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Improvement of Low-Grade Silica Sand Deposits In Jeddah Area

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ABSTRACT. There is no shortage of high-grade silica sand deposits in Saudi Arabia, but they are located about 1000 km from Jeddah industrial city. Therefore, the transportation cost becomes formidable. There are several low-grade silica sand deposits near Jeddah, but they require upgrading to provide raw material acceptable for the glass industry. This study reports beneficiation of two low-grade silica deposits near Jeddah. Techniques involving froth flotation, shaking table and magnetic separation have been utilized for the purpose. Proposed flow sheets and processing plant layouts for upgrading the impure sand to a level acceptable for bottle grade silica sand are presented.

KEYWORDS: beneficiation, flotation, shaking table, magnetic separation..

1. Introduction

There is a considerable demand for the bottle grade silica sand in the city of Jeddah. This demand is presently met by the supply of high-grade silica sand trucked in from deposits in central Saudi Arabia, located about 1000 kilometers from Jeddah [1-4]. Obviously the cost of transportation is prohibitive. There are no high-grade sand deposits near Jeddah. However, friable sandstone deposits exist within a radius of 50 km from Jeddah. These deposits contain a considerable proportion of alumina and lime as well as coloring matter consisting of iron, titanium and chromium minerals. Strict specifications regulate the requirements for the silica sand raw material for the glass industry. The minimum SiO_2 content ranges from 97.5% for low quality products such as colored bottle glass to 99.75% for crystal and optical glass. The maximum

Fe_2O_3 content ranges from 0.008% for optical glass to 0.3% for green glass. The sand grain size ranges from 0.1 to 0.63 mm [1].

Several deposits of silica sand in the Jeddah-Makkah area have been located by the Deputy Ministry of Mineral Resources (DMMR). A basic information about these deposits, including location, size, thickness, tonnage and mineralogical composition is available in a DMMR report of investigation [5]. Among these deposits, Wadi Si'al and Jabal Abu Siba were selected for this study because of their high silica and low alumina and iron contents. The thickness of the sand layer as well as depth and type of overburden were also considered during the selection process.

Wadi Si'al deposit may be described as multicolored, banded, very fine to medium, friable sandstone. Whereas, Jabal Abu Siba deposit is light cream to off-white, stiff, very fine to medium, friable, slightly cemented sandstone. It contains sparse light brown to brown thin bands of the same material. This deposit appears to be a good raw material for silica sand.

2. Improvement Techniques

Various combinations of mineral processing techniques [6, 7] were applied to upgrade samples collected from Wadi Si'al and Jabal Abu Siba deposits. These were: screening, scrubbing, froth flotation, shaking table, and magnetic separation. Froth flotation and shaking table were the principal mineral processing methods adopted in this study.

When the method of froth flotation was employed, the fundamental operations were: sampling, scrubbing and de-sliming, flotation, magnetic separation and chemical analysis. In case of shaking table, the fundamental operations were sampling, washing and de-sliming, shaking table, magnetic separation and chemical analysis.

2.1 Sample Preparation

The bulk sample was disintegrated using a jaw crusher. The size of the sample was reduced using a chute rifler. One of the split portions was kept in a container while the other portion was screened in order to obtain a fraction of – 500 + 100 micron. This fraction was further split into two portions A and B. Portion A was further split into samples C and D, while B was split into samples E and F. The samples C and E were combined and split to obtain the two portions G and H. Each of the samples G and H were further split into two samples, B1, B2 and B3, B4, respectively. Similarly, samples D and F were combined and split to obtain the two samples J and K. Each of the samples, J and K were further split to get B5, B6 and B7, B8, respectively. Any one of the samples B1 to B8 could be used as a representative sample to determine the particle size distribution and analysis of feed sample [8]. The sample B1 was used in the case of each deposit.

Tables 1 and 2 give the size distribution of Wadi Si'al and Jabal Abu Siba sands, respectively. The results of size distribution are also illustrated in Fig. 1 and Fig. 2 respectively. Only about 16% of Wadi Si'al sand was finer than 100 microns. The sand ore of Jabal Abu Siba was even better with just about 5% fines. Generally, the sand in both cases is well graded.

2.2 Attrition Scrubbing

An attrition scrubbing cell was used for mechanically eliminating impurities stuck on the surfaces of the silica particles. The sample was poured in the attrition scrubbing cell and just enough water was added to make a thick slurry having a solids content of 65-70%. The scrubbing machine was operated for 10 minutes at 700 rpm. Wet sieving was conducted for 5 to 10 minutes using a 100 microns sieve and a bottom pan to remove – 100 micron particles.

