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Abdel Tawab NEGM[*], Abdel Zaher ABOUZEID[*], Tawfik BOULOS[**], Hussin AHMED[**]

NEPHELINE SYENITE PROCESSING FOR GLASS AND CERAMIC INDUSTRIES

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There are several localities in the Eastern Desert in Egypt where nepheline syenite has been located. Among these localities are: Gabal Elkahfa, Gabal Abuikhrug, Gabal Nigrub Elfogani, Gabal Elnaga, and Gabal Mishbih. One of these ores, El-Kahfa nepheline ore, was selected for beneficiation to produce a product suitable for ceramic and glass manufacturing. An ore sample from El-Kahfa was characterized chemically and mineralogically. The chemical analysis of the sample was 57.8% SiO_2, 17.1% Al_2O_3, 5.3% Fe_2O_3, 9.2% Na_2O, and 5.5% K_2O. Mineralogically, it was found that the ore consists mainly of: orthoclase, andesite, nepheline, biotite, hornblend, and augite. The main objective of this research work was to reduce the iron content of the ore to a permissible limit to be used in glass and ceramics. Using a dry high intensity magnetic separator, a product assaying 0.5% Fe_2O_3 (about 0.35% Fe) from a size fraction -0.125+0.045 mm was obtained. When a wet high gradient magnetic separator was used at solid/liquid ratio of 1:9, the iron content was reduced down to 0.32% Fe_2O_3 using feed of -0.045 mm size fraction. By reverse flotation technique, a concentrate containing 0.4% Fe_2O_3 was obtained. Combining flotation with magnetic separation, i.e., subjecting the nonmagnetic fraction from the high gradient magnetic separator to anionic flotation, it was possible to get a final product assaying 0.21% Fe_2O_3 at a recovery of 70% using feed of - 0.075 mm.

Key words: nepheline, syenite, ceramic raw material, processing, flotation, magnetic separation.

INTRODUCTION

Feldspathoid rocks e.g. nepheline syenite, aplite and feldspar are indispensable raw

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[*] Cairo University, Faculty of Engineering, Dept. of Mining, Egypt

[**] Centeral Metallargical Research & Development Institute, Egypt

materials in glass, ceramics and fillers production. However, nepheline is the most common of all due to its higher alkalis and alumina content per unit weight, it has been a formidable competitor to feldspar in North America and parts of Western Europe.

The low fusion point of nepheline syenite lowers the melting temperature, promoting faster melting, higher productivity and fuel savings in glass industry (Guillet 1994). In ceramics 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 temperatures and faster firing schedules.

In plastic, it is used as an inert, low cost filler in PVC, epoxy and polyester resin systems. Because it exhibits a low resin demand, high filler loadings 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, all of which allows it to be used in nearly transparent stock. Finely ground nepheline syenite is especially employed as an inert filler in paints, both latex and alkaloid systems, as metal primers, wood stains, etc. it contributes a high dry brightness, high bulking value and easy wetting and dispersion in paint formulation.

Environmentally, nepheline syenite, which contains no free silica, is less health hazardous than feldspar, particularly in ultrafine grinding for fillers and extenders production in both plastics and paint fields.

In Egypt, research and development projects were not able to confirm the techno-economic feasibility of the Red Sea nepheline syenites in production of alumina and Portland cement (Ismail 1976). Nevertheless, direct utilisation of beneficiated rock in glass and ceramics production might be another option for making the most of 90 million tons of ore reserves in the different localities of the Eastern Desert (El-Ramly 1970).

For all these reasons, this research will be devoted to the study of the amenability of nepheline syenite from Gabal El-Kahfa locality of the Eastern Desert in Egypt, to beneficiation for different industrial applications. Characterisation of the samples by routine chemical analysis, thermal analysis and ore microscopy will be carried out prior to concentration. Both dry and wet magnetic separation methods will be demonstrated. Reverse flotation of iron bearing contaminants will, also, be employed either separately or in combination with magnetic separation for the objective of producing high quality nepheline concentrates.

ORIGIN, TYPES AND CHARACTERISTICS

Nepheline syenite is a light-coloured igneous rock, not a mineral, which is similar in its medium to coarse-grained appearance to granite. In an alkali-rich rock magma deficient in silica, nepheline will form instead of albite feldspar (Minnes 1983; Guillet 1994). However some nepheline gneisses and other nepheline rocks may also have formed by metasomatic nephelinization process.

