Beneficiation of some Egyptian glass sands

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QUALITY silica sands required by the glass industry have brought about the need for processing contaminated sand deposits. In addition, the continual increase in glass sand requirements in U. A. R., coupled with the losses of its resources in Sinai, has emphasized the need to develop new local deposits. One source, 'Wadi El Natrun' depression, has been employed in this investigation. In its raw state, the sand contains iron bearing minerals of different types. These may occur with clays, as a surface contaminant, as iron oxide in the form of a stain on the surface, or deposit in the fissures of quartz particles. These deposits must be removed for the sand to qualify for glass production. In addition to iron impurities, most of the raw sands were found to contain a relatively high percentage of heavy mineral particles such as magnetite, chromite, ilmenite, staurlite, epidotes, hornblende, zircon and sometimes mica, chlorite and calcite.

Flotation methods[1] have been successfully employed by many workers for the refining of glass sands. But it may be economical to investigate other methods like tabling or magnetic separation since electrical power produced by the 'Aswan High Dam' is available economically.

Experimental

Attrition-scrubbing

Scrubbing was conducted in a perspex container of a laboratory 'Fagergren' flotation cell to effect disintegration of the ferruginous clayey coating on quartz. The effects of the solid/liquid ratio, time of attritioning and the impeller speed were studied. The scrubbed sand was then deslimed at 0·152 mm and dry-screened to remove the +1·003 mm fraction.

Tabling

A 18″ × 40″ "Wilfley" shaking table type 13 was adopted to separate most of the free heavy minerals. A rough test on a laboratory superpanner table appeared promising. The scrubbed fraction, −1·003+0·152 mm, was employed for studying the different factors.

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SYNOPSIS

A three-stage process for the refining of some silica sands from "Wadi El Natrun" depression, was investigated. Attrition-scrubbing in an intensely agitated high density pulp, followed by classification was suitable for the disintegration of the ferruginous clayey coating on quartz grains, and a substantial decrease in iron and alumina was achieved. Further tabling of the classified product led to the rejection of some of the free heavy mineral particles, but fine opaques are still retained. High intensity magnetic separation gave better results. This implies the attainment of a single particle layer on the main belt of the "Dings" separator, and a proposed formula to fulfil this requirement was worked out. Although shielding of fine heavy minerals by relatively coarse quartz grains actually occurs on the main belt, further cleaning yields a product which may be suitable for the production of some forms of glass.

Magnetic separation

The 'Dings' high intensity crossbelt magnetic separator was employed to effect better separation of the heavy minerals. Having different magnetic permeabilities, it is possible to separate the different minerals at fields somewhat stronger than conventional low-intensity magnetic fields.

A single particle layer was fed to the main belt by a highly flexible locally-made vibrating feeder.

Results and discussion

The chemical analysis of the original sand shows that silica is the main constituent of these white sands with an average of 94·26% SiO_2. Alumina, lime and magnesia are relatively high and exceed the permissible contents of table-ware and sheet glass. Iron forms the main harmful colouring ingredient (0·28% Fe). However, spectral analysis revealed also faint lines of chromium and titanium. Screen analysis, Table I shows that most of the alumina and other iron-bearing minerals are present in the fine size fraction −0·152 mm. Mineralogical investigation indicates that clay minerals are dominant in this slime fraction together with magnetite, chromite, epidote, mica, garnet and tourmaline. How-

TABLE I Chemical and size analysis of the original sand

Size mm	Weight %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %
+1·003	1·52	92·60	0·378	0·812
+0·853	3·61	97·09	0·345	0·389
+0·699	3·60	95·98	0·487	0·620
+0·599	7·50	96·25	0·185	0·500
+0·422	16·42	96·05	0·205	0·570
+0·353	13·02	95·85	0·243	1·053
+0·295	12·28	95·98	0·212	1·033
+0·210	25·53	93·74	0·252	1·767
+0·152	13·10	92·30	0·429	2·748
+0·104	22·25	84·68	3·586	4·800
—0·104	1·17	75·75	5·352	8·480

