Nepheline Syenite Beneficiation for Glass and Ceramics Industries

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Beneficio de Nefelina Sienita para industrias de vidrio y cerámica

Beneficis de la Sienita Nefelina per a les indústries del vidre i la ceràmica.

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ABSTRACT

This study aims to treat nepheline syenite for the glass and ceramics industries. Nepheline syenite has many uses in the glass and ceramics industries. It uses to lower the melting point and fuel savings. In the glass industry, nepheline syenite acts as a source of alumina, which increases resistance to scratching and breaking, improves thermal endurance, and increases chemical durability. A series of processing methods such as dry magnetic separation, flotation, and leaching methods were used respectively to treat nepheline syenite ore. In this paper, the results of combined magnetic, flotation, and leaching Processes of the cleaner concentrate having 0.1% Fe_2O_3 and 23.25% Al_2O_3.

Keywords: Nepheline Syenite Beneficiation, Magnetic Separation, Flotation, and Leaching.

RESUMEN

Este estudio tiene como objetivo tratar la sienita nefelina para las industrias del vidrio y la cerámica. La sienita nefelina tiene muchos usos en las industrias del vidrio y la cerámica. Se utiliza para bajar el punto de fusión y ahorrar combustible. En la industria del vidrio, la nefelina sienita actúa como fuente de alúmina, lo que aumenta la resistencia al rayado y la rotura, mejora la resistencia térmica y aumenta la durabilidad química. Se utilizaron una serie de métodos de procesamiento, como la separación magnética seca, la flotación y los métodos de lixiviación, respectivamente, para tratar el mineral de nefelina sienita. En este trabajo se presentan los resultados de los procesos combinados de magnetización, flotación y lixiviación del concentrado más limpio con 0,1% Fe_2O_3 y 23,25% Al_2O_3.

Palabras clave: Beneficio de nefelina sienita, separación magnética, flotación y lixiviación

RESUM:

Aquest estudi pretén tractar la sienita nefelina per a les indústries del vidre i la ceràmica. La sienita nefelina té molts usos a les indústries del vidre i la ceràmica. S'utilitza per reduir el punt de fusió i estalviar combustible. A la indústria del vidre, la sienita de nefelina actua com a font d'alúmina, la qual cosa augmenta la resistència al rascat i al trencament, millora la resistència tèrmica i augmenta la durabilitat química. Una sèrie de mètodes de processament com la separació magnètica en sec, la flotació i els mètodes de lixiviació es van utilitzar respectivament per tractar el mineral de sienita nefelina. En aquest article, els resultats dels processos combinats magnètics, de flotació i de lixiviació del concentrat de neteja amb un 0,1% de Fe_2O_3 i un 23,25% d'Al_2O_3.

Paraules clau: beneficis de la sienita nefelina, separació magnètica, flotació i lixiviació

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INTRODUCTION

Nepheline syenite in ceramics and glass industries like feldspar, it is a source of alkalis materials that use to lower the melting point of a ceramic or glass mixture. The main problem of nepheline syenite development for commercial use of ceramic is the difficulty of removing iron-bearing minerals [1-3]. nepheline syenite used for glass production should be its size range of 420 to 75 µm. Its iron content should not exceed 0.1% Fe_2O_3 while alumina (Al_2O_3) and alkali (Na_2O, K_2O) should be as high as possible, typically at least 23 and 14%, respectively

The main reserves of nepheline syenite ores are found mainly in Russia, Norway, Canada, Turkey, and Brazil[1-4]. The main producing countries of marketable nepheline syenite are Brazil, Canada, China, Norway, Russia, and Turkey. Majority of the Russian production of nepheline syenite is used locally to obtain alumina production[5-6]. In order to use nepheline syenite for ceramic and Glass industries, the ore is comminuted (crushed and milled) then some magnetic minerals such as hematite and magnetite are separated or removed by magnetic separation [7-8]. Cinar and Dugut [9] studied Turkish nepheline syenite to produce concentrate fit to industrial products such as ceramics and glass industries. Saudi nepheline syenite is located in Sawda mountain 7 km east of EL Aqbaa Gulf and 35 km south of ALhaql port. The nepheline syenite ore covers an area of seven square kilometers [10].