Nepheline rocks are composed essentially of nepheline, sodic plagioclase (usually albite or oligoclase) and microcline but in varying proportions, with small amounts of biotite, hornblende, magnetite, pyroxene, muscovite, sodalite, garnet, zircon, apatite, ilmenite, calcite, pyrite and zeolites as impurities or colouring minerals (Hewitt 1961).

The structural formula of nepheline is $Na_3KAl_4Si_4O_{16}$. Potassium is always present in nepheline, most frequently, in a ratio of Na/K =3:1, although ratios of 4:1 and 6:1 are known (Minnes 1983 and Guillet, 1994). It crystallises in the hexagonal system and frequently forms 6 to 12 sided prisms. It has a distinct and imperfect cleavage and a subconchoidal fracture. It is brittle with hardness of 5.5-6 in Mohs' scale and specific gravity of 2.5 to 2.7.

MAJOR WORLD DEPOSITS, POTENTIAL AND PRODUCTION

Nepheline Syenite deposits are rarely of great areal extent. However, although size is not a very important criterion in commercial considerations, more important are the purity and the location of the deposit.

Nepheline syenite reserves are considered limitless in the former USSR, Norway, Canada and recently Turkey. The largest potential nepheline syenite deposits are those of the Kola Pennisula, Russia, about 100 billion ton covering two areas of 450 and 250 square miles (Notholt 1983). In Norway, at Norsk Nefelin, the volume of proven nepheline syenite exceeds 135 million cubic meter representing nearly 400 million tons of a nature the company considers suitable for mining. In Canada, Idusmin Co. has published a reserve figure of 240 million tons of nepheline syenite found in Blue Mountain area. The Canaan deposit of Brazil extending in two localities 300 and 100 square miles was found to represent only 120 million tons (de Ferran 1983). Reserves of the rock in Turkey, was recently estimated and was found over 1 billion ton (Gulsoy 1993). Most other countries are typically much smaller.

The principal producing countries of glass and ceramic grades of nepheline syenite are Canada and Norway, where 70% of their production is directed towards the glass industry, 28 % to manufacturers of ceramic bodies and 2% for use in fillers (Harben 1995). The combined production of the two countries has grown from 250,000 ton in 1961 to 740,000 ton in 1972 (Minnes 1983). The total production of both Canada and Norway represented 26% of the world production in 1995 taking into consideration that Republic of Russia production in the same year reached 70% of the world production (2.5 million tons) (Harben 1995). Former USSR production in the years 1980 – 1994 range between 2.3 – 2.45 million tons / year.

NEPHELINE SYENITE DEPOSITS OF EGYPT

The presence of nepheline syenite in Egypt is confined to the ring complexes. These complexes are circular igneous structures formed after magma solidification. They are located in the southern sector of the Eastern Desert, south Idfu - Mersa Alam road in a square limited by the longitudes 33°and 36°and latitudes 22° and 25°. The nepheline syenite localities were studied from the geological point of view by the „Egyptian Geological Survey". Photogeological maps were prepared. The various rock types were identified, also mineralogical and chemical compositions were determined. (Ramely et.al. 1969).

MATERIALS AND METHODS

SAMPLE CHARACTERIZATION

A grab sample from El Kahfa locality of the Eastern Desert was crushed in a jaw crusher to less than 1 inch and then in a roll crusher to less than 3 mm. The sample was thoroughly mixed and divided into small bags for grinding. Chemical analyses and petrographic examination were carried out on representative sample of the ore. Granulometric analysis of the crushed sample was carried out, and each size fraction was chemically analysed. Sink and float tests were conducted on the different size fractions of the crushed samples using bromoform (2,889 g/cm^3). The Frantz isodynamic tester was used to separate magnetic heavy contaminants of the nepheline syenite sample.