Original ore analysis %

SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Cr_2O_3	$CaCO_3$	$MgCO_3$
94·260	0·400	1·444	0·132	0·560	1·450	1·090

TABLE II Dry and wet screening of sand

Process	Weight% or size fractions mm.			Analysis of —1·003+0·152 mm.	
	+1·003	+0·152	—0·152	%Fe	%Al
Dry	1·47	95·13	3·40	0·127	0·701
Wet	1·25	95·12	3·63	0·089	0·580

TABLE III Effect of changing time of attritioning

Time min.	Weight% of size fractions mm.			Analysis of −1·003+0·152 mm.	
	+1·003	+0·152	—0·152	%Fe	%Al
5	1·18	94·71	4·11	0·073	0·549
10	0·94	95·04	4·03	0·069	0·535
15	0·95	94·56	4·49	0·068	0·543
20	0·93	94·77	4·30	0·069	0.537

Solid/liquid ratio 1 : 5, impeller speed 2500 r.p.m.

ever, staining of the quartz grains by iron was predominant also, although it is more abundant in the coarser size. Sometimes, iron deposits are embedded in the fissures of these coarser sizes.

When ordinary wet classification methods were applied, a very slimy and clayey fraction was removed by water and the quartz grains appeared relatively clean and rounded. A corresponding decrease in iron and alumina was observed in the collected size fraction, −1·003+0·152 mm (Table II). This implies the importance of scrubbing as a primary step for sand preparation.

Attrition-scrubbing of sand

Although the different methods for sand washing are well known, it was preferable to use the impeller to the "Fagergren" flotation cell in order to keep the entire mass of the sand in a violent movement. In this case, actual rubbing of the wet sand grains, one against another, in an intensely agitated pulp is ensured.

(a) Effect of time of attritioning

The effect of changing the time of attritioning at other constant factors was studied. The results (Table III) showed that attritioning 10 minutes is enough for a considerable decrease in the iron and alumina in the collected size fraction −1·007+0·152 mm.

