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S.S. IBRAHIM, H.A. MOHAMED, T.R. BOULOS*

DRY MAGNETIC SEPARATION OF NEPHELINE SYENITE ORES

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Different types of dry high intensity magnetic separators are applied to remove the iron bearing contaminants from two nepheline syenite samples. Ding's cross belt separator was applied in this study as a "pick up" separator, while "Carpco" induced roll was employed as a free fall kind of separator, that is widely used with dry sand size materials. Magnaroll magnetic separator, the latest design by Boxmag Rapid that uses rare earth permanent magnets for high intensity magnetic separation, was also applied. The main parameters affecting the separation efficiency of these machines were studied. It was found that Magnaroll separator was of high performance, as compared with the other separators. It was possible to produce clean concentrates containing 0.24% and 0.28% iron oxide from original samples containing 6.0% and 5.3% Fe_2O_3, respectively. These products are acceptable as glass grade materials in amber glass and fiberglass industries, as well as for ceramic purposes.

Kay words: magnetic separation, Magnaroll separator, iron oxide concentrate, glass, ceramic

INTRODUCTION

Feldspathic minerals are intermediate igneous techto-silicate rocks, having general compositional formula of Na,K,Ca aluminum silicate. They are indispensable raw materials in glass, ceramics and filler industries. However, nepheline is the most common (Guillet 1994). Due to its high alkali and alumina content per unit weight, it has been a formidable competition to feldspar.The low fusion point of nepheline syenite lowers the melting temperature, promoting faster melting, higher productivity and fuel savings in glass industry. In ceramic industry, the high fluxing capacity of nepheline allows it to act as a good vitrifying agent and permits a lower flux content in the ceramic body, lower firing temperature and faster firing schedules. In plastics, nepheline syenite is used as an inert, low cost filler in PVC, epoxy and polyester resin

* CMRDI, P.O.Box 87, Helwan, Cairo, Egypt

systems. Because it exhibits a low resin demand, high filler loading are possible, permitting reduced requirements for more expensive components. In PVC resins, it exhibits a low tinting strength, has a refractive index close to that of vinyl resin and has a very low optical dispersion (Guillet 1994). Finely ground nepheline syenite is especially employed as an inert filler in paints, both latex and alkalid type, for use in high traffic areas, as metal primers, wood stains, etc. It contributes a high dry brightness, high bulking value, easy wetting and dispersion in paint formulations**.**

In Egypt, the presence of nepheline syenite is confined to the ring complexes which are circular igneous structures formed after magma solidification. These structures are located in the southern sector of the Eastern Desert, south Edfu-Marsa Alam road in a square limited by the longitudes 33^o and 36^o and latitudes 22^o and 24^o (Dardir et al., 1994). Reserve estimation of these deposits are exceeding 90 million tons (El-Ramely et al., 1971).

Research and development projects in Egypt, were not able to conform the techno-economic feasibility of the Red Sea nepheline syenite in production of alumina and portland cement (Ismail 1976). Nevertheless, direct utilization of the beneficiated rock as filler in plastics industry or/and in glass and ceramic production might be another option for making the most of 90 million tons of ore reserves in the Eastern Desert, (Bolger 1995, Harben 1995). Since it would be most unusual to find a nepheline syenite ore that could be used commercially for glass and ceramics purposes without beneficiation, and due to the arid nature of the Egyptian ore deposits, it is important to study the amenability of this ore to dry beneficiation. Nevertheless, the dry processing is to be preferable than wet one from the point of view of the cost.

The effective capture of fine particles using dry high intensity magnetic separation depends mainly on the magnetic attractive force as well as the other competing forces including centrifugal and gravitational forces. The magnetic attractive force acting on a particle is the product of the particle magnetization and the magnetic filed gradient. The competing forces vary as the mode of separation varies (Cohen 1973, Mathieuand Sirois 1988). Dry high intensity separators typically consists of a grooved or laminated magnetized roll that generates high magnetic field gradients. The rotor is magnetized by using an external electromagnetic circuit or by using rare earth permanent magnets in the construction of the rotor. Separation occurs when the paramagnetic minerals are magnetically deflected from the non-magnetic stream (Arvidson 1995).

