RECOVERY OF NEPHELINE FROM APATITE FLOTATION TAILINGS OF APATITE-NEPHELINE COMPLEX MINERAL COMPOSED ORES

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ABSTRACT

The recovery of all possible useful components from ores corresponds to modern approach to the mineral raw materials processing and provides a reduction in the amount of waste sent to tailings dumps. The increasing complexity of the mineral composition of the ore leads to the fact that the existing beneficiation methods and regimes do not provide the necessary quality of the obtained concentrates. This study shows the peculiarities of nepheline recovery from apatite flotation tailings of apatite-nepheline ores with low nepheline fraction.

Two reagent regimes were tested for nepheline reverse flotation: a mixture of pine and foliate tall oil, a mixture of tall oil and polyalkylbenzene sulfonic acid, which previously showed high selectivity of separation of nepheline and dark-coloured minerals. On the studied apatite-nepheline ore samples the necessary selection of flotation separation was not observed. Mineralogical analysis shows that losses of nepheline with froth products occur both at the expense of nepheline in intergrowths with associated minerals and at the expense of liberated minerals. Nepheline is quite actively floated, which is associated with a change in the surface properties of the mineral. The quality of flotation nepheline concentrates is reduced due to liberated grains of amphiboles, pyroxenes, and mica.

The high content of feldspar in the ore, which during flotation predominantly remains in the chamber product, also affects the quality of the nepheline concentrate. It was possible to increase the Al_2O_3 content in the concentrate to the required values only after magnetic separation in a strong field.

Keywords: *reduction of concentration wastes, integrated processing, apatite-nepheline ore, nepheline concentrate*

INTRODUCTION

Comprehensive processing of mineral raw materials with the extraction of all possible useful components makes it possible to reduce the volume of beneficiation wastes stored in a tailing dump and polluting the environment [1], [2]. Nepheline is the second most important mineral of the Khibiny apatite-nepheline ores; its content varies from 20 to 70% [3]. In the existing apatite-nepheline ore beneficiation technologies the recovery of nepheline concentrate is envisaged at the second stage from the apatite flotation tailings. However, obtaining nepheline concentrate that meets the requirements of the processing industry (Al_2O_3 content not less than 28%) can be difficult from ores with a complex mineralogical composition with a high proportion of pyroxenes, amphiboles, mica, as well as secondary altered minerals [4], [5], [6]. As a result of hypergenic processes, nepheline is subjected to destruction; clay minerals and hydromica appear in the ore, the main among which are potassium hydromica - libenerite and minerals of montmorillonite group.

RESULTS AND DISCUSSION

Two samples of apatite-nepheline ore from one of the Khibiny deposits (ANO-1 and ANO-2), characterized by significantly different mineral and chemical composition, and were considered as research objects (Tables 1,2).

Table 1. *Mineral composition of apatite-nepheline ore samples by X-ray diffraction analysis*

Mineral	Ore samples	
	ANO-1	ANO-2
P_2O_5, %	6.10	15.90
Fluorapatite	**14.98**	**37.39**
Nepheline	**29.99**	**12.32**
Feldspar, total	15.13	6.74
Aegirine	3.44	1.74
Aegirine calcium	2.95	1.46
Amphiboles, total	7.83	8.62
Titanite	2.69	2.22
Ilmenite	0.70	0.24
Magnetite titanous	0.56	0.23
Cancrinite	2.27	1.20
Sodalite	0.87	0.36
Lamprophyllite	1.01	0.76
Micas, total	14.51	24.77
Incl. hydromicas	4.49	3.46
Zeolites (natrolite, phillipsite)	3.07	1.95

Table 2. *Chemical composition of apatite-nepheline ore samples*

Ore sample	Content, %						
	P_2O_5	TiO_2	$Al_2O_{3tot.}$	$Al_2O_{3acid\text{-}soluble}$	$Fe_{tot.}$	Na_2O	K_2O
ANO-1	6.10	2.54	15.96	12.08	5.41	7.39	5.79
ANO-2	15.90	2.16	10.66	8.81	4.29	5.38	3.27

At the first stage according to the existing technology apatite concentrates were produced from ANO-1 and ANO-2 samples with 39.0% P_2O_5 content at recoveries of 70% and 86% respectively. Then the apatite flotation tailings were de-slurried, the yield of slurry was ~12.0% (ANO-1) and ~7.5% (ANO-2). Characteristics of nepheline flotation feed for the studied samples (Tables 3 and 4) have shown the closeness of the apatite flotation tailings in their characteristics in both cases, despite different nepheline content in the initial samples. At the same time the ANO-2 sample is characterized by higher mica content and lower feldspar content in comparison with ANO-1 sample.