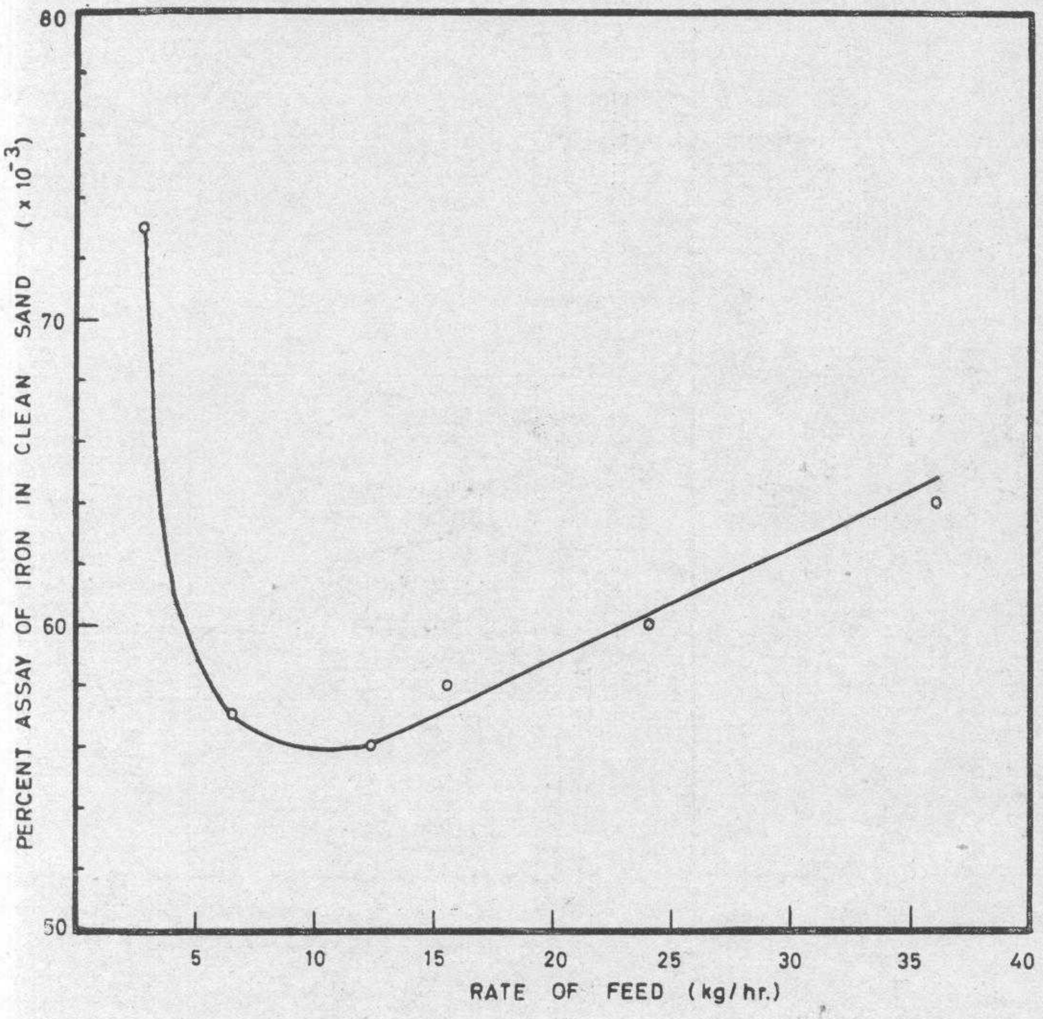
(b) Effect of impeller speed

It is clear from Table IV that under the same conditions, higher speeds affect markedly the disintegration of the coating film on quartz grains. This demonstrates the main difference between ordinary wet classification methods and attrition-scrubbing. A maximum speed of 2500 r. p. m. was used in all the experiments.

TABLE IV Effect of changing the impeller speed

Speed r.p.m.	Weight% of size fractions mm.			Analysis of —1·003+0·152 mm.	
	+1·003	+0·152	—0·152	%Fe	%Al
1500	1·03	95·10	3·86	0·085	0·570
2000	1·19	94·65	4·17	0·075	0·561
2500	0·94	95·04	4·03	0·069	0·535

Solid/liquid ratio 1 : 5, Time of attritioning 10 mins.



1 *Effect of rate of feed*

(c) Effect of solid/liquid ratio

It was always recommended to use high solid/liquid ratio in the attritioning of glass sands[2], as this increases the probability of rubbing different particles together in an intensely crowded pulp. The present finding supports this idea as a minimum assay of iron was reached at the higher solid/liquid ratio (Table V).

TABLE V Effect of solid/liquid ratio

Solid/ liquid ratio	Weight% of size fractions mm			Analysis of −1·003+0·152 mm	
	+1·003	+0·152	−0·152	%Fe	%Al
1·5	0·94	95·04	4·03	0·069	0·535
1·2	1·58	94·19	4·23	0·068	0·540
1·1	1·13	94·32	4·55	0·065	0·533

Time of attritioning 10 mins. Impeller speed 2500 r.p.m.

