sand. The integrated flow sheet provides insight into all the upgrade steps. The final concentration of silica sand in the treated sample was 74.36%.

5. Recommendations

Any development that affects the production of silica sand in this area will have implications and



Fig. 10. Photograph of raw (A) and processed (B) sample from Elwadi Elgedid area, Western desert, Egypt.

repercussions for the use of silica sand in other areas and on the costs, supply, and quality of raw materials going to manufacturing industries. So, this study's aim is to attempt to improve silica sand from the Elwadi Elgedid area. Our results are summarized below.

- No significant improvement occurred in the silica sand using dry magnetic separation at a field intensity of 5 kilogauss; on the contrary, Mustafa *et al.*'s [23] uses the rare earth magnetic separator device under different circumstances at 16 kilogauss.

- Acid leaching conditions with sulfuric acid concentration (5 g.l^{-1}), oxalic acid concentration (5 g.l^{-1}), and leaching time (1 h) are comparable with the optimum conditions of 4.99 g.l^{-1} , 10.1 g.l^{-1} , and 2.28 h in El Sayed *et al.* [28] for releasing iron oxide.

- These techniques can be used in combination with screening to produce sand compatible with the requirements of silicon raw materials.

- These techniques can also be used with suggested parameters of 16 kilogauss and sulfuric acid and oxalic acid concentrations of 4.99 and 10.1 g.l^{-1} for 2.28 h.

6. Conclusion

Experiments were conducted on silica sand from the Elwadi Elgedid area of the Western Desert to upgrade its value-added utility. The principal impurities of the feed sample were restricted to iron and titanium minerals. This study dealt with the elimination of these contaminating minerals composed of undesirable oxides. The techniques are summarized in the flow-sheet that adopted primary recovery procedures beneficial to silica sand. In particular, dry sieving, magnetic separation, and acid leaching were undertaken for a special class of silica sand. Unfortunately, the

silica sand sample obtained after enrichment was insufficient to meet the silica sand requirements for the semiconductor industry. However, according to British standards (B.S.) specifications for the glass market, it is suitable for grade F or the manufacturing of colored glass containers. The studied glass sand is also suitable for sheet and plate glass according to the American Ceramic Society and National Bureau of Standard, and according to the specifications of the Indian standards (I.S.), it is considered medium-grade and is suitable for pale-coloured glass wares. Additionally, the sand was found to be suitable for foundry paints, plastics, polymeric compounds, rubber, sealants, resins, adhesives, and ceramics industries.