Table 3. *Chemical composition of nepheline flotation feeding*

Product	Content of elements, weight %				
	Al_2O_{3tot}	$Al_2O_{3acid\text{-}soluble}$	Fe_{tot}	TiO_2	P_2O_5
ANO-1 feeding	18.80	14.00	6.78	2.95	0.55
ANO-2 feeding	18.67	14.16	8.35	3.12	0.45

Table 4. *Mineral composition of nepheline flotation feeding**

Sample	Mineral content, weight %										
	Nepheline	Feldspars	Pyroxenes Amphiboles	Apatite	Titanite	Micas	Titanium-magnetite	Ilmenite	Hydromicas	Zeolites	Other
ANO-1	42.0	16.0	27.5	2.0	3.0	1.7	1.0	1.7	3.0	0.8	1.3
ANO-2	42.0	10.0	26.0	2.0	5.0	6.5	1.0	1.5	4.5	0.5	1.0

*in the Nepheline field – joint content of nepheline and sodalite;

In the Micas field – content of lepidomelane and biotite, single plates of phlogopite

In the Other field – content of lamprophyllite, lorenzenite, aenigmatite, sulphides

Earlier studies have shown the effectiveness in the reverse nepheline flotation of the collection mixture (CM), which includes a reagent PABSA (polyalkylbenzene sulfonic acid) [7]. Therefore, two reagent regimes were tested for the studied samples:

CM_1 – 70%foliate tall oil + 30% pine tall oil;

CM_2 – 60% CM_1 + 40% PABSA (polyalkylbenzene sulfonic acid).

The results of reverse nepheline flotation (per feeding operation) are given in Table 5.

According to the results, a qualitative nepheline concentrate was not obtained in any of the cases. Increasing the collector consumption did not lead to a significant increase in quality, and there was no effective separation of the mineral complex: nepheline - dark-coloured minerals. In all cases there are large losses of nepheline with the froth product. Mineralogical analysis was carried out for the beneficiation products as well as the flotation feed itself. The content of intergrowths was assessed by an optical method.

The analysis has shown the proportion of altered nepheline in ANO-1 sample to be about 5-7% wt. (Figure 1a). The nepheline grains which have undergone secondary changes, in ANO -2 sample make about 10-15 % from the entire sample's mass (Figure 1b). Such grains have a cream, brown, or brownish-red colour due to the presence of hydromica scales coloured by iron hydroxides. The distribution of intergrowths for both samples is close, mainly in material larger than 0.1 mm (Table 6). The intergrowths are mostly rich (55-75% of grain volume) and very rich in nepheline (75-95%), less often medium-rich (25-55%). The morphology of nepheline intergrowths is shown in Figure 2.

Table 5. *Results of reverse nepheline flotation from apatite-nepheline ore samples*

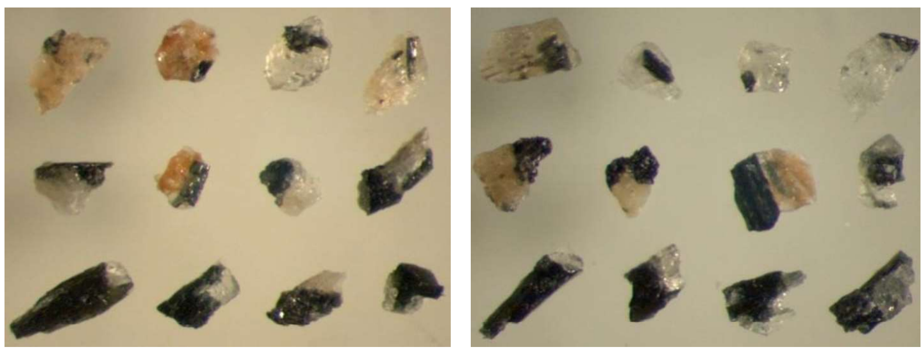
Consum-ption in rough flotation, g/t	Chamberproductofscavenger flotation (flotationnephelineconcentrate)					Reagent regime
	Yield, %	Content, %			Recovery, %Al_2O_{3tot}	
		$Al_2O_{3\,total}$/ $Al_2O_{3ac.-soluble}$	TiO_2	Fe_{tot}		
Sample ANO-1						
400	42.8	23.91 / 17.73	0.76	2.62	54.8	CM_1: foliate tall oil - 70% pine tall oil - 30%
740	27.9	24.90 / 17.29	0.47	1.84	37.2	
1,000	24.4	24.19 / 16.77	0.49	2.14	31.6	
500	62.1	24.51 / 19.00	0.66	2.76	81.5	CM_2: CM_1 – 60% PABSA– 40%
740	50.5	25.10 / 18.92	0.53	2.47	67.9	
1,000	47.6	25.14 / 18.82	0.51	2.00	64.1	
Sample ANO-2						
600	46.4	24.20 / 18.80	1.01	4.60	59.7	CM_1: foliate tall oil – 70% pine tall oil – 30%
1,100	26.8	24.90 / 17.79	0.78	4.37	35.5	
2,000	19.1	24.37 / 16.44	0.76	4.15	25.1	
600	48.0	24.67 / 19.70	0.85	3.99	63.0	CM_2: CM_1 – 60% PABSA– 40%
1,100	41.9	25.92 / 20.39	0.67	3.34	57.8	
1,500	42.5	26.08 / 20.68	0.69	3.15	58.9	

a) b)