PROCESSING TECHNIQUES

High intensity magnetic separation was carried out using different types of dry and wet separator that vary in field intensity and mode of operation. The „Dings" cross belt separator used in this investigation is a dry pick up type with an auxiliary permanent magnet for the separation of ferro-magnetic material ahead of the electromagnet at a minimum air gap of 3 mm. The „Carpco" induced roll magnetic separator was also used. It is a free – fall separator that is widely used with dry sand size materials. On the other hand, wet methods were investigated using high intensity high gradient magnetic separate the laboratory „Boxmag Rapid" magnetic separator consists of a canister packed with magnetized stainless steel wool matrix. The main parameters affecting the process are feed size, type of matrix, deep rate and packing density. Reverse floatation of heavy minerals contaminants of the nepheline syenite samples was carried out in a „Denver D – 12" flotation cell using different collectors and constant pH. Combined magnetic separation followed by reverse flotation of the non magnetic fraction was also conduced to ensure ultimate removal of the iron bearing mineral.

RESULTS AND DISCUSSIONS

CHEMICAL ANALYSIS OF THE ORIGINAL SAMPLES

Results of the complete chemical analysis of the original nepheline syenite sample is shown in Table (1) which indicate that the sample is low in alumina high in iron content, and out of market specifications for glass and ceramics production.

Table 1. Complete Chemical Analysis of Gabal El – Kahfa Nepheline Syenite Ore

Consitituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2
%	57.82	17.08	5.30	0.87	0.20	9.18	5.46	0.13
Consitituent	P_2O_5	S	Cl	CO_2	Humidity	L.O.I	Total	
%	0.01	0.02	0.05	0.15	0.48	0.53	97.28	

PETROGRAPHIC EXAMINATION

Microscopic examination of both thin and polished sections of the nepheline syenite samples shows that they are composed mainly of perthitic orthoclase and albite (oligoclase and andesine) from 50 to 70 %, nepheline from 15 to 25 % and green hornblende from 4 to 6%. Other minerals include small amounts of augite, biotite and hornblende with traces of free silica.

X-ray diffraction analysis of the bulk samples confirms the above conclusions for the major components. Oligoclase, andesine orthoclase and nepheline minerals are abundant with minor hornblende, biotite and augite. On the other hand XRD analysis of the sink fraction (separated by bromoform) depicts peaks for biotite, hornblende and augite, and feldspar.

GRANULOMETRIC ANALYSIS OF THE CRUSHED SAMPLES

Size distribution curve of the secondary crushed sample is shown in Table 2. A general unimodal representation is exhibited for the sample with d_{50} equals 1.85 mm.

Table 2. Dry Size Analysis and Chemical Analysis of El-Kahfa Nepheline Syenite Crushed Sample

Size, mm	Wt., %	Cum. Wt. % passing	Fe_2O_3 %	Al_2O_3 %	Distribution, %	
					Fe_2O_3	Al_2O_3
+6.68	4.93	100	5.28	17.31	4.89	4.99
-6.68 + 4.67	7.05	95.07	5.18	17.26	6.86	7.13
-4.67 + 2.40	28.89	88.02	5.27	17.27	28.61	29.23
-2.40 + 1.67	12.99	59.13	5.3	16.86	12.94	12.83
-1.67 + 0.85	16.95	46.14	5.23	16.96	16.66	16.84
-0.85 + 0.58	6.83	29.19	5.21	17.28	6.69	6.91
-0.58 + 0.40	6.54	22.36	5.26	16.86	6.47	6.46
-0.40 + 0.20	5.28	15.82	5.28	16.79	5.24	5.19
-0.2 + 0.106	4.23	10.54	5.43	16.96	4.32	4.20
-0.106 + 0.074	1.82	6.31	5.86	16.89	2.00	1.80
-0.074	4.49	4.49	6.20	16.86	5.23	4.43
Total (Calc.)	100		5.42	17.36	100	100
Head	100		5.30	17.08	100	100

LIBERATION STUDIES

Evidently, a gradual decrease in the iron content is exhibited with the corresponding decrease in size. From an average of 5.25 % Fe_2O_3 in the head sample, it reaches 0.85 % in the float of size -0.106+0.075 mm. The problem of such high iron content in the float fraction can not be attributed to the liberation of the different mineral phases only, but also to the presence of biotite which is a light iron bearing mineral (sp.gr. 2.7-3.2). This agreed with the phases encountered in the float fraction studied by XRD.

It is clear that the sink-float technique is not the most appropriate technique for studying the degree of liberation of these types of samples due to the presence of light iron bearing minerals, such as biotite, which joins the desired species in the float fraction. Consequently, the Frantz isodynamic high intensity magnetic tester was used for the liberation studies as discussed below.