Table 1: Feed size distribution of Wadi Si'al sand deposit.

Particle size (microns)	Wt (gm)	Wt (%) retained	Cumulative % under size
+ 500	0.5	0.13	99.87
- 500 +355	29.5	7.77	92.1
-355 +250	62.8	16.54	75.56
-250 +125	122.8	32.36	43.2
-125 +100	103.4	27.25	15.95
-100	60.5	15.95	

Table 2: Feed size distribution of Jabal Abu Siba sand deposit.

Particle size (microns)	Wt (gm)	Wt (%) retained	Cumulative % under size
+ 500	1.0	0.24	99.76
- 500 +355	38.1	9.12	90.64
-355 +250	121.3	29.02	61.62
-250 +125	212.6	50.87	10.75
-125 +100	25.1	6.00	4.75
-100	19.8	4.75	

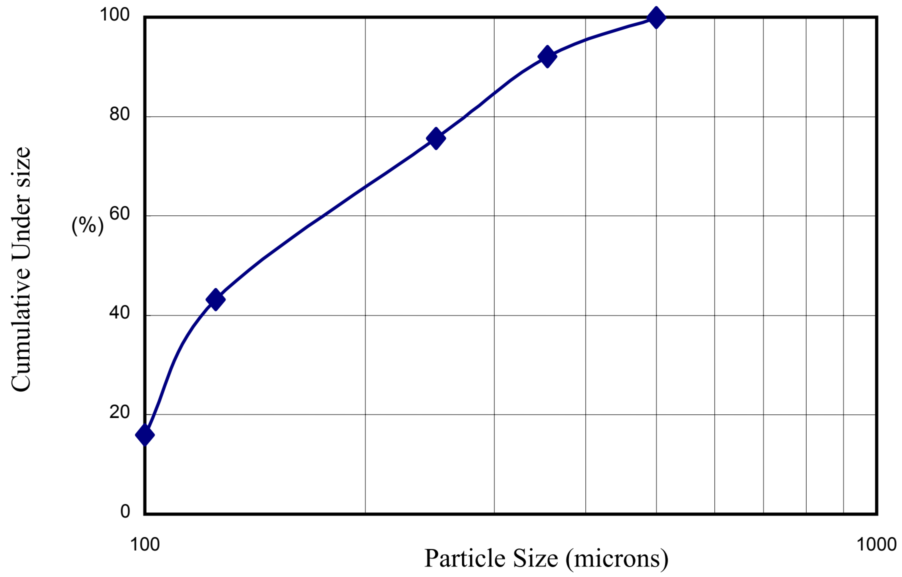

Fig. 1: Feed size distribution for flotation and shaking table for Wadi Si'al sand deposit.

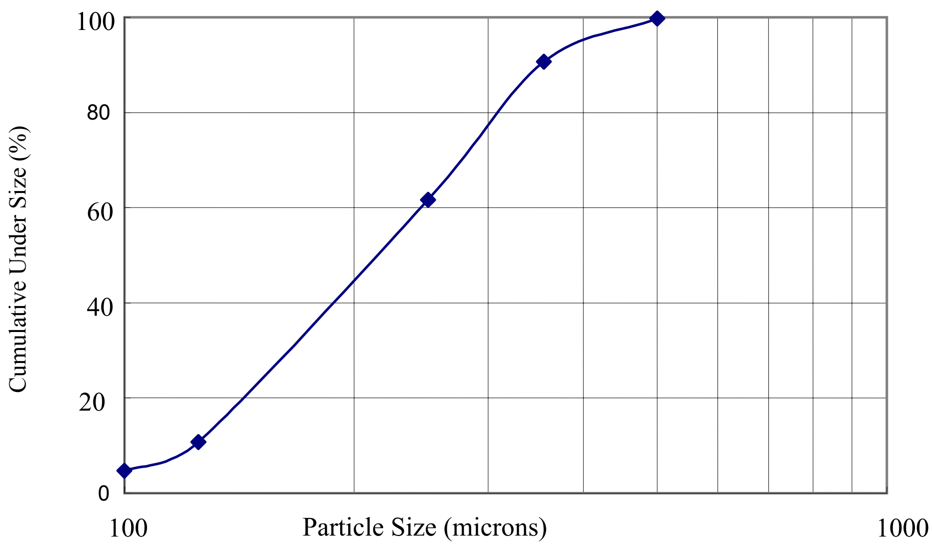

Fig. 2: Feed size distribution for flotation and shaking table for Jabal Abu Siba sand deposit.