This study aims to decrease impurities of Saudi nepheline syenite at Sawda mountain by physical and physico-chemical methods. In this study, nepheline syenite sample was crushed then milled and sized for processing by magnetic separation, flotation, and leaching.

MATERIALS AND METHODS

MATERIALS

The representative sample of nepheline Syenite was obtained from Swada area, northwest of Saudi Arabia. This material was chosen to be free of apparent defects. The sample was subjected to a primary crusher by jaw crusher to produce a product -2.5 cm and then subjected to a secondary crusher to obtain a product less than -8 mm by using a laboratory jaw crusher to prepare the sample for grinding stage. A laboratory roll mill was used to grind 5kg of each sample, the samples well mixed and then split by a “chut rifle” sampler. The rod mill was fed with the -8 mm of secondary crushed ore leading to produce 100% -0.297 mm as a feed to magnetic separation. In order to produce feed samples for flotation, the final concentrate of Dings magnetic separation was wet ground by a ball mill to produce the target size -74µm. Chemical analysis was carried out on a representative sample. Required chemical analysis of optimization test for Fe_2O_3 was determined by standard method of sample dissolution using HNO_3 or HCl.

PROCESSING METHODS

Magnetic separation

High-intensity magnetic separator was used at different field intensities to decrease iron content. The type is Dings cross-belt separator. Dings cross-belt separator was applied as a dry separator. Optimization of separation parameters such as magnetic field, feed rate were considered.

Flotation Method

The flotation technique was used for processing non-magnetic nepheline syenite concentrate. As known from the literature review, in the case of feldspar flotation, mica is floated by suitable amine collectors at acidic pH from 2.5 to 3.5. After obtaining the best-operating conditions of mica flotation, then iron-bearing oxide minerals are floated by the addition of sulfonate type collectors at acidic pH from 3 to 4 [11]. The laboratory flotation machine is a self-aerated Denver D12 flotation cell, the operating conditions are 25 wt. % solids, impeller speed of 1500 rpm for 15 min. It was known that liberation degree and particle size play a very important role in flotation, as stated by flotation studies of different types of ores [3]. The -74 µm size feed was used for flotation.

Leaching Method

Leaching was used for obtaining high-quality glass or ceramics materials, iron components in different ores such as feldspar, clay, and silicate ores are required to be less than 0.1% to obtain a good level of whiteness. Many leaching experiments were made using different acids. In the literature, many studies were carried out using different inorganic and organic acids [8,11-13]. Hydrochloric and sulfuric acids have been tried, but a majority of the studies have been concentrated on organic acids due to low cost and environmental effects[14-17]. Also, it has different advantages such as it does not show a hazard for the contamination of the processed material and effective reagent during the leaching.

RESULTS AND DISCUSSIONS

CHEMICAL AND SIZE ANALYSES OF REPRESENTATIVE SAMPLE

The chemical analysis of the nepheline syenite representative sample is shown in Table 1. The ore sample is low in grade and out of market specifications for ceramics and glass productions, this is because the sample is high iron content (7.75 % Fe_2O_3) and low alumina content (20.73 % Al_2O_3) compared with at least 23%.

Physical and chemical analysis of primary crushed nepheline syenite sample is shown in table 2. The relation between screen size and cumulative passing is shown in figure (1). It is clear from the table (2) and figure (1) that d_{50} is 1.7mm.

The size reduction study of the ground nepheline syenite sample is shown in table 3. Physical and chemical analysis of produced nepheline syenite sample is shown in figure 2. It shows that d_{50} is 0.18 mm

Table 1. *Chemical analysis of the nepheline syenite representative sample*

Compound	Content	Compound	Content %
SiO_2	53.91	K_2O	6.52
Al_2O_3	20.73	TiO_2	0.08
Fe_2O_3	7.75	$P2O_5$	0.02
CaO	0.95	S	0.02
MgO	0.21	Cl	0.06
Na_2O	8.16	*LOI	1.57