Fig.1. *General View of nepheline flotation feed, class -0.315+0.20 mm a) ANO -1 sample b) ANO-2 sample*

Table 6. *Nepheline proportion in a liberated phase and in intergrowths in nepheline flotation feeding*

Classes, mm	ANO -1sample			ANO -2 sample		
	Yield of class %	Nepheline, relat. %		Yield of class %	Nepheline, relat. %	
		liberated	In intergrowths		liberated	In intergrowths
+0.20	6.8	80.0	20.0	7.7	70.0	30.0
-0.20+0.16	9.7	85.0	15.0	10.5	80.0	20.0
-0.16+0.10	22.0	92.0	8.0	21.8	90.0	10.0
-0.10+0.071	18.3	95.0	5.0	18.5	95.0	5.0
-0.071+0.050	10.7	98.0	2.0	10.8	98.0	2.0
-0.050	32.5	99.0	1.0	30.7	99.0	1.0
Total:	100.0	**94.0**	**6.0**	100.0	**92.0**	**8.0**



a) nepheline flotation feeding, ANO-1 sample   b) nepheline flotation feeding, ANO-2 sample

***Fig. 2**. Nepheline intergrowths with rock-forming minerals: rich (upper row), medium (middle row) and poor (lower row), size class -0.315 +0.2 mm*

Mineralogical analysis of froth products of the rough flotation and flotation nepheline concentrates with 24.9% Al_2O_3 content for ANO-1 sample (collection mixture CM_1) and for ANO-2 sample 25.9% Al_2O_3 (collection mixture CM_2) is presented in Table 7.

The analysis has shown the nepheline presence in froth products mainly in the liberated state, as well as minerals contaminating nepheline concentrate.

The share of nepheline in intergrowths with silicate minerals in the froth product produced from the ANO-1 sample is 7.5-8.0%, with about 70% of intergrowths concentrated in the material larger than 0.1 mm. In the froth product of nepheline flotation, produced from the ANO-2sample, the share of nepheline in the intergrowths is 10.0%; about 66% of intergrowths are concentrated in the material larger than 0.1 mm.

Table 7. *Mineral composition of froth products of nepheline production**

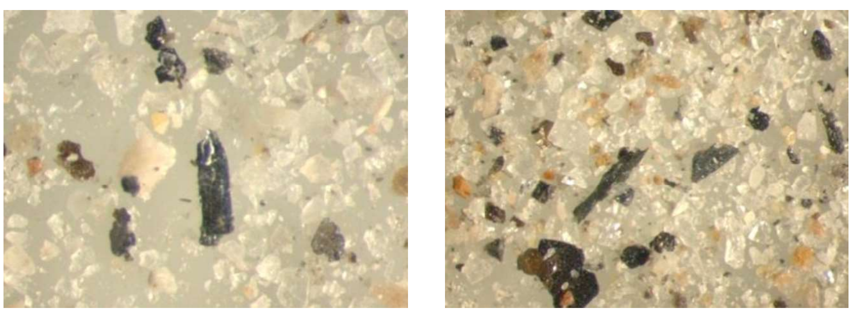
Sample	Mineral content, weight%										
	Nephe-line	Feld-spar	Pyroxenes Amphiboles	Apa-tite	Tita-nite	Mi-cas	Titanium-magnetite	Ilme-nite	Hydro-mica	Zeo-lites	Other
ANO-1	38.0	11.0	36.0	1.0	4.0	1.8	1.5	3.5	2.0	0.2	1.0
ANO-2	29.0	6.0	42.0	1.5	8.0	3.0	2.0	5.0	2.0	0.6	0.9

*in the Nephelinefield – joint content of nepheline and sodalite;

In the Micas field – content of lepidomelane and biotite, single plates of phlogopite

In the Other field – content of lamprophyllite, lorenzenite, aenigmatite, sulphides

The obtained nepheline concentrates are mainly represented by nepheline and feldspar - by 95-96% for the ANO-1 sample, and by 93-95% for the ANO-2 sample. The impurities in the concentrates are represented mainly as large, liberated, short- and long-prismatic grains of pyroxenes, amphiboles, and thick-medium mica beds. (Figures 3a,b). In the nepheline concentrate from the ANO-1 sample, the fraction of spreusteinized nepheline was 4-5%; in the nepheline concentrate from the ANO-2 sample 15-20% of nepheline was spreusteinized.