The aim of this paper is to study the amenability of dry beneficiation of two nepheline syenite samples from Gabel Abu-Khrug and Gabel El-Khafa localities in the Eastern Desert of Egypt to overcome typical problem of no water resources, as well as to reducethe operating cost of the beneficiation process. Application of the final products specifications for various industrial applications was considered.

EXPERIMENTAL

SAMPLES CHARACTERIZATION

Two nepheline syenite repesentative samples were supplied from the Gabel Abu-Khrug and El-Kahfa localities, Eastern Desert of Egypt. The complete chemical analysis of the original samples are shown in Table 1.

Table 1.Complete chemical analysis of nepheline syenite samples (in %)

Constituent	Gabal Abu Khrug	El-Kahfa
SiO_2	59.50	57.82
Al_2O_3	18.42	17.08
Fe_2O_3	6.00	5.30
CaO	0.37	0.87
MgO	0.40	0.20
Na_2O	7.70	9.18
K_2O	4.60	5.46
TiO_2	0.42	0.13
P_2O_5	0.02	0.01
S	0.07	0.02
Cl	0.06	0.05
CO_2	0.26	0.15
Humidity	0.86	0.48
L.O.I.	0.88	0.53

Table 2. Size analysis of Abu-Khrug (I) and El-Kahfa (II) crushed samples

Size, mm	Cumulative Wt. % Passing		Fe_2O_3, %		Al_2O_3, %	
	I	II	I	II	I	II
+6.68	100	100	5.84	5.28	17.99	17.31
-6.68+4.67	96.06	95.07	5.87	5.18	17.68	17.26
-4.67+2.40	88.52	88.02	6.03	5.27	18.61	17.27
-2.40+1.67	57.18	59.13	5.89	5.3	18.29	16.86
-1.67+0.85	45.35	46.14	5.95	5.23	18.24	16.96
-0.85+0.58	28.74	29.19	5.97	5.21	18.73	17.28
-0.58+0.40	22.76	22.36	5.81	5.26	18.06	16.86
-0.40+0.20	17.22	15.82	5.77	5.28	18.48	16.79
-0.20+0.106	9.80	10.54	5.82	5.43	18.46	16.96
-0.106+0.074	4.56	6.31	5.75	5.86	17.02	16.89
-0.074	6.54	4.49	5. 91	6.20	17.97	16.86
Calculated			5.93	5.42	18.35	17.36
Head			5.30	6.00	18.42	17.08

Results indicate that both samples are of low grade according to the market specifications for glass and ceramic production as well as bulk filler grade requirements (Harben 1995). Their alumina content is between 17.1 % and 18.4% as compared with at least 23% for glass manufacture. Similarly, their alkali content ranges between 12.3% and 14.6%, slightly lower or on the border line of the market specification which is 14%. Both samples have high iron content, that is 5–6 % Fe_2O_3.

The samples were primary crushed in a Denver pilot jaw crusher followed by Wedag roller to less than 3.36mm. Chemical analysis of different size fractions of the secondary crushed samples shows nearly even distribution of alumina and iron oxide, indicating no differential friability of components (Table 2).

Microscopic examination and x-ray diffraction of the samples show that they costitute mainly of perthitic orthoclase and albite with minor amounts of various iron bearing minerals, for example augite, biotite and hornblend.

LIBERATION STUDY OF THE SAMPLES USING FRANTZ ISODYNAMIC TESTER

Frantz isodynamic laboratory separator was used as a dry tool to study the liberation characters of the samples. Ferromagnetic particles were first separated from the feed samples by hand magnet and the reminder was subjected to magnetic separation under various field strength at constant angle of inclination (15^o forward, and 5^o degree side angle of inclination). Different magnetic and non-magnetic fractions were collected, weighed and analyzed. Results shown in Tables 2 and 3 indicate that it might be possible to obtain an ambre glass nepheline syenite products from Abu-Khrug sample (0.24%Fe_2O_3 and 25% Al_2O_3) and ceramic grade product from El-Kahfa sample (0.1% Fe_2O_3, 25.1% Al_2O_3) by fine grinding to less than 0.053mm.