Results of the magnetic separation of the different size fractions is depicted in Fig. 1. Obviously, the results are quite different, concerning concentrate iron content than in sink-float tests. The percentage of Fe_2O_3 in the - 0.053 + 0.045 mm fraction reached 0.1 % but with an alumina recovery of 77.5%.

Table 3 shows the sink-float results for the different size fractions of the ground sample using bromoform (2.889 g/cm^3).

Table 3. Sink-float results of the nephelme syenite of Gabal El-Kahfa ground sample using bromoform (2.889 g/cm^3)

Size, mm	Product	Wt., %	Fe_2O_3 %	Al_2O_3 %	Distribution, %	
					Fe_2O_3	Al_2O_3
-0.25 + 0.211	Float	89.8	1.38	19.03	23.03	97.54
	Sink	10.2	40.6	4.20	76.97	2.46
	Total	100	5.38	17.52	100	100
	Head	17.54	5.46	17.46	100	100
-0.211 + 0.125	Float	86.5	1.2	19.68	19.89	97.89
	Sink	13.8	30.33	3.08	8.01	2.11
	Total	100	5.22	17.39	100	100
	Head	42.6	5.32	17.5	100	100
-0.125 + 0.106	Float	83.4	0.96	19.93	15.60	96.18
	Sink	16.6	26.08	3.97	84.40	3.82
	Total	100	5.13	17.28	100	100
	Head	10.05	5.10	17.20	100	100
-0.106 + 0.075	Float	79.6	0.85	20.06	12.86	91.24
	Sink	20.4	22.47	7.51	87.14	8.76
	Total	100	5.26	17.5	100	100
	Head	12.53	5.32	17.35	100	100
-0.075 + 0.053	Float	81.3	1.43	19.78	22.39	93.77
	Sink	18.7	21.6	5.71	77.64	6.23
	Total	100	5.2	17.15	100	100
	Head	8.18	5.25	17.35	100	100
-0.053 + 0.045	Float	83.4	2.06	19.3	32.30	94.40
	Sink	16.6	21.7	5.81	67.70	5.60
	Total	100	5.32	17.06	100	100
	Head	5.21	5.12	17.10	100	100

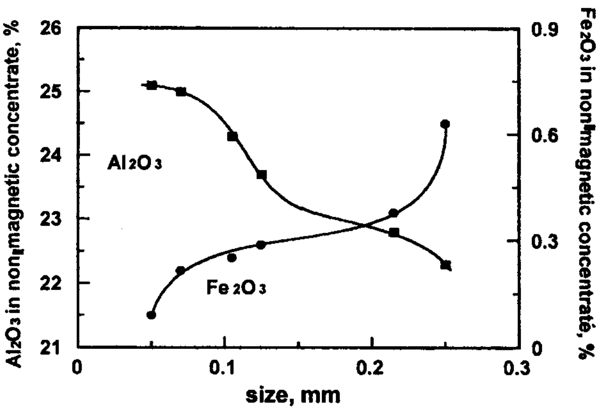

Fig. 1. Effect of the degree of fineness on the alumina and iron assays of El-Kahfa ground sample separated by Frantz Isodynamic Tester.

The cross belt 'Dings' dry magnetic separator was used under predetermined optimum conditions. A non magnetic concentrate having 0.98% Fe_2O_3 was obtained. Better results were achieved with the size fraction –0.25 + 0.045 mm feed, as shown in Table 4.

Table 4. Separation of Nepheline Syenite Using the „Dings" Magnetic Separator

Feed size mm	Product	Wt., %	Fe_2O_3	
			Ass. %	Dist. %
-0.25 + 0.125	Conc.	72.46	0.98	13.68
	Tail	27.54	16.27	86.32
	Total	100	5.19	100
	Head	94.2	5.25	92.6
-0.125 + 0.045	Conc.	73.69	0.58	8.38
	Tail	26.31	17.76	91.62
	Total	100	5.10	100
	Head	87.7	5.20	74.80

On the other hand, using the „Carpco" induced roll separator a non-magnetic concentrate assaying 0.58 Fe_2O_3 was achieved as shown in Table 5.