2.3 Flotation

The scrubbed sample (- 500 + 100 microns) was transferred to the flotation cell. Enough water was added to produce slurry having 60 – 70% solids. The impeller was operated at 1500 rpm with the air inlet closed. The pH was checked and adjusted to a value between 3 and 4 by adding sulfuric acid in a requisite amount. An aero anionic reagent (petroleum sulfonate promoter) was added and the pulp was allowed to condition for 10 minutes. Two or three drops of frother, (Methyl isobutyl carbinol) were added and the cell was filled to normal working volume (2 liters) with clean water. The air inlet was, then, opened and the froth was removed by scraping only the top surface. The air inlet was closed and the impeller switched off. The purified sand was removed from the cell. The concentrate and tailings were filtered, dried, weighed and bagged for analysis.

2.4 Shaking Table

The samples were prepared by washing with water on a 100 microns sieve. The slope of the table was set at the required value. The table was started and the washing water was opened. The prepared pulp (solids + water) was transferred to the table using a Masterflex easy-load pump or batch-wise. Feeding was continued until the solids distribution on the table attained, approximately, a steady state. The collected fractions were filtered, dried, weighed and bagged for analysis.

3. Concentration of Wadi Si’al Silica Sand

The representative samples were prepared by scrubbing and de-sliming. This was followed by concentration by froth flotation. A further concentration was conducted by dry magnetic separation. Another procedure adopted for concentration of the same ore involved the use of Wilfley’s shaking table before magnetic separation, at a magnetic field strength of 2.5 Tesla.

For the flotation process, pH was kept within a range of 3 to 4. The amount of frother was kept constant at 0.01 g/l while various concentrations of collector were tried between 1 and 3 g/kg. An optimum value was found to lie between 2 and 3 g/kg. In all cases, the amount of froth (tailings) collected was relatively small.

The results of concentration by froth flotation are presented in Table 3. It appears from Table 3 that the flotation technique improves the silica content from 81.4% to between 93.6 and 94.4% (TACP, T2, T22,T33, T32).

Table 3 : Concentration by froth flotation of Wadi Si'al sand

Description			SiO_2 %	Al_2O_3 %	Fe_2O_3 %	Ca O %	Mg O %	TiO_2 %	Cr_2O_3 %	ZrO_2 %
Sample No.	Wt %	Untreated feed	81.4	5.2	0.6	< 1	< 1	0.75	0.005	< 0.054
1 Collector 3 g/Kg	92	T2: Not floated (Concentrate)	93.7	1	0.2	< 1	< 1	0.19	0.002	< 0.034
	8	C2: Floated (Tailing)	80.2	3.6	2.8	< 1	< 1	5.19	0.056	0.426
2 Collector 0.8 g/Kg	94	T22: Not floated	93.9	1.2	0.2	< 1	< 1	0.25	0.002	< 0.034
	6	C22: Floated	82.4	3	2.8	< 1	< 1	5.19	0.039	0.518
3 Collector 1.6 g/Kg	95	T32: Not floated	93.6	< 1	0.1	< 1	< 1	0.07	< 0.001	< 0.034
	5	C32: Floated	86.9	2.1	0.8	< 1	< 1	1.27	0.015	0.054
4 Collector 3.2 g/Kg		T33: Not Floated	94.4	1	0.1	< 1	< 1	0.07	< 0.001	<0.034
		C33: Floated *	-	-	-	-	-	-	-	-
5 Collector 1.2 g/Kg		TACP:Not folated	94.3	1.2	0.3	< 1	< 1	0.35	0.003	<0.034
		CACP:Floated *	-	-	-	-	-	-	-	-
6	75	Scrubbed only	93.4	1.4	0.2	< 1	< 1	0.31	0.002	<0.034
7	84	Washed	93.2	1.8	0.3	< 1	< 1	0.35	0.002	<0.034
8	16	-100 microns	68.1	18.9	1.4	1.5	< 1	1.46	0.012	0.071

* Sample too small to be analyzed

Scrubbing the untreated feed sample (without flotation) upgrades silica content to 93.4% which is comparable with the flotation concentrate. Washing alone, without flotation, does increase the silica content to slightly less than flotation and scrubbing, but the iron content remains high. However, the fine size (-100 microns) has the highest iron content which is undesirable for the glass industry. Hence the size below 100 microns was discarded.

The flotation reduces iron content from 0.6% to 0.1%. Most of the iron oxide goes into the froth, increasing it to 2.8%. The same applies to the other oxides content such as Al_2O_3, Cr_2O_3 and T_iO_2.