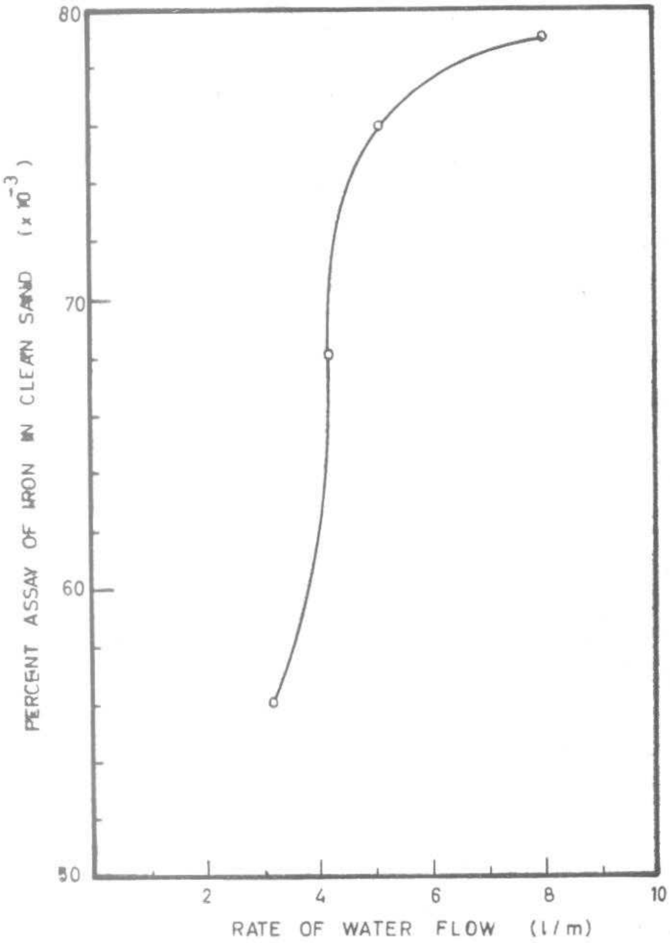
Acid attritioning

It was found feasible to try the etching of the iron staining on quartz particles by chemicals. Commercial HCl was primarily used at the optimum conditions for attritioning and at room temperature, but the results (Table VI) are more or less discouraging, indi-

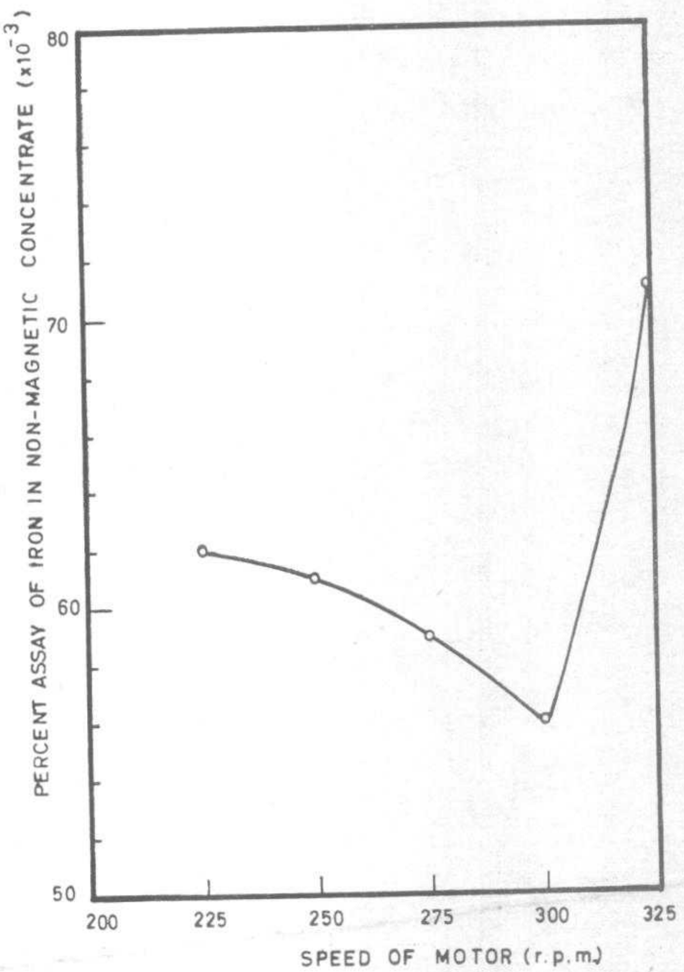
TABLE VI Effect of HCl on sand attritioning