Table 3. Effect of "Dings" beltspeed on the separation efficiency

Belt speed m/min	Product	Wt. %	Fe_2O_3	
			Assay Wt.%	Dist.Wt.%
2	Conc.	87.6	2.89	45.61
	Tail	12.4	24.34	54.39
4	Conc.	88.1	2.93	46.2
	Tail	11.9	25.28	53.8
6	Conc.	90.8	3.72	60.6
	Tail	9.2	24.09	39.4
8	Conc.	93.8	4.3	72.03
	Tail	6.2	25.27	27.97

FEED PREPARATION FOR BENEFICIATION

A Wedag rod mill was used for feed preparation for concentration process to minimize slimes production and to get a narrow sized material. The mill is operated in a locked cycle regime with duration time of 15 min./cycle, fed with 1kg sample of the –3.36mm ore and operated in a closed circuit with a 0.25 mm screen or 0.125mm one.

After each grinding period the mill was discharged and the ground product was screened to remove the under size from the circuit. The mill was then compensated with an amount of a feed equivalent to the removed fraction. 9 grinding rods and 15min grinding time were applied to prepare 100% -0.25mm or –0.125mm feed for the beneficiation process. On the other hand preparation of finer feed samples was conducted dry in planetary porcelain mill. Calculations of the Work Index Wi, required for dry grinding of both nepheline synite samples indicate the high hardness of the ores, reaching about 26-30 kWh/Mg (Bond 1985).

DRY HIGH INTENSITY MAGNETIC SEPARATION OF THE GROUND SAMPLES

Different types of dry magnetic separators that vary in the field intensity and the mode of separation were carried out. “Dings” cross-belt separator was applied as a dry pick up separator with an auxiliary permanent magnet for the separation of ferromagnetic material ahead of the electromagnet. Optimization of the main parameters affecting separation efficiency including applied magnetic field, feed size and rate were studied.

”Carpco” induced roll magnetic separator was employed in this investigation as a free fall kind of separator that it is widely used with dry sand size materials. Higher capacities are attained by such equipment compared with the pick-up type separators. However, “Carpco” induced roll used in this investigation model MIH (13) (111-5) is characterized by its capability of processing granular material up to 90 kg/h , variable magnetic field intensity up to 0.96T(tesla) and 127mm diameterX 50.8mm length laminated roll with variable speed 0–100 rpm. Optimization of the separation process including, roll speed, magnetic field intensity and both rate andsize offeeding material, was carried out.

“Magnaroll” magnetic separator used in this study is the latest design introduced by “Boxmag Rapid” that features the incorporation of rare earth permanent magnets in high intensity magnetic separation. It is considered as a dry HIMS. This particular type of magnetic pulley separator model MR 1.125 attains a magnetic field intensity up to 1.45T. Belt speed, feed rate and feeding material grain size were studied as the main woking parameters.

RESULTSAND DISCUSSIONS

The effect of changing the main belt speed of “Dings” separator, which determines the residence time of the particles in the magnetic field, is shown in Table 3. This was carried out using Abu-Khrug sample under one particle layer feed, feed size – 0.25 mm, magnetic field of 1.0T and a minimum air gap of 3 mm..

The results indicate that at a belt speed of 2 m/min, it was possible to obtain a concentrate with Fe_2O_3 of 2.89% from a head sample containing 5.5% F_2O_3 i.e with about 54.39% Fe_2O_3 operational removal. Changing the number of feed layers on the belt at its optimum speed and under the same operating conditions resulted in deterioration of the separation process due to the shielding effect. This has a major effect on the quality of the concentrate and the capacity of separator as well. Results shown in Table 4 indicate that at a four-particle layer feed, a non magnetic concentrate having 4.61 % Fe_2O_3 was obtained from a feed assaying 5.5% Fe_2O_3 i.e. only 16.2% removal of iron bearing impurities was achieved. By increasing the magnetic field strength to its maximum of 1.3,T under the predetermined optimum conditions, relative improvement in the quality of the concentrate was achieved and its iron content was decreased to 1.96% Fe_2O_3 i.e. about 69.9% removal of magnetic impurities was achieved (Table 5).