Table 5. Results of Magnetic Separation Using The „Carpco" Induced Roll Magnetic Separator

Feed size mm	Product	Wt., %	Fe_2O_3	
			Ass. %	Dist. %
-0.25 + 0.125	Conc.	70.86	1.03	14.14
	Tail	29.14	15.2	85.86
	Total	100	5.16	100
	Head	94.2	5.25	92.6
-0.125 + 0.045	Conc.	71.68	0.61	8.36
	Tail	28.32	16.92	91.64
	Total	100	5.23	100
	Head	87.7	5.20	74.8

Regardless of the improved results obtained with the induced roll magnetic separator the nepheline syenite concentrates did not satisfy the requirements for glass and/or ceramics production.

Wet high gradient magnetic separation of Gabal El-Kahfa sample gave relatively better results. Using 1.5 mm iron spacing as a magnetic matrix a systematic decrease in the iron content of the non magnetic concentrate was obtained with decrease in feed size. The iron content reached 0.4 % and 0.32 % Fe_2O_3 with the -0.075 mm and the -0.045 mm feed, respectively, using the steel wool matrix as shown in Table 6.

Table 6. Effect of Feed Size on the Wet High Gradient Magnetic Separation of Nepheline Syenite

Feed size mm	Magnetic Matrix	Product	Wt., %	Assay, %		Distribution, %	
				Fe_2O_3	Al_2O_3	Fe_2O_3	Al_2O_3
-0.075	Stainless	Conc.	63.6	0.41	23.48	4.86	87.23
	Steel	Tail	36.4	14.0	6.00	95.14	12.77
	Wool	Total	100	5.36	17.12	100	100
	Matrix	Head	100	5.30	17.08	100	100
-0.045 at 10%	Stainless	Conc.	58.6	0.32	23.82	3.57	81.39
solid no	Steel	Tail	41.4	12.25	7.70	96.43	18.61
soduim	Wool	Total	100	5.26	17.15	100	100
silicate (S.S)	Matrix	Head	100	5.30	17.08	100	100
-0.045 at	Stainless	Conc.	49.6	0.20	23.76	1.86	68.91
5% solid	Steel	Tail	50.4	10.34	10.55	98.14	31.09
and 0.2	Wool	Total	100	5.31	17.10	100	100
kg/t S.S	Matrix	Head	100	5.30	17.08	100	100

When the -0.074 mm size feed was used in flotation, with the collector „Cyanamid" Aeropromotors mixture, the best nepheline syenite concentrate was obtained (Table 7). From 5.3 % Fe_2O_3 and 17.1 % Al_2O_3 in the feed, the flotation concentrate had 0.4 Fe_2O_3 % and about 23.5 % Al_2O_3 with alumina recovery of 93 %.

Table 7. Results of Reverse Anionic Flotation of El-Kahfa Sample(100 % -0.075 mm Feed) Using Cyanamid collector

Collector Dose	Product	Wt., %	Assay %		Distribution %	
			Fe_2O_3	Al_2O_3	Fe_2O_3	Al_2O_3
2.25 kg/t	Conc.	67.86	0.40	23.46	5.37	92.99
	Tail	32.14	15.63	3.73	94.73	7.01
	Total	100	5.31	17.12	100	100
	Head	100	5.30	17.08	100	100

Combined Magnetic Separation–Flotation of the Finely Ground Nepheline Syenite Samples

It was interesting to investigate the amenability of cleaning the -0.075 mm finely ground non magnetic concentrates obtained by using the wet „Boxmag Rapid" high gradient separator through anionic flotation in view of the unsatisfactory results achieved with each process separately. However, the same technique was successfully employed by Golsoy et al. (1993) for the treatment of the Turkish nepheline syenite deposit of Kirsehir Kaman District. Results shown in Table 8 indicate that from the non magnetic nepheline syenite concentrate of El Kahfa sample assaying 0.41% Fe_2O_3 and 23.48% Al_2O_3, a clean flotation concentrate having 0.21 % Fe_2O_3 and 23.63% Al_2O_3 was obtained at a total recovery of about 81%.