Conc. lb./ton	Weight% of size fractions mm.			Analysis of −1·003+0·152 mm.	
	+1·003	+0·152	−0·152	%Fe	%Al
1	0·94	94·93	4·13	0·063	0·520
2	1·27	94·52	4·23	0·062	0·515
3	1·20	94·40	4·40	0·062	0·520
4	1·08	95·06	3·87	0·061	0·519

Conditions are the same as in Table V, solid/liquid ratio 1 : 1



2 *Effect of water flow*



3 *Effect of motor speed*

cating that the iron staining is not superficial. However, other reagents may be more efficient especially on heating.

Thus, it was decided to separate the coarser sizes in which the iron staining is abundant. But an unexpected increase in the iron and alumina in the size fraction −0·699+0·152 mm. was observed (0·080% Fe and 0·560% Al), indicating that the main harmful colouring ingredients are the free heavy minerals present in the finer sizes and staining of coarser sizes is relatively of secondary effect. However, it is that free fraction which must be more or less eliminated.

Beneficiation tests

A–Tabling

Although the sand contamination with free magnetite, chromite or ilmenite particles appears very small to be handled by gravity method, yet the difference in size and shape of particles between the heavy minerals and quartz, as well as a concentration criterion of 2 or more may effect reasonable separation.[3]

The most important of all the experiments is the assay of iron in the table tails, which is shown in figures. On the other hand, the recovery lies always above 90%.

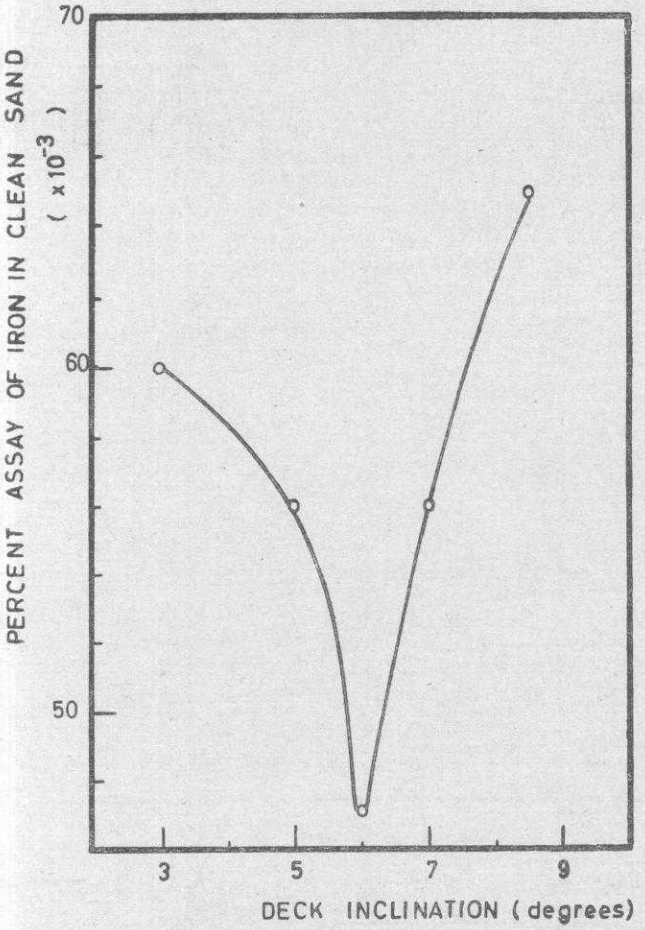
(a) Effect of rate of feed

Results in Fig. 1 show that the optimum rate of feeding is 12·4 kg/h, below or above which the assay of iron in the clean sand increases.

It seems that at higher feeds the space between the table cleats becomes clogged by sand and further dilation of the bed is hindered. This allows the escape of entrained fine heavy minerals with the cross water stream to the tail portion of the table.