* *LOI: loss on ignition*

Table 2. *Size Analysis and Chemical Analysis crushed nepheline syenite sample*

Size, mm	Wt.,%	Cum. Wt. % passing	Fe_2O_3,%	Al_2O_3,%	Distribution, %	
					Fe_2O_3	Al_2O_3
-8.0+6.3	4.68	100	8.03	20.73	4.86	4.69
-6.3+4.76	6.51	95.32	8.05	20.59	6.78	6.48
-4.76+2.83	31.07	88.81	7.69	20.71	30.91	31.10
-2.83+1.66	13.38	57.74	7.91	20.82	13.69	13.46
-1.66+0.841	16.05	44.36	7.56	20.68	15.70	16.04
-0.841+0.42	6.52	28.31	7.51	20.65	6.33	6.51
-0.42+0.21	12.31	21.79	7.63	20.76	12.15	12.35
-0.21+0.125	4.89	9.48	7.71	20.79	4.88	4.91
-0.125+0.074	0.93	4.59	7.63	20.74	0.92	0.93
-0.074+0.063	1.89	3.66	7.63	20.29	1.87	1.85
-0.063+0.044	0.92	1.77	7.65	20.01	0.91	0.89
-0.044	0.85	0.85	8.53	20.13	0.94	0.83
Total (Calc.)	100		7.72	20.70	100	100
Head	100		7.75	20.73	100	100

Table 3. *Size Analysis and Chemical Analysis ground nepheline syenite sample*

Size, mm	Wt.,%	Cum.Wt. % passing	Fe_2O_3,%	Al_2O_3,%	Distribution, %	
					Fe_2O_3	Al_2O_3
-0.297+0.250	11.14	100	7.73	20.74	11.14	11.17
-0. 250+0.210	28.23	88.86	7.75	20.61	28.30	28.12
-0.210+0.177	13.52	60.63	7.74	20.75	13.54	13.56
-0.177+0.149	17.67	47.11	7.76	20.83	17.74	17.79
-0.149+0.125	6.08	29.44	7.54	20.67	5.93	6.07
-0.125+0.105	5.74	23.36	7.61	20.69	5.65	5.74
-0.105+0.088	7.58	17.62	7.73	20.74	7.58	7.60
-0.088+0.074	5.47	10.04	7.81	20.82	5.53	5.50
-0.074+0.063	1.08	4.57	7.62	20.76	1.06	1.08
-.0.063+0.053	1.43	3.49	7.74	20.32	1.43	1.40
-0.053+0.044	1.19	2.06	7.78	19.91	1.20	1.15
-0.044	0.87	0.87	8.53	19.82	0.96	0.83
Total (Calc.)	100		7.73	20.69	100	100
Head	100		7.75	20.73	100	100

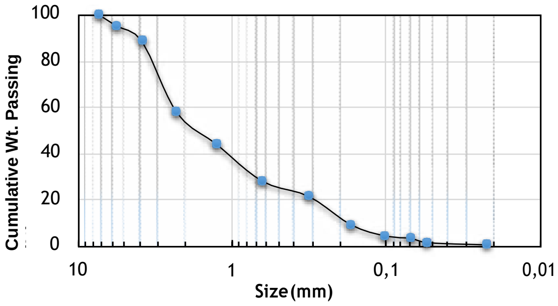

Figure (1) *size distribution of crushed nepheline syenite sample*

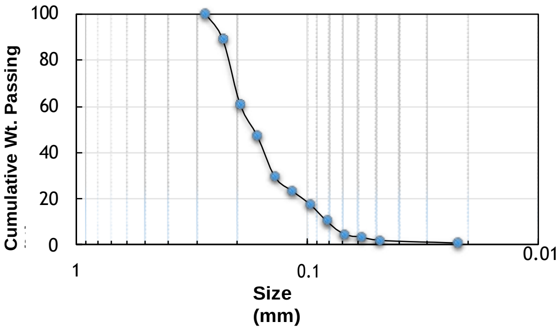

Figure (2) *size distribution of ground nepheline syenite sample*

MAGNETIC SEPARATION RESULTS

Dings cross-belt magnetic separation experiments were used to reduce the iron content. The belt speed of the magnetic separator is the main parameter that controls the moving time of the particles in the magnetic field. The effect of belt speed on the separation process is shown in table (4). The operating conditions are 12 kg/h feed rate, size of feed -0.297mm, magnetic field 1.0 T, and Fe_2O_3 of the head sample is 7.73 %. Table (4) indicates that the concentrate contains 3.12 % Fe_2O_3 from a feed containing 7.73 at a minimum belt speed of 2m/min, which means 59.74% Fe_2O_3 was removed in the tail. The results show that by increasing the belt speed the quantity of concentrate is increasing but the quality is decreasing due to percentage Fe_2O_3.

