Evaluating influence of luminescence excitation and recording on the efficiency of apatite recovery from Khibiny low-grade ore

DN Pavlishina1*, BA Vlasov1,2 and SV Tereshchenko1, 2

1Mining Institute, Kola Science Center, Russian Academy of Sciences, Apatity, Russia
2Apatity Division, Murmansk Arctic State University, Apatity, Russia
E-mail:*shibaeva_goij@mail.ru,

Abstract. X-ray luminescence separation efficiency depends on a number of factors among which the most important is the algorithm for excitation and recording of luminescence in ore particles. The comparative evaluation of efficiency of one- and two-way algorithms for luminescence excitation and registration is carried out on apatite-bearing ore. It is found that the one-way algorithm performance yields no change in the X-ray luminescence separation efficiency in terms of the analyzed ore type. The choice of this algorithm and the sustained admissible separation level make it possible to reduce a number of parts and size of a separator, to increase its specific productivity and to decrease its cost.

An amount of the main valuable component (phosphorus pentoxide) in Khibin apatite ore tends to lower with time under a number of factors including the depletion of rich and easy-to-handle ore reserves, complication of mining and geological conditions, application of high-performance mining machines and ever-increasing obligations of miners for ecological safety of mining operations. Moreover, so far substantial mining waste dumps can be evaluated as technogenic reserves consisting of valuable component (VC)-bearing rocks of cut-off grade. Nowadays a dump material grade can be comparable to a poor ore grade, taking into account the evolution of technological parameters in development of mineral deposits with time. In terms of Khibin deposit it is explicit that the cut-off grade has been lowered from 12 to 2–4% P2O5 (Figure 1). All the above provides the grounds to foster mastering of ore processing techniques, to search ways of economically efficient, ecofriendly low-grade ore beneficiation.

One of promising trends in Khibin apatite processing is the X-ray luminescence separation (XLS) as a bulk material pre-treatment stage. Expedience of application of apatite luminescence as an attribute of separation is justified by apatite capacity to be luminescent intensively under certain conditions unlike the rest rock-forming minerals [1].

Considering this apatite property along with sufficient statistical research work on establishment of relation between VC content in a test ore lump and a recorded signal (Figure 2) made it possible to single out exclusively the material which VC content exceeds a preset cut-off grade level from the
entire ore flow under processing. Gangue and poorly mineralized rocks are rejected from the concentrator feed, thus improving a grade of the feed and lowering energy costs per a ton of produced apatite concentrates along with less volume of resultant finely-ground tailings of apatite flotation [2, 3]. The last factor indirectly influences a service life of tailing dumps and diminishes the negative mining impact on environment [4].

Investigation into XL characteristics of Khibin apatite-bearing ores and feasibility to realize XLS in their processing have been the study objects at Mining Institute, Kola Science Center, RAS, since 1982 [5]. The research findings [1–3, 6–9] justify perspectiveness of XLS application and reasonability of full-scale tests of this process.

Transition from laboratory tests to pilot and semi-commercial tests implies special attention to choice of XLS equipment.
In view to RF import-replacement government strategy the feasibility was considered to apply Russian machinery capable to handle bulk material of more than 20 mm in size to separate apatite-bearing ores:

− UAS-type radiometric separator, AO VNIIKhT, Moscow [10];
− X-ray luminescence separator, OOO EGONT, Saint Petersburg [11];
− SNR-10 radiometric separator, AO Soyuzsvetmetavtomatika, Moscow [12].

The above separators are equipped with one-way (for separators nos. 1 and 2) and two-way (for separator no. 3) algorithms for excitation and registration of X-ray luminescence of mined bulk ore.

In [1] the study object was the current run-of-mine ore; the researcher assessed the separation efficiency of scheelite, apatite, and fluorite ores and found that the separation was improving with increase in number of measured sides of ore lumps,

Separation efficiency was assessed under procedure described in [1]:

\[ \mathcal{E} = \frac{\Pi}{M} \]

where \( \Pi \) is parameter of the attribute for separation, a dimensionless unit.

\[ \Pi = \frac{\sum_{i=1}^{n} (x_{if} - \alpha) \gamma_{if}}{\alpha \sum_{i=1}^{n} \gamma_{if}} \]

\( n \) is number of fractions in the study object; \( z_{if} \) is VC content per a fraction; \( \alpha \) is average VC content in the study object; \( \gamma_{if} \) is the fraction yield from all the elementary volumes of the study object; \( M \) is contrast parameter.

\[ M = \frac{\sum_{i=1}^{n} (y_{i} - \alpha) \gamma_{i}}{\alpha \sum_{i=1}^{n} \gamma_{i}} \]

\( y_{i} \) is VC content in an elementary volume; \( \gamma_{i} \) is yield of an elementary volume of the study object.

Evaluation of separation efficiency by one- and two-way algorithms for excitation and registration in terms of the technical specifications of the test separators was studied on Partomchopp poor apatite-bearing ore specimens, be precise, two main apatite-nepheline and sphene-apatite-magnetite species of \(-50+20 \) mm in size.

Figure 3 demonstrates variations in registered luminescence signals of lumps by one- and two-ways algorithms for excitation and registration. Green color denotes the selected separation threshold, excess of its magnitude indicates a necessity to refer a single analyzed volume to an ore component of the ore flow under separation.

The comparative analysis of XL signals from apatite-nepheline ore by one- and two-way algorithms for excitation and registration reveals the actually identical behavior of graphs. Table 1 summarizes results of XLS realization by one- and two-way algorithms for excitation and registration.

Analysis of separation results in transition from two-way to one-way algorithms for excitation and registration of luminescence of apatite-bearing ore lumps indicated their negligible variation:

− yield of XLS tailings increases by 1.9–3.2 % and by 0.77–1.4% for apatite-nepheline and sphene-apatite-magnetite specimens, respectively;
− growth of VC loss in XLS tailings is 4.84–5.58% and 1.88–2.77% for apatite-nepheline and sphene-apatite-magnetite specimens, respectively;
− dilution of XLS concentrate with gangue and weak mineralized rocks is not higher than 3%.
Figure 3. Record diagram of a X-ray-luminescence signal of apatite-nepheline ore lumps

Table 1. Results of XLS realization by one- and two-way algorithms for excitation and registration

| Separation products | Two-side survey | One-side survey | One-side survey |
|---------------------|----------------|----------------|----------------|
|                     | Yield, % | P₂O₅ content, % | Yield, % | P₂O₅ content, % | Yield, % | P₂O₅ content, % |
|                     |          |                  |          |                  |          |                  |
| Apatite-nepheline ore |        |                  |          |                  |          |                  |
| XLS concentrate     | 45.9     | 9.4             | 49.1     | 9.1             | 47.8     | 8.9             |
| XLS Tailings        | 54.1     | 1.3             | 50.9     | 1.3             | 52.2     | 1.2             |
| Primary ore         | 100.0    | 5.7             | 100.0    | 5.3             | 100.0    | 5.3             |
| Sphene-apatite-magnetite ore | | | | | |
| XLS concentrate     | 45.9     | 8.8             | 49.1     | 8.9             | 47.8     | 9.0             |
| XLS Tailings        | 54.1     | 1.6             | 50.9     | 1.6             | 52.2     | 1.6             |
| Primary ore         | 100.0    | 6.0             | 100.0    | 5.9             | 100.0    | 6.1             |

The efficiency of the selected algorithm can be presented graphically as contrast and concentration curves which can be plotted under the known procedure [5] (Figure 4). In the Figure it is obvious that tailing yield and VC content in the ore product vary under the