(b) Effect of water flow rate

It is stated that the water flow and transverse slope of the deck are interdependent and both are dependent on the size of feed. The requirements are that, solids should settle in the riffles, the pulp should be sufficiently fluid to allow stratification and that there should be sufficient velocity of cross water flow to



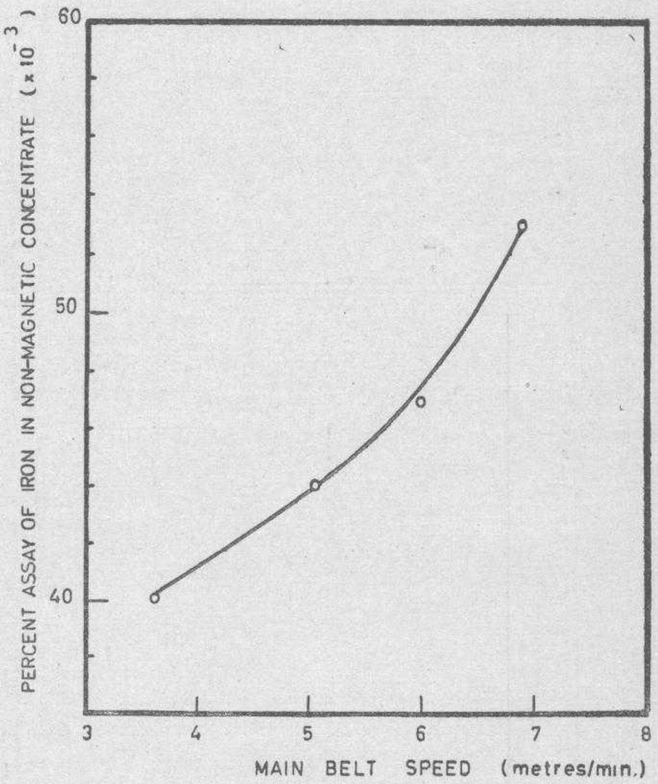
4 *Effect of deck slope*

carry off the upper strata as the riffle support is withdrawn.

Fig. 2 shows that increasing the rate of water washes down some of the heavy mineral particles with the table tails. This is visualized by a relative increase in the weight per cent of this fraction. However, the table slope may be overlapping, as will be shown later. Below 3·2 l/min., the flowing water is not sufficient to form a freely moving film on the deck deep enough to cover the largest particles.

(c) Effect of motor speed and stroke length

These two factors are suitably adjusted, a low speed and long stroke being suitable for coarse feeds and the reverse for fine feeds. For the applied size range, the optimum motor speed was 300 r.p.m. (Fig. 3). Below this speed sticking of fine heavy minerals to the deck surface or packing of the riffles at the head-motion end actually occurs and gradually works down into the tailing. A moderate stroke length, 9 mm was found to yield tailings having 0·051% Fe, at the optimum speed (Table VII).



5 *Effect of belt speed*

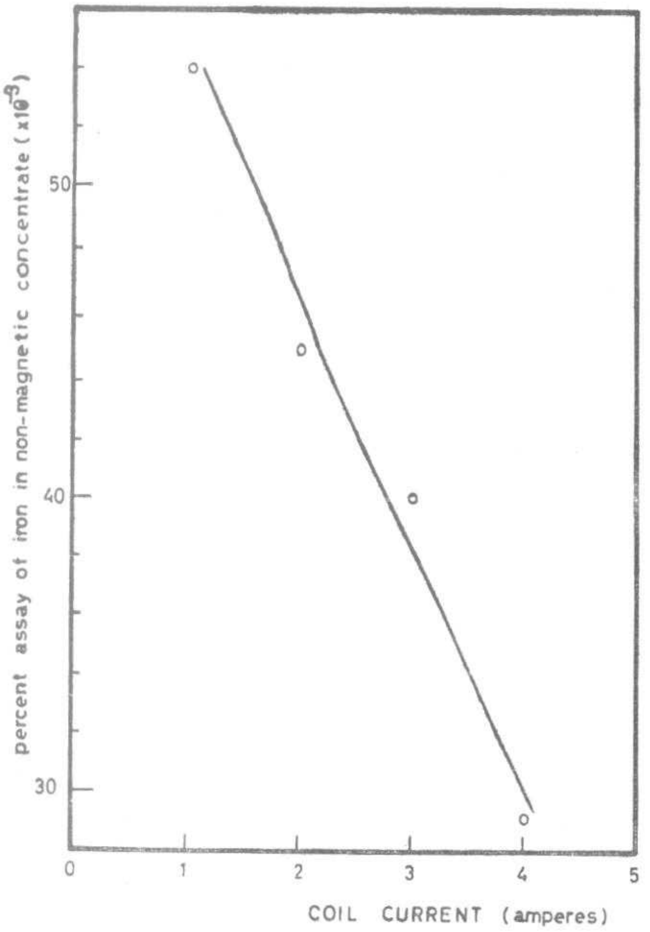
TABLE VII Effect of changing stroke length