Table 4. Effect of "Dings"cross belt feeding rate on the separation efficiency

Feed rate, kg/h	Product	Wt. %	Fe_2O_3	
			Assay %	Dist. Wt. %
12	Conc. Tail	87.6 12.4	2.89 24.34	45.61 54.394
24	Conc. Tail	89.6 10.4	3.10 26.94	49.8 50.2
36	Conc. Tail	92.01 7.99	3.86 25.8	63.3 51.1
48	Conc. Tail	94.2 5.8	4.61 22.19	77.14 22.86

Table 5. Separation of Abu-Khrug sample at maximum magnetic field strength

Feed size, mm	Product	Wt.%	Fe_2O_3	
			Assay %	Dist. Wt..%
-0.25mm	Conc. Tail Total Head	85.0 15 100 93.8	1.96 25.8 5.53 5.5	30.1 69.9 100 88.34

However better result was obtained by fractionating of the -0.25 mm feed into two size cuts, - 0.25 + 0.106mm and – 0.106 mm. A corresponding decrease in the iron content of the final concentrate to 1.4% Fe_2O_3 was obtained with 74.5% removal of the iron content. This confirms the shielding effect of coarse particles and necessitates using very closed size feeds with this kind of separator. Using a finer feed i.e.– 0.125mm, under a monolayer feed rate (about 12 kg/h), belt speed of 4 m/min, and maximum field strength of 1.3T resulted in an apprecialde decrease in the iron content of the concentrate to 1.3% Fe_2O_3,(Table 6).

On the other hand, when El-Kahfa sample was subjected to separation using the cross belt dry magnetic separator under the predetermined optimum conditions, better results were achieved. A non magnetic concentrate having 0.98% Fe_2O_3 was obtained with the – 0.25mm feed, and decreased to 0.58% Fe_2O_3 with the – 0.125 mm feed, (Table 7).

Table 6. Effect of feed fractionation prior to separation

Fraction size, mm	product	Wt. %	Fe_2O_3	
			Assay %	Dist. Wt.%
-0.25+0.106	Conc. Tail	83.1 16.9	1.46 24.3	22.80 77.20
-0.106+0.045	Conc. Tail	81.6 18.4	1.25 27.6	16.72 83.27
-0.125+0.045	Conc. Tail	80.6 19.4	1.3 21.66	19.96 80.04

Table7. Separation of El-Kahfa sample at "Dings"optimum working conditions

Feed size, mm	Product	Wt.%	Fe_2O_3	
			Assay %	Dist. Wt. %
-0.25+0.045	Conc. Tail	72.46 27.54	0.98 16.27	13.68 86.32
-0.125+0.045	Conc. Tail	73.69 26.31	0.58 17.76	8.38 91.620

One can conclude that, within the afore mentioned limits of experimentation on these samples, that it was not possible to produce high quality nepheline syenite concentrates by this type of magnetic separators only.

Although the magnetic flux intensity of "Carpco" separator is relatively less than that of the "Dings" cross-belt (0.96T as compared with 1.3T), yet it can handle sandy – sized feeds at a much higher capacity than the latter one. In the mean time, having a roll of diameters 88.9mm D X 50.8mm L with a variable speed controller from 0 to 100 rpm, the generated centrifugal force with the free fall of the feed create much more favorable conditions for separation, as compared with the "shielding" effect of belt separators. That might result in producing concentrates with better grades.

Table 8. Effect of changing"Carpco"feeding rate on the separation effeciency

Feed rate, kg/h	Product	Wt. %	Fe_2O_3	
			Assay %	Dist. Wt. %
12	Conc. Tail	70.98 29.02	1.74 15.21	21.97 78.13
24	Conc. Tail	74.86 25.14	1.76 16.99	23.57 76.43
36	Conc. Tail.	76.2 23.8	1.96 17.59	26.3 73.7
48	Conc. Tail	73.86 26.14	2.38 14.77	31.28 66.72