Several representative samples of Wadi Si'al silica sand were also concentrated by means of shaking table using different inclinations and flow rates. The best results are presented in Table 4 at flow rate of 1.50 l/min and an inclination of 1.2 degrees. These results indicate that using the shaking table technique improves the silica content from 81.4% to 91.2% and reduces the iron content from 0.6% to 0.3%. However, the results are lower than the corresponding results obtained using froth flotation.

Table 4 : Concentration by shaking table of Wadi Si'al sand.

Description	Wt %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	TiO_2 %	Cr_2O_3 %	ZrO_2 %
Concentrate	85	91.2	0.3	1.8	0.3	<0.05	0.35	0.002	<0.034
Tailings	15	78.2	4.5	2.5	0.5	0.08	8.11	0.005	1.076

The untreated feed, the concentrates (un-floated) obtained by flotation as well as the product of washing and scrubbing were subjected to concentration by dry magnetic separation, using a Frantz magnetic separator. The results are listed in Table 5. These results indicate that there was considerable improvement of silica content in all cases (TACP, T2, T22, T32, T33) up to 98.6 % . The magnetic separator improves the silica content for the untreated feed from 81.4% to 92.7% and Al_2O_3 is reduced from 5.2% to 3.6%. The magnetic separation of scrubbed feed improves the silica content from 93.4% to 97.7% and for washed feed from 93.2% to 97.3%. The Ti O_2 content is tremendously reduced in all cases.

The concentrate of shaking table was also subjected to magnetic separation. The results are shown in Table 6. A comparison of Table 4 and Table 6 indicates that magnetic separation improves silica content of the concentrate of shaking table from 91.2% to 95.8%.

Table 5: Results of magnetic separation of Wadi Si'al sand

Description	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	Ca O %	Mg O %	TiO_2 %	Cr_2O_3 %	ZrO_2 %
Untreated feed	92.7	3.6	0.4	< 1	< 1	0.31	0.002	<0.034
TACP	98.2	< 1	0.1	< 1	< 1	0.14	<0.001	<0.034
T2	98.4	< 1	0.1	< 1	< 1	0.07	<0.001	<0.034
T22	98.3	< 1	0.1	< 1	< 1	0.08	<0.001	<0.034
T32	98	< 1	0.1	< 1	< 1	0.05	<0.001	<0.034
T33	98.6	< 1	0.1	< 1	< 1	0.05	<0.001	<0.034
Scrubbed	97.7	< 1	0.1	< 1	< 1	0.114	<0.001	<0.034
Washed	97.3	1.3	0.2	< 1	< 1	0.16	<0.001	<0.034
- 100 microns	74.2	11.6	1.3	1.5	< 1	1.4	0.011	0.107

Table 6: Magnetic separation of the shaking table concentrate from Wadi Si'al sand

Description	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	Ca O %	Mg O %	Ti O_2 %	Cr_2 O_3 %	ZrO_2 %
Concentrate	95.8	1.7	0.2	0.30	<0.05	0.16	<0.001	<0.034

3.1 Proposed Processing Plant for Wadi Si'al Sand

On the basis of batch trials of various beneficiation operations, flow-sheets for processing plants for each deposit have been proposed. Figures 3 and 4 show the flowsheet and the processing plant, respectively, for Wadi Si'al sand.

The sand ore is delivered to the crusher for breaking the large pieces of friable rock The product of the crusher flows on vibrating screen to remove the coarse fraction (+ 500 microns). Next, the sand ore is delivered to the attrition scrubbing cell. Water is added to produce a slurry with 70 % solids. Then, the product of the attrition cell is diluted to produce 30 % solids and pumped to the cyclone classifier. The minus 100 microns material overflows and is discharged by gravity to the thickener. The cyclone underflow material contains the desired size (– 500 + 100 microns) and is discharged by gravity to the flotation conditioning tank where the pulp is diluted to 60 % solids and the flotation reagents are added. The conditioned pulp is discharged by gravity to the flotation cells where the pulp is diluted to 30 % solids to remove unwanted iron materials as froth and the desired sand minerals as un-floated product using an ionic controller such as petroleum sulfonate in an acidic media. The collected tailings are pumped to the thickener after neutralizing with pH modifier. The un-floated sand is pumped to a cyclone. The cyclone underflow goes to a filter unit to recover the flotation water and produce the desired sand. Then, the dry sand is passed through the magnetic separator to remove the magnetic minerals and produce the silica sand for the glass industry. The cyclone overflow and underflow water is pumped to the flotation conditioning tank. The thickener overflow is recycled to the plant for reuse while the underflow contains the minus 100 microns materials and the iron rich minerals are pumped to the tailings disposal site.