Stroke length mm	Tails	Weight% midd. and conc.	Analysis of tails %Fe	%Al
7	90·47	9·53	0·056	0·457
9	88·65	11·35	0·051	0·414
12	85·10	14·90	0·059	0·461

Rate of feed 12·4 kg/h, rate of water flow 3·2 l/min., stroke length 7 mm., deck inclination 5° (from the horizontal), speed of motor 300 r.p.m.

(d) Effect of deck slope

On a horizontal deck (90°), there is no motion of particles. As the deck is tilted, particles begin to move until all of them are moving. Results shown in Fig. 4 indicate that at 6° (from the horizontal) a clean tail could be obtained having 0·047% Fe. By increasing the slope, the transporting power of particles increases which is considered, sometimes, economical,



6 *Effect of magnetic field*

but it narrows the bands of the various products at the concentrate end and makes accurate splitting difficult.

It could be concluded that cleaning of glass sands by tabling is not sharp, and entrainment of some fine heavy minerals in the table product could be still observed under the binocular microscope. When cleaning was conducted at the optimum conditions, a final product assaying 0·045% Fe was obtained. However, efficient desliming of sand could be achieved by tabling resulting in a noticeable decrease in the alumina content and hence lime and magnesia.

B-Magnetic separation

High intensity magnetic separators have been always of considerable value for removing iron-bearing contaminants from such non-metallic materials as glass sands. The converging magnetic field of the "Dings" cross-belt separator was therefore applied to examine the separation of different magnetic impurities. Owing to the variation in the relative attractabilities of the different minerals[4], it may be possible to separate them at fields somewhat stronger than conventional low-intensity magnetic fields.

For such type of separators, it is necessary to attain one-particle layer of the feed on the main belt in order to achieve proper separation as presentation of more than one-particle layer results in the shielding of the underlying magnetic particles from the magnetic field and escape to the non-magnetic portion.[5] Although this condition affects the capacity of the machine, a constant one-particle layer, rate of feed, was maintained through all the experiments. This could be fulfilled from the following relation:

Rate of feeding = mean particle diameter
× width of the magnetic
zone × speed of main belt
× specific gravity of ore.

A vibrating feeder was adjusted to deliver the calculated rate of feed on the main belt.

Effect of particle size

The rate of feeding necessary for each size fraction was calculated by formula. Results of separating the two size fractions − 1·003+0·152 mm and − 0·5+0·152 mm (Table VIII) reveal a marked decrease in iron, in the non-magnetic fraction in the case of the finer size. It seems that shielding of the fine heavy minerals by coarser sand particles occurs in the case of the size fraction − 1·003+0·152 mm resulting in the escape of such fine heavy particles to the non-magnetic fraction. The coarser sand size − 1·003+0·5 mm was, therefore, rejected and the remaining sand size — 0·5+0·152 mm was applied in magnetic separation. However, the former coarse fraction appeared free from liberated heavy minerals and just stained by an iron oxide film. Disseminated heavy minerals sometimes appear in the fissures of some of these coarse particles. Chemical analysis of this fraction shows that it contains 0·025% Fe and 0·15% Al. Although it may be suitable for the production of some forms of sheet glass, chemical leaching at varying temperatures, before use, is required.