a) b)

Fig. 3. *General view of nepheline concentrate a) ANO-1 sample, b) ANO-2 sample*

The unsatisfactory quality of nepheline concentrates, apparently, is caused by a large share of feldspar in the concentrate. With a low degree of selectivity of flotation nepheline goes to the froth product a greater extent. The ratio of nepheline / feldspar in the froth products for both samples is higher than in the flotation feed (Table 7). For ANO-1 sample in the froth product this ratio is 3.45 compared to 2.62 in the flotation feed. For the ANO-2 sample, the nepheline/feldspar ratio is 4.83 in the froth product of the rough flotation and 4.2 for the flotation feed. It can be said that as a result of flotation of ANO-1sample, chamber product (flotation nepheline concentrate) is "enriched" with feldspars to a greater extent, compared with ANO-2sample.

Subsequent magnetic separation of flotation nepheline concentrates (current strength 5A) has selected concentrates with content of 26.9% Al_2O_3 for ANO-1 sample, and 27.9% Al_2O_3 for ANO-2 sample into non-magnetic fraction. In the case of ANO-2 sample, for which the degree of "enrichment" of chamber product by feldspar is less, after magnetic separation it was possible to produce nepheline concentrate of proper quality (~28% Al_2O_3). While for the ANO-1 sample, it was not possible to bring nepheline concentrate to the required quality.

CONCLUSION

Thus, the studies have shown that the recovery of nepheline concentrate from apatite-nepheline ores with complex mineral composition is possible only after finishing the flotation concentrate by magnetic separation in a strong field. The high content of amphiboles, pyroxenes and mica in the initial sample leads to contamination of the flotation concentrate by these minerals, and the impurities are present in it in a liberated form. A decrease in the proportion of nepheline in the initial ore, an increase in the content of feldspar, and the presence of minerals secondary altered by nepheline also affects the content of Al_2O_3 in the concentrate. The ratio of $Al_2O_{3total}/Al_2O_{3acid\text{-}soluble}$ in the ore and produced flotation concentrates is about the same. At the same time there is a change in the surface properties of nepheline itself from this type of ore; its flotation activity increases, which leads to large losses of nepheline with froth flotation products.

It should be noted that the spreusteinized nepheline to a greater extent remains in the chamber product of the reverse nepheline flotation. As a result, from the apatite-nepheline ore containing 29.99% nepheline it was possible to obtain nepheline concentrate with 26.9% Al_2O_3. From the ore with nepheline content of 12.32%, nepheline concentrate was characterized by the quality of 27.9% Al_2O_3. Reducing losses of nepheline in the flotation cycle of nepheline concentrate recovery requires the development of new highly selective reagent modes of separation of dark-coloured minerals and nepheline.

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RECYCLING OF IRON ORE PROCESSING WASTES FOR REDUCTION OF INDUSTRIAL IMPACT ON THE ENVIRONMENT

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ABSTRACT

The paper presents the results of the research on the recovery of hematite from stockpiled tailings produced by the mineral processing plant of Olcon JSC (the northern-western Arctic zone of Russia). The authors investigated material composition of tailings samples and determined its granular and mineralogical characteristics. The content of total, magnetic and hematite iron in a sample of the tailings dump material is 8.76%; 1.53% and 3.67% respectively. The technology for hematite concentrate production from the tailings material has been substantiated, including several stages of spiral separation to recover the rough concentrate and its following concentration by a shaking table. The authors have determined optimal conditions for the disintegration of the middlings of the spiral separation, which made it possible to achieve selective liberation of the grains of valuable mineral. A recommended technological flowsheet for the processing of the tailings dump material provides for the production of hematite concentrate with a total iron content of more than 62% and through recovery of hematite iron of about of 76%. Involvement of the tailings in processing will help to reduce the human impact on the environment and improve ecological situation in the plant area.

Keywords: *industrial waste, tailings, hematite, spiral separation*

INTRODUCTION

The formation and accumulation of a significant mass of mining wastes containing ore and non-metallic components is an inevitable part of the development of most ore deposits. These wastes occupy huge land areas; change the natural landscape, soil and vegetation cover; negatively affect the atmosphere and water system, and pollute the environment.

Mining and mineral-processing wastes are one of the world's largest chronic waste concerns. Their reuse should be included in future sustainable development plans, but potential impacts on a number of environmental processes are highly variable and must be thoroughly assessed. The chemical, mineral, granular compositions and physical properties of wastes determine which uses are most appropriate and whether reuse is economically feasible. If properly evaluated, mining waste can be reused to re-extract valuable minerals, supply construction