By applying the separation of Abu Khrug sample at various drum speeds a pronounced decrease in the iron oxide content of the product was recorded up a roll speed of 60 rpm. A product with a weight recovery of 75% with an assay of 1.76% Fe_2O_3 was obtained. By elevating the drum speed over this value , a remarkable drop in the product grade was noticed. The increasing in the feed rate to 48 kg/h at this optimum roll speed i.e. 60rpm, keeping all other parameters constant, a corresponding grade deterioration occurred (Table 8). An appreciable improvement in the concentrate quality was achieved by increasing the applied magnetic field to the maximum (0.96T) at optimum feed rate of 24 kg/h (Table 9). A concentrate assaying 1.4% Fe_2O_3 was reached as compared with 1.96% Fe_2O_3 with the“Dings” cross-belt separator at its maximum magnetic field strength. Separation of – 0.125 mm feed under these optimum conditions resulted in a remarkable decrease in the iron content of the concentrate to 0.72% Fe_2O_3, (Table 9).

Table 9.Magnetic separation of sample I at “Carpco” maximum magnetic field

Feed Size, mm	Product	Wt. %	Fe_2O_3	
			Assay %	Dist. Wt.%
-0.25+0.045	Conc.	73.5	1.4	17.71
	Tail	26.5	18.04	82.29
-0.125+0.045	Conc.	70.22	0.72	9.72
	Tail	29.78	15.53	90.28

Table 10. El-Kahfa separation at ” Carpco” optimum conditions

Feed size, mm	Product	Wt.%	Fe_2O_3	
			Assay %	Dist. Wt.%
-0.25+0.045	Conc.	70.86	1.03	14.14
	Tail	29.14	15.2	85.86
-0.125+0.045	Conc.	71.68	0.61	8.36
	Tail	28.32	16.92	91.64

Table 11. "Magnaroll" belt speed effect in the separation of Abu-Khruq sample

Belt speed, m/min	Product	Wt. %	Fe_2O_3	
			Assay %	Dist. Wt. %
2	conc.	53.9	0.24	2.44
	Tail	46.1	11.216	97.56
4	conc.	57.2	0.24	2.59
	Tail	42.8	12.06	97.41
6	conc.	59.5	0.45	5.05
	Tail	40.5	12.43	94.95
10	conc.	64.3	0.62	7.52
	Tail	35.7	13.73	92.48

Magnetic separation of El-Kahfa sample, under the predetermined optimum conditions, gave relatively better results. Non magnetic concentrates assaying 1.03 and 0.61% Fe_2O_3 were obtained with the – 0.25mm feed and the – 0.125mm feed, respectively (Table 10). Regardless of the improved results obtained with the induced roll magnetic separator, the nepheline syenite concentrate did not satisfy the requirements for glass and ceramics production. Although the magnetic flux intensity of “Carpco”separator is relatively less than that of the “Dings” cross-belt (0.96T as compared with 1.3T), yet it can handle sandy – sized feeds at a much higher capacity than the latter one. In the mean time, having a 88.9mm D X50.8mm L roll with variable speed 0–100 rpm, the generated centrifugal force with the free fall of the feed create much more favorable conditions for separation, as compared with the "shielding" effect of belt separators. That might result in producing concentrates with better grades.

Table 11 indicates that at the "Magnaroll" belt speed of 4 m/min and feed rate of 12 kg/h a non magnetic concentrate assaying 0.27% Fe_2O_3 was obtained by separating the – 0.125mm feed, which is the most clean concentrate obtained as compared with the other separators. A magnetic flux intensity as high as 1.45T incorporated by the rare earth permanent magnets of this separator, leads to increasing the separation efficiency of paramagnetic particles, beside lowering the operating cost of the process, where no power is required to generate the magnetic field during the operation.

Table 12. "Magnaroll" feed rate effect on separation of Abu-Khruq sample

Feed rate, kg/h	Product	Wt.%	Fe_2O_3	
			Assay %	Dist. Wt. %
6	Conc. Tail	57.2 42.8	0.24 12.06	2.59 97.41
12	Conc. Tail	59.6 40.4	0.27 12.56	3.07 96.93
18	Conc. Tail	61.3 38.7	0.58 13.06	6.57 93.43
24	Conc. Tail.	65.1 34.9	0.64 13.99	7.86 92.14
30	Conc. Tail	68.3 31.7	0.81 15.16	10.32 89.68