TABLE VIII Effect of particle size on magnetic separation

Size mm.	Rate of feed kg/h	M.	Weight% N.M.	Analysis of N.M. %Fe	%Al
−0·5+0·152	9·58	0·50	99·50	0·040	0·517
−1·003+0·152	16·97	0·53	99·47	0·047	0·591

Belt speed 3·70 metres/min., ampere 3, air gap 5·04 mm

Effect of speed of main belt

In order to separate a single particle layer at the different belt speeds, the rate of feeding employed at each speed was calculated by equation. Thus although the nominal rate of feeding changed from one experiment to another, a single particle layer was always fed to the separator.

It is clear from Fig. 5 that increasing the speed of the main belt decreases the length of time during which the particles will be subjected to the influence of magnetism. A relative increase in the iron content in the non-magnetic fraction indicates clearly the escape of some magnetic impurities to it.

Effect of magnetic field

The magnetic field intensity may be changed either by varying the current supplied to the magnet coil or by changing the gap between the two poles, both of which were tried.

The results are shown in Fig. 6. Results of separation, at the same current but different gaps, are shown in Table IX. On increasing the current, much more magnetic impurities were rejected and a corresponding decrease in the iron content of the non-magnetic fraction was obtained.

TABLE IX Effect of changing air gap

Air gap mm.	Weight% M.	N.M.	Analysis of N. M. %Fe	%Al
2·52	51·00	69·0	0·037	0·586
5·04	0·90	99·1	0·029	0·515
7·53	5·00	95·0	0·041	0·605

Rate of feed 9·58 kg/h., belt speed 3·70 metres/min., air gap 5·04 mm.

Although the field intensity may be increased to overcome the adverse effect of feed layering or fineness on separation, economic demand usually necessitates minimum power consumption.

On the other hand, non-homogeneity in the magnetic field effects separation. In practice, this is increased by bringing the wedge-shaped pole piece closer to the square pole i.e. by decreasing the air gap. This also increases field intensity and brings the particles closer to the collecting pole. However, it is clear from Table IX that an optimum air gap (5·04 mm) was reached, above which the effect of non-homogeneity as well as the strength of the magnetic field is lessened leading to further escape of the magnetic impurities to non-magnetic fraction.

Thus although it seems that the efficiency of magnetic separation is relatively superior to tabling, yet entrainment of fine impurities in the non-magnetic concentrate still occurs. However, further cleaning of this product, at the optimum conditions yields a final concentrate having a minimum assay of the iron-bearing minerals, Table X.

TABLE X Cleaning of the non-magnetic concentrate

Overall weight% M.	N.M.	Analysis of clean N. M. %SiO_2	%Fe_2O_3	%Cr_2O_3	%TiO_2	%Al_2O_3
0·3	98·8	98·014	0·035	0·013	0·01	0·961

Rate of feed 9·58 kg/h., belt speed 3·70 metres/min., ampere 4, air gap 5·04 mm.

Acknowledgement

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References

1. 'Non-metallic Mineral Benefication, Silica Sands', Technical Bulletin No. **G-14,** *Armour Chemicai Industries Ltd.*, October, (1958).
2. 'Benefication of Silica Sand', *Deco Trefoil*, Vol. **23 No. 5,** November-December (1959).
3. Taggart, A. F. : 'Handbook of Mineral Dressing', John Wiley and Sons, Inc., p. 11–84, (1953), New York.
4. Davies, quoted in Taggart, A. F. : Handbook of Mineral Dressing', John Wiley and Sons, Inc., p. 13–20, (1953), New York.
5. Boulos, T. R. : 'M. Sc. Thesis, Cairo University', (1963).