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References

- [1] International Silica Industries, retrieved April 16, 2022 from <https://silica-jo.com/index.php?q=en/node/16>.
- [2] Uses of Silicon (Si) - Chemical Properties of Silicon & Polymers of Silicon, Founded Nov, 30, 2011, Headquarters: Bengaluru, India, retrieved April 16, 2022 from <https://byjus.com/chemistry/silicon/>.
- [3] R.A. Osman, Assessment of chemical and mineralogical features on silica sand and its potential industrial applications at Elwadi Elgedid, Western Desert, Egypt, *Int. J. Innov. Sci. Eng. Tech.* 8 (2021) 99-115.
- [4] R.A. Osman, Investigation of microtextures on the surface of mesozoic quartz grains to study the prevailing paleoenvironmental conditions on silica sand, Elwadi Elgedid, Western Desert, Egypt, *Curr. Sci. Int.* 10 (2021) 89-96.
- [5] A. Hussein, Mineral deposits, In: R. Said, Ed., *The Geology of Egypt*, Taylor and Francis Publishers, London, 1990, pp. 511-566.
- [6] M. A.W. Gaber, Evaluation of some natural ores from Egyptian eastern desert to be utilized in producing of paint materials, *J. Petrol. Gas Expl. Res.* 2 (2012) 17-26.
- [7] A.I. Gamal, S.M. Ahmed, Y.M. Tarek, A. El-Hariri, M.H. Ibrahim, New industrial use of White Sands from Wadi EL Dakhl area, Eastern Desert, Egypt, *nt. J. Innov. Sci. Eng. Tech.* 3 (2016) 516-524.
- [8] M. Ezz-El Din, A.M. Abouzeid, Kh. El Maadawy, A.M. Khalid, R.E. El Sherif, Mineral industry in Egypt- Part II. Non-metallic commodities - Silica ores, *J. Min. World Exp. (MWE)* 5 (2016) 9-27.
- [9] G.E.A. Ibrahim, A.S. Mousa, T.Y.M.A. El-hariri, I.M. Hassnien, N.I. Zakzouk, New industrial use of Egyptian White Sands from Wadi ElDakhl Area, Eastern Desert, Egypt, *Int. J. Innov. Sci. Eng. Tech.* 3 (2016) 516-525.
- [10] A.N. Banza, J. Quindt, E. Gock, Improvement of the quartz sand processing at Hohenbocka, *Int. J. Miner. Process.* 79 (2006) 76-82.
- [11] E. Jamieson, A. Jones, D. Cooling, N. Stockton, Magnetic separation of red sand to produce value, *Miner. Eng.* 19 (2006) 1603-1605.
- [12] N.R. Shaffer, The time of sands: Quartz-rich sand deposits as a renewable resource, *Electronic Green Journal* (2006) 24. <http://dx.doi.org/10.5070/G312410669> Retrieved from <https://escholarship.org/uc/item/6m743258>.
- [13] D. Mowla, G. Karimi, K. Ostadnezhad, Removal of hematite from silica sand ore by reverse flotation technique, *Sep. Purif. Technol.* 58 (2008) 419-423.
- [14] M. Sundararajan, S. Ramaswamy, P. Raghavan, Evaluation for the beneficiability of white silica sands from the overburden of lignite mine situated in Rajparadi district of Gujarat, India, *J. Miner. Mater. Charact. Eng.* 8 (2009) 701-714.
- [15] Z. Zhang, J. Li, X. Li, H. Huang, L. Zhou, T. Xiong, High efficiency iron removal from quartz sand using phosphoric acid, *Int. J. Miner. Process.* 114 (2012) 30-34.
- [16] S.S. Ibrahim, A.Q. Selim, A.A. Hagrass, Gravity separation of silica sands for value addition, *Particul. Sci. Technol.* 31 (2013) 590-595.
- [17] S.S. Ibrahim, M.M. Farahat, T.R. Boulos, Optimizing the performance of the RER magnetic separator for upgrading silica sands, *Particul. Sci. Technol.* 35 (2017) 21-28.
- [18] A. Tuncuk, A. Akcil, Removal of iron from quartz ore using different acids: A laboratory-scale reactor

- study, *Min. Proc. Ext. Met. Rev.* 35 (2014) 217-228.
- [19] H.H.M. Ali, M.H. El-Sadek, M.B. Morsi, K.A. El-Barawy, R.M. Abou-Shahba, Production of metallurgical-grade silicon from Egyptian quartz, *J. S. Afr. I. Min. Metall.* 118 (2018) 143-148.
- [20] T.R. Boulos, A. Yehia, M.B. Morsi, S.S. Ibrahim, High quality fused silica from Egyptian silica sand concentrate, *Int. J. Sci. Eng. Invest.* 6 (2017) 160-166.
- [21] O.W. Flörke, H.A. Graetsch, Ullmann's Encyclopedia of Industrial Chemistry, Chapter 2. Silica, Wiley-VCH GmbH & Co., Weinheim, 2007.
- [22] A.M.Kh. Mustafa, I.Kh. Fleah, T.V. Khachiek, Preliminary upgrading of silica sand for silicon and silicones industries from Ardhuma, Iraqi Western Desert, *Iraqi Bulletin of Geology and Mining*, 9 (2013) 75-84.
- [23] A. Thompson, J.S. Poole, Cuesta Consulting Limited, Silica Sand Study (Final Report): updated and revised edition of the report originally published as "The Soft Sand & Silica Sand Study, 2015", Nov. 2016, pp. 1-75.
- [24] B.S. Xakalashé, M. Tangstad, Silicon processing: from quartz to crystalline silicon solar cells, *S. Afr. Pyrometall.* (2011) 83-100.
- [25] I. Brooks, Geomorphology and quaternary geology of the Dakhla oasis, *Quaternary Sci. Rev.* 12 (1993) 529-552.
- [26] Magnetic Separators-IMSC group, retrieved April 16, 2022 from <https://www.imsc-group.com/blog/2019/1/5/the-attraction-of-rare-earth-magnetic-separators>.
- [27] H.B. Goldman, Glass raw materials, In D.D. Carr (Eds.), *Industrial minerals and rocks*, Littleton: Society for Mining, Metallurgy, and Exploration, 1994, pp. 869-877.
- [28] M.A. El Sayed, W.M. Fathy, A.M. Salleh, S.S. Ibrahim, M.R. Moharam, Processing of Wadi Qena Kaolinitic White Sands by selective dispersion and leaching for industrial uses, *Journal of Al-Azhar University Engineering Sector*, Article 21, 13 (2018) 530-545.