Table 13. Separation of El-Kahfa at "Magnaroll"optimum working conditions

Feed size, mm	Product	Wt.%	Fe_2O_3	
			Assay %	Dist. Wt.%
-0.25+0.045	Conc. Tail Total Head	74.38 25.62 100 94.2	0.77 18.45 5.30 5.25	10.81 89.19
-0.125+0.045	Conc. Tail Total Head	68.6 31.4 100 87.7	0.28 15.69 5.12 5.25	3.75 96.25

Increasing the feed rate of "Magnaroll" to more than 12 kg/h at an optimum belt speed of 4 m/min led to over crowding in the separation zone and, hence a corresponding deterioration in the quality of the concentrate took place, (Table 12). Separation of sample 2 under the predetermined optimum conditions yielded nepheline syenite concentrate assaying 0.48% Fe_2O_3 and 0.28% Fe_2O_3 for both the –

0.25mm and the – 0.125mm feeds, respectively (Table 13). These concentrates could be intentionally acceptable as glass grade products in amber glass and fiberglass industries, as well as ceramic purposes. Microscopic studies of the nepheline syenite concentrates shows a brownish tinge of iron-bearing minerals which can be a surface coating or disseminated fine grains in a matrix of syenite. This might explain the difficulty of obtaining higher quality products. Some additional improvement may be possible by further size reduction of the feeding materials by applying wet process with special"Carpco" or "Jones" magnetic separators, or by flotation, but it will be at the expense of higher losses and additional cost.

CONCLUSIONS

Characterization of two nepheline syenite samples from Gabel Abu-Khrug and El-Kahfa localities in the Eastern Desert of Egypt, indicated that both samples are low in grade with 17.1% - 18.4% Al_2O_3, 12.3 – 14.6% $Na_2O + K_2O$ and high in iron content 5.3 – 6% Fe_2O_3. Granulometric analysis of the secondary crushed samples showed a unimodal trend with respect to both alumina and iron oxide contents. Liberation study of the ground samples using Frantz isodynamic laboratory separator, implied fine grinding, some times to less than 0.053 mm, to achieve a reasonable degree of liberation of minerals. Applying the dry high intensity magnetic separation of the ground samples using "Ding's" cross belt separator at a maximum magnetic field intensity of 1.3T, and feed size 0.125 + 0.045 mm gave nepheline concentrates having 1.3% and 0.58% Fe_2O_3 for Abu-Khrug and El-Kahfa samples, respectively.

Using "Carpco" induced roll magnetic separator, as a free fall technique, showed better separation with doubling the feeding rate (24 kg/h) andat nearly the same magnetic field strength, concentrates having 0.72% and 0.61% Fe_2O_3 were obtained with the – 0.125 + 0.045 mm feed of both samples, respectively.

Application of "Magnaroll" rare earth permanent magnetic separator, with a field intensity of 1.45T at a feed rate of 12 kg/h and belt speed of 4 m/min resulted concentrates with a substantial decrease in the iron content, reaching 0.24% and 0.28% for Abu-Khrug and El-Kahfa samples, respectively. These concentrates satisfy the international specifications for amber glass and fiberglass production as well as local ceramics industries**.**

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Stosowano różne, działające na sucho, separatory magnetyczne o dużej intensywności pola magnetycznego do usuwania minerałów żelazonośnych z dwóch rud nefelinowo-sjenitowych. Do separacji wstępnej użyto separatora typu Dingo o skrzyżowanych taśmach. Jako separator właściwy zastosowano separator indukcyjny bębnowy typu Carpco, który jest szeroko stosowany do przeróbki piasków na sucho. Użyto także separator magnetyczny typu Magnaroll, najnowszy model separatorafirmy Boxmag – Rapid, który posiada stałe magnesy wykonane z pierwiastków ziem rzadkich. Badano wpływ głównych parametrów na proces separacji magnetycznej. Stwierdzono, że najlepsze wyniki uzyskuje się stosując separator Magnaroll. Wytworzono koncentraty zawierające 0,24% i 0,28% tlenków żelaza z nadawy zawierającej odpowiednio 6,0 i 5,3% Fe_2O_3. Uzyskane produkty mogą być stosowane do produkcji szkła miodowego oraz włókna szklanego oraz ceramiki.