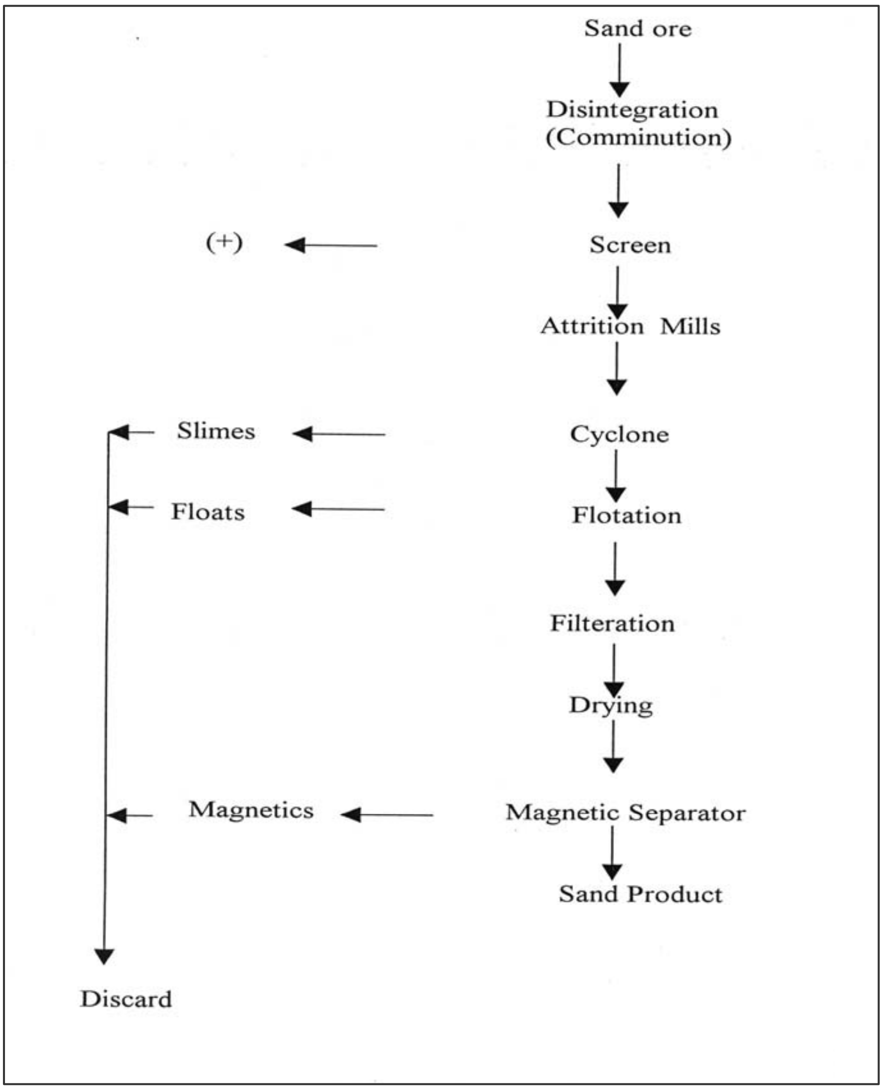

Fig. 3. Proposed flow-sheet for processing sand from Wadi Si’al.