Table 8. Magnetic Separation–Flotation Results of El–kahfa Nepheline Sample (100%-0.075 Feed)

Process	Product	Wt., %	Assay, %		Distribution, %	
			Fe_2O_3	Al_2O_3	Fe_2O_3	Al_2O_3
Magnetic Separation Using Boxmag Wet Separator	Conc.	63.6	0.41	23.48	4.86	87.23
	Tail	36.4	14.00	6.00	95.14	12.77
	Total	100	5.36	17.12	100	100
	Head	100	5.30	17.08	100	100
Reverse Anionic Flotation Using „Cyanamid" 0.4 kg/t	Conc.	58.47	0.21	23.63	2.32	80.8
	Tail	5.31	2.94	22.14	2.84	6.64
	Total	63.6	0.43	23.51	5.16	87.44
	Head	63.6	0.41	23.48	4.86	87.23

CONCLUSIONS

Optimisation of the dry high intensity magnetic separation of the ground samples using the „Ding's" cross-belt separator at a maximum magnetic field intensity of 13 kGauss, minimum air gap of 3mm, and feed size -0.125+0.045 mm gave nepheline concentrate having 0.58% Fe_2O_3.

Using the „Carpco" induced roll magnetic separator, a free-fall device, a concentrate having 0.61% Fe_2O_3 was obtained with the same size fraction –0.125 + 0.045 mm feed.

Using the wet „Boxmag Rapid LHW" high gradient magnetic separator with a field intensity of 14 kGauss at a pulp density of 10 % solid, and feed rate of 6 kg/h solids (1 lit./min. suspension) it was possible to obtain cleaner nepheline syenite concentrates from finely ground feed, i.e. 100% less than 0.045 mm by using the stainless steel wool magnetic matrix. Product having 0.32% Fe_2O_3 was obtained with an alumina content of about 24 %.

When separation was conducted at a diluted pulp density (5% solid instead of 10%) in presence of sodium silicate as a dispersing agent, a nepheline concentrate assaying 0.2% Fe_2O_3 and 23.76% Al_2O_3 was obtained from a feed having 5.3 % Fe_2O_3 and 17.1

% Al_2O_3 of El-Kahfa sample at alumina recovery of 68.9%.

Optimisation of the reverse flotation process for minimising the iron bearing contaminants, a concentrate was obtained with El-Kahfa nepheline sample using the „Cyanamid" Aeropromoter, reaching 0.4% Fe_2O_3 and 23.5% Al_2O_3 from a feed having 5.3% Fe_2O_3 and 17.1% Al_2O_3.

Combined magnetic separation flotation of the finely ground samples yielded cleaner concentrates having 0.21% Fe_2O_3 and 23.63 % Al_2O_3 at recoveries of 81%. This means that combined magnetic separation – flotation technique improved the alumina recovery almost the same grade as the high gradient magnetic separation.

Microscopic studies of the nepheline syenite concentrates shows a brownish tinge of iron-bearing minerals which can be a surface coating which were not separated by mechanical attrition or disseminated fine grains in a matrix of syenite. This might explain the difficulty of obtaining high quality products that satisfy the international specifications for glass and ceramics production. However, these concentrates can be used in the local ceramics industry.

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W Egipcie istnieje kilka złóż sjenitu nefelinowego, wśród nich Gabal El-Kahta, G. Abuikhrug, G. Nigrub Elfogani oraz G. Mishbih. W tej pracy do badań użyto surowiec z El-Kahta, który dokładnie scharakteryzowano pod względem chemicznych i mineralogicznym. Badany materiał zawierał 57.8% SiO_2, 17.1% Al_2O_3, 5.3% Fe_2O_3, 9.2% Na_2O i 5.5% K_2O, a jego głównymi minerałami były ortoklaz, andezyn, nefelin, biotyt, hornblenda i augit. Głównym celem pracy było zredukowanie zawartości żelaza w rudzie do poziomu dopuszczalnego dla surowców do produkcji szkła i ceramiki. Przez zastosowanie separatora magnetycznego o dużym polu uzyskano produkt zawierający 0.5% Fe_2O_3, czyli około 0.35% Fe dla frakcji o uziarnieniu 0.045 - 0.125 mm. Z kolei stosując separator działający na mokro, przy stosunku zawartości części stałych do cieczy jak 1:9, zawartość żelaza została zredukowana do 0.32% dla nadawy o wielkości ziarn -0.045 mm. Za pomocą odwrotnej flotacji uzyskano zaś koncentrat o zawartości 0.4% Fe_2O_3. Łącząc flotację z separacją magnetyczną, tj. poddając produkt niemagnetyczny separacji magnetycznej o wysokim gradiencie pola oraz flotacja w obecności anionowych kolektorów uzyskano końcowy produkt zawierający 0.21% Fe_2O_3 z uzyskiem 70% dla nadawy o uziarnieniu -0.075 mm.