Table (5) shows that changing of feed rate at optimum belt speed and under the same operating conditions. It is clear from table (5) at a maximum feed rate of 48 kg/h, a concentrate having 5.18 % Fe_2O_3 was obtained from 7.73 % Fe_2O_3 in the feed i.e. 32.99. % removal of Fe_2O_3. By increasing the magnetic field strength to 1.3 T with optimum operating conditions, the quality of concentrate was relatively improved and Fe_2O_3 was decreased to 2.15% as shown in table (6).

Table (4) *Effect of belt speed on separation efficiency of Dings magnetic separations*

Belt Speed m/min	Product	Wt. %	Fe_2O_3	
			Assay Wt. %	Dist. Wt. %
2	Concentrate	86.9	3.12	35.08
	Tail	13.1	38.31	64.92
3	Concentrate	87.3	3.37	38.06
	Tail	12.7	37.70	61.94
4	Concentrate	87.6	3.53	40.00
	Tail	12.4	37.40	60.00
5	Concentrate	88.5	4.07	46.59
	Tail	11.5	35.90	53.41
6	Concentrate	90.2	4.25	49.59
	Tail	9.8	39.76	50.41
7	Concentrate	92.3	4.65	55.52
	Tail	7.7	44.65	44.48
8	Concentrate	93.3	5.18	62.52
	Tail	6.7	43.24	37.48

Table (5) *Effect of feed rate on separation efficiency of Dings magnetic separations*

Feed rate kg/hr	Product	Wt. %	Fe_2O_3	
			Assay Wt. %	Dist. Wt. %
12	Concentrate	86.9	3.12	35.08
	Tail	13.1	38.31	64.92
24	Concentrate	88.8	3.41	39.17
	Tail	11.2	42.23	60.83
36	Concentrate	91.3	4.19	49.49
	Tail	8.7	44.83	50.51
48	Concentrate	93.5	5.83	70.52
	Tail	6.5	35.08	29.48

Table (6) *Separation results at maximum field of Dings magnetic separations*

Feed Size mm	Product	Wt. %	Fe_2O_3	
			Assay Wt. %	Distribution Wt. %
-0.297	Concentrate	84.7	2.15	23.56
	Tail	15.3	38.62	76.44
	Total	100	7.73	100.00

FLOTATION RESULTS

Flotation processes were conducted to remove mica and iron minerals from the nepheline syenite. In the mica flotation step, it was needed to determine optimum operating conditions of mica separation. Then, in the iron flotation stage, feed material was tested to find the best iron flotation conditions.

Mica Flotation

Due to the nature of the mica shape, it may pass from the sieve surface without ground enough and size control. Minerals of mica such as biotite and muscovite cause defects surface and color of ceramic production due to the coarser size of grain and content of iron. Mica removal was investigated by analysis of Al_2O_3%. As known from the literature review, in the case of feldspar flotation, mica is floated by suitable amine collectors at acidic pH from 2.5 to 3.5. After mica flotation iron-bearing oxide minerals are floated by the addition of sulfonate type collectors at acidic pH from 3 to 4 [18]. Flotation experiments aimed to find the best dose concentration of Custamine 9024 at pH 3. The Al_2O_3 % in feed material to mica flotation was 20.69 %. Al_2O_3 % increased to 24.51 at collector dose concentration 500 g/Mg of Custamine 9024 as shown in table (7).

Table (7) *Al_2O_3 and Fe_2O_3 values after mica flotation with different concentration of Custamine 9024*

Concentration (g/Mg)	100	200	300	500	1000	1500
Al_2O_3	22.23	22.20	23.91	24.51	22.87	22.85
Fe_2O_3	0.91	0.88	0.83	0.79	0.80	0.81

Iron Flotation

After mica flotation, SM15 was used as flotinor collector to decrease iron content. The best-operating conditions were 300g/Mg for collector concentration and 3.5 for pH. Fe_2O_3 was decreased to 0.2 % and the main constituent of concentrate are shown in Table 8.