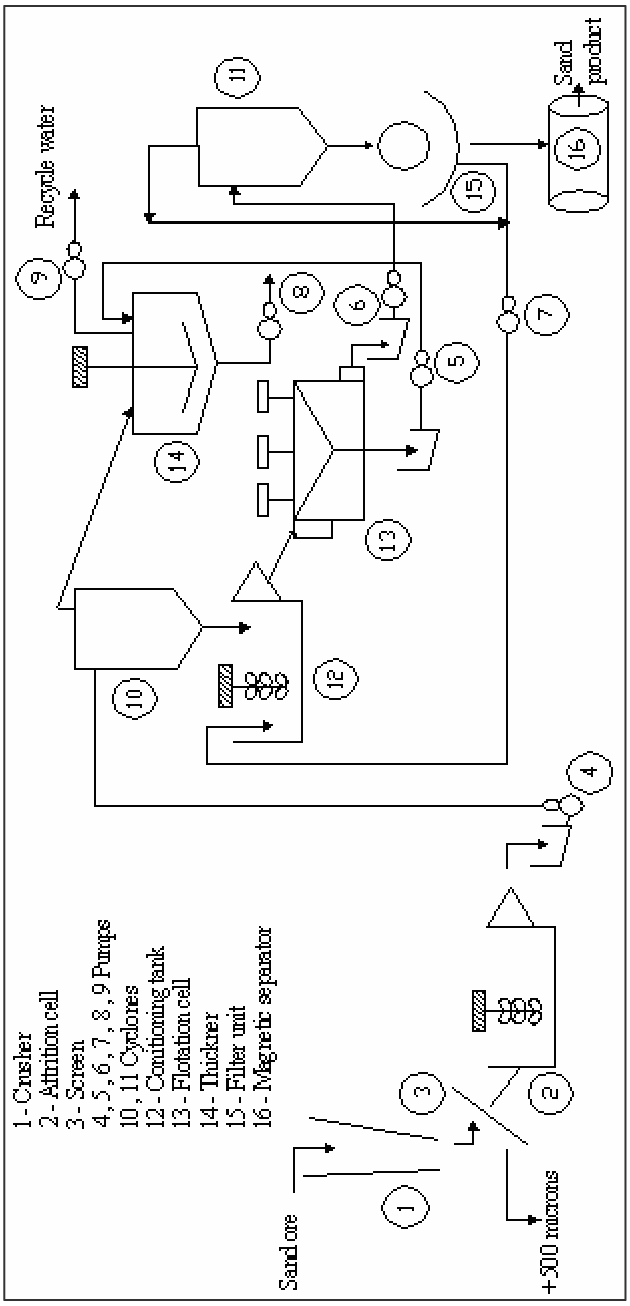

Fig. 4. Proposed beneficiation plant for Wadi Si’al sand.

The sample chunks being very weak were easily broken by hand without the use of crusher. The sand was, thus, scrubbed and de-slimed. This was followed by concentration by froth flotation using flotation reagents. A further concentration was conducted by dry magnetic separation. Another procedure for concentration of the same ore was carried out using shaking table followed by magnetic separation.

The best results of concentration by froth flotation are presented in Table 7. These results are better than the corresponding results for the Wadi Si'al samples. However, further concentration by magnetic separation (with a magnetic field of 2.5 Tesla) was carried out. The results of magnetic separation are presented in Table 8. A comparison of results in Table 7 and Table 8 indicates that the silica content is improved by magnetic separation from 94.5% to 98.5%.

Table 7 : Results of concentration by froth flotation of Jabal Abu Siba Sand (Collector 1.2g/Kg)

Description	Wt %	SiO_2 %	Al_2O %	Fe_2O_3 %	Ca O %	Mg O %	TiO_2 %	Cr_2O_3 %	ZrO_2 %
TN: Not floated	95	94.5	< 1	0.1	0.1	< 0.05	0.05	<0.001	<0.034
CN: floated (Tailings)	5	80.9	7	0.4	0.5	< 0.05	0.83	0.027	0.122

Table 8 : Results of magnetic separation of Jabal Abu Siba Sand

Description	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	Ca O %	Mg O %	TiO_2 %	Cr_2O_3 %	ZrO_2 %
TN: Not floated	98.5	< 1	0.1	0.1	<0.05	0.04	<0.001	<0.034

Concentration by shaking table was carried out on raw sample from South of Jabal Abu Siba at different flow rates of water and table inclinations. Next, magnetic separation was carried out on the concentrate of the shaking table. The results are presents in Table 9. The best results with 98.9% SiO_2 and 0.05%

Fe_2O_3 were obtained at flow rate of 1.5 l/min at an inclination 1.2 degrees (initial setting) of the table.

Table 9 : Magnetic separation of the shaking table concentrate of Jabal Abu Siba Sand.

Description	Flow rate of water l/min	Inclination of table	SiO_2 %	Fe_2O_3 %
Sample 1	0.5	1.2	98.5	0.07
Sample 2	1	1.2	95.45	0.25
Sample 3	1.5	1.2	98.9	0.05
Sample 4	2	1.2	96.25	0.3

4.1 Proposed Processing Plant for Jabal Abu Siba Sand

Figures 5 and 6 show the flow-sheet and processing plant, respectively, for South of Jabal Abu Siba deposit. The plant is similar to the one for Wadi Si'al sand, with the difference that concentration at the intermediate phase is carried out by a shaking table rather than by flotation.

5. Discussion of Results

Using the flotation or shaking table technique alone for beneficiation of the silica sand ore does not produce a suitable product for glass manufacture [9-10]. However, any of these techniques, followed by magnetic separation may produce a product suitable for glass manufacture. Most of the gangue minerals were removed in the floated fraction. Also, the fine sizes (- 100 microns) contains the high percentage of gangue minerals.

Beneficiation tests performed on Wadi Si'al sand ore using flotation and magnetic separation increased the silica content to 98.5% and reduced the iron content to 0.1% (Fe_2O_3). Beneficiation tests performed on South of Jabal Abu Siba using shaking table and magnetic separation increased the silica content to 98.9% and reduced the iron content to 0.05% (Fe_2O_3). In both cases, the resulting product is suitable for glass manufacture.

6. Conclusions

The following conclusions may be drawn from beneficiation of low-grade silica sand deposits of Wadi Si'al and south of Jabal Abu Siba:

1) The untreated feed subjected to either washing or scrubbing alone, does not satisfy the requirements of glass manufacture.
2) Any one of the subsequent beneficiation methods such as flotation or Wilfley's table, followed by magnetic separation does upgrade the sand to satisfy the requirements of the glass industry.
3) The beneficiation tests performed on Wadi Si'al sand ore using flotation and magnetic separation increased the silica content to 98.5% and reduced the iron content to 0.1% Fe2O3 resulting in a product suitable for the glass industry.

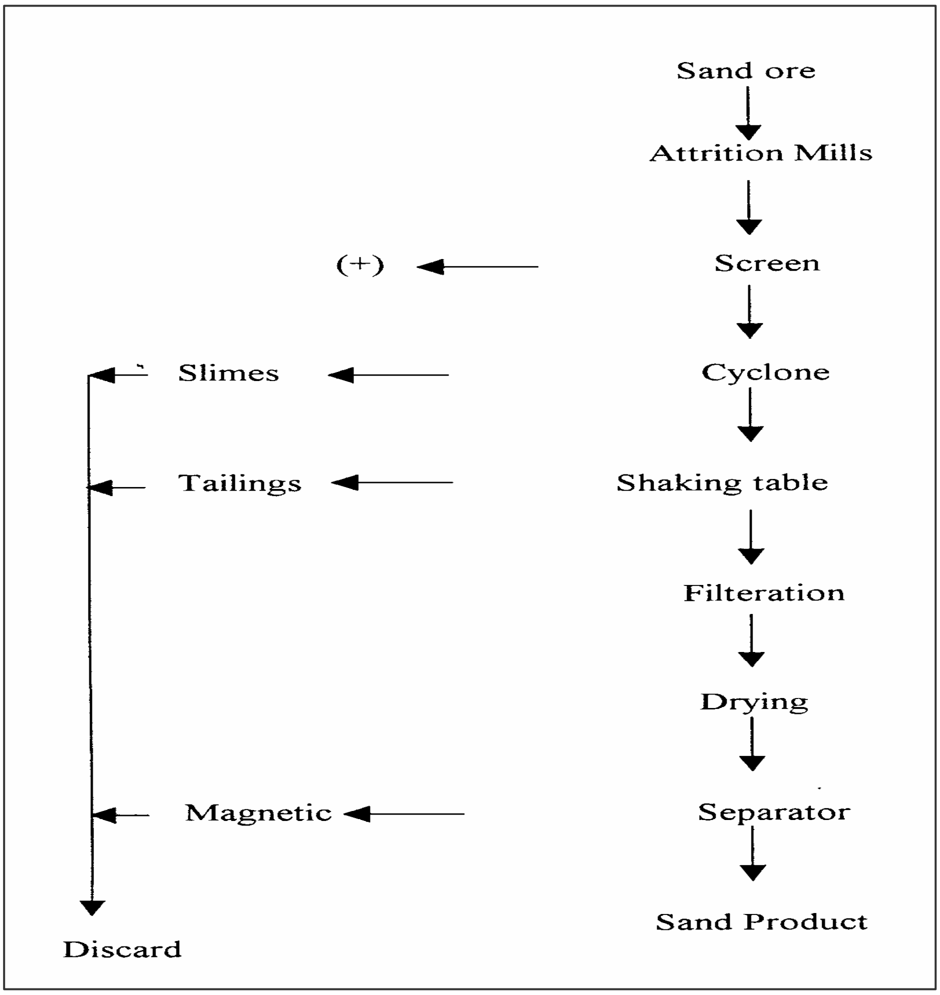

Fig. 5: Proposed flow-sheet for processing sand from south of Jabal Abu Siba.

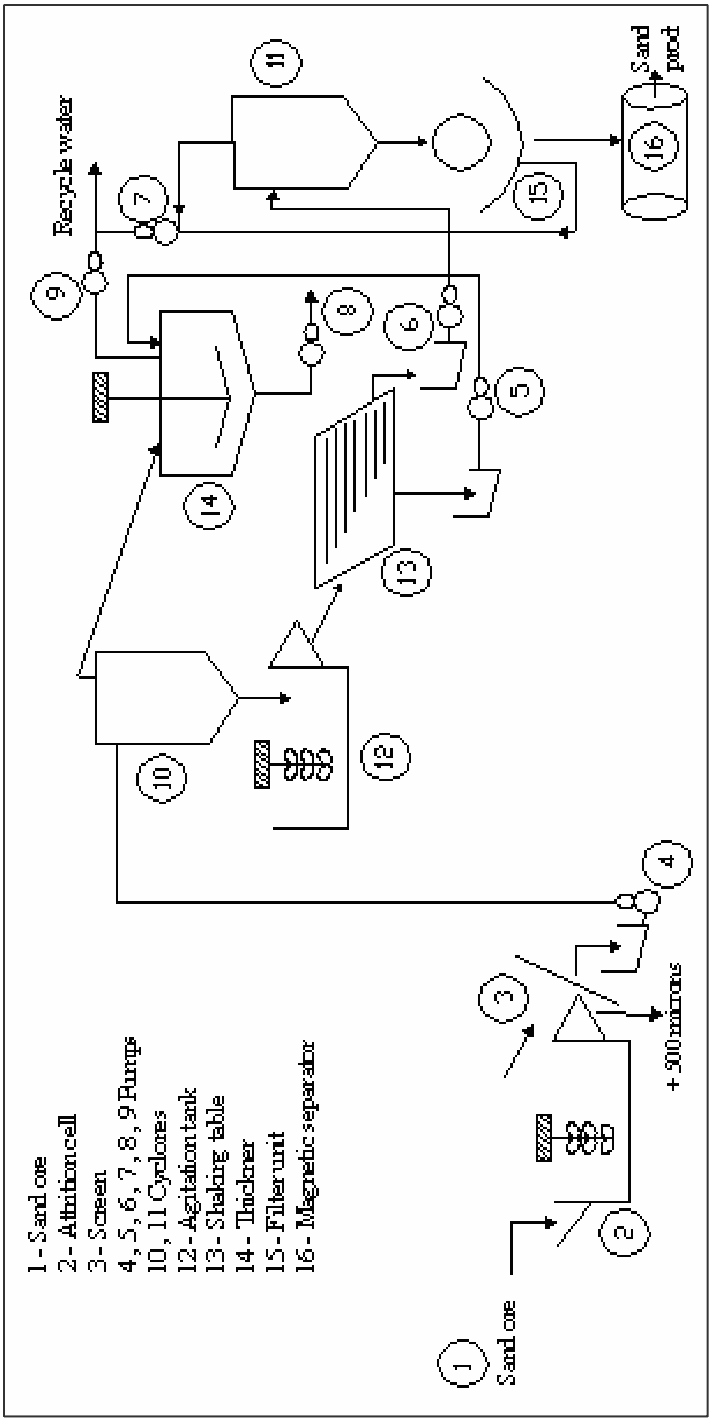

Fig. 6 : Proposed Beneficiation Plant for Jabal Abu Siba Sand.

4) The beneficiation tests performed on south of Jabal Abu Siba using shaking table and magnetic separation increased the silica content to 98.9% and reduced the iron content to 0.05% Fe2O3, resulting a product, suitable for the glass industry.
5) Processing plant has been designed and presented for each type of sand.
6) It may be possible to have one processing plant which can be adjusted to serve both types of sand. Further research may be warranted in this area.

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تحسين خامات رمال السليكا منخفضة النقاوة في منطقة جدة

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المستخلص : توجد رمال السليكا عالية النقاوة على بعد ١٠٠٠ كم من مدينة جدة الصناعية, ولهذا يعتبر نقلها إلى مدينة جدة مكاف جدًا. بينما توجد رمال السليكا منخفضة النقاوة بالقرب من مدينة جدة حيث يتطلب الأمر معالجتها لرفع درجة نقاوتها لكي تكون ملائمة لصناعة الزجاج. هذا البحث اشتمل على معالجة موقعين لرمال السليكا الواقعين بالقرب من مدينة جدة لرفع درجة تركيزهما إلى مستوى ملائم لصناعة الزجاج. وقد استخدمت طريقة التعويم، الطاولة الهزازة، والفصل المغناطيسي لتحقيق ذلك الغرض. وأيضًا تم اقتراح مخطط للعمليات المتتابعة في المعالجة وأيضًا مصنع المعالجة لكلٍ من هذين الموقعين.

الكلمات الدالة: تحسين، التعويم، الطاولة الهزازة، الفصل المغناطيسي.