Table (8) *Main constituent % after iron flotation*

Constituent	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O
%	58.81	24.39	0.2	9.12	6.98

LEACHING RESULTS

Leaching tests were carried out after magnetic separation and flotation, this process was desired to remove the iron selectively. Different effects of acids on iron removal were studied to investigate the ability of Fe_2O_3 dissolution as shown in table (9). Table (9) shows that the best efficient results for iron removal were satisfied using oxalic acid.

Table (9) *Fe_2O_3 % content in the nepheline syenite after leaching with different acids*

Organic Acids	Cake Amount (%)	Fe_2O_3 Content (%)	Al_2O_3
Acetic acid	91.8	0.12	23.15
Citric acid	91.5	0.13	23.22
Oxalic acid	92.2	0.10	23.25
Formic acid	91.2	0.12	23.05
Feed	100	0.20	24.39

The optimum operating conditions using oxalic acid were 0.3 mol/dm^3 acid concentration, two hours leaching time, 20 % weight solid, 25 °C reaction temperature (room temperature) and pH is 2. As the best result of the leaching studies using oxalic acid at optimum conditions, Fe_2O_3 was reduced to 0.10%.

COMPLETE NEPHELINE SYENITE BENEFICIATION EXPERIMENTS FLOWSHEET

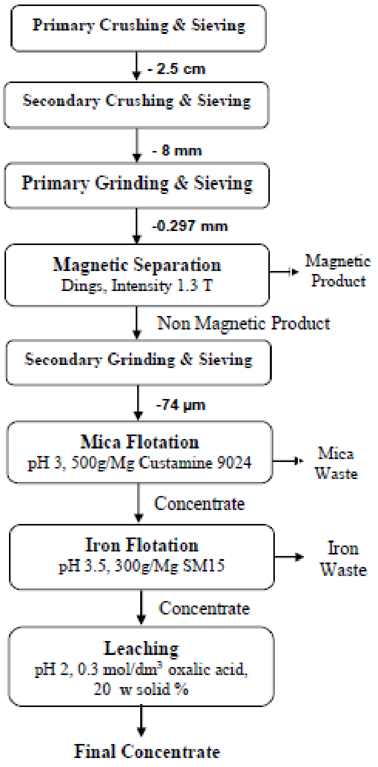

Figure (3) *Flowsheet of nepheline syenite beneficiation experiments*

The nepheline syenite was subjected to the following steps of beneficiation experimental tests. The representative sample was crushed by a primary jaw crusher to produce a product -2.5 cm and then subjected to a secondary crusher to obtain product -8 mm to prepare the sample for the grinding step. A laboratory roll mill was used to produce 100% -0.297 mm as a feed to magnetic separation. Due to magnetic separation, the non-magnetic material was ground by a ball mill and sieved to produce -74 µm for the mica flotation stage. The concentrate of mica flotation was subjected to iron flotation to decrease the iron content from 0.79 % to 0.2% Fe_2O_3. The Leaching stage was carried out using oxalic acid, the content of Fe_2O_3 was reduced to 0.1 %. Nepheline Syenite beneficiation experiments flowsheet is shown in figure (3).

CONCLUSIONS

Based on the presented results, the following conclusions may be drawn:

- Iron and Mica minerals are the main impurities of Nepheline Syenite of Jabal Sawda.
- Nepheline syenite ore was investigated to obtain a product suitable for the glass and ceramic industries.
- Dry magnetic separation, flotation, and leaching methods were used respectively to treat nepheline syenite ore.
- Magnetic separation using Dings cross-belt was used to reduce Fe_2O_3 content from 7.73% to 2.15 % at a mag- netic field strength of 1.3T.
- Mica flotation process was conducted to remove mica mineral from the nepheline ore.
- The iron content of concentrate after mica flotation was decreased to 0.79 % Fe_2O_3 at optimum conditions of 500 g/Mg concen- tration of Custamine 9024 at pH 3.
- Iron flotation process was investigated after mica flota- tion in order to remove iron minerals.
- The iron content of concentrate after iron flotation was decreased to 0.2 % Fe_2O_3 under conditions of SM15 as flotinor collector, 300g/Mg for collector concentration, and 3.5 for pH.
- Leaching technique was carried out using oxalic acid with 0.3 mol/dm^3 acid concentration, two hours leaching time, 20 % weight solid and pH is 2. Fe_2O_3 content was reduced to 0.1% due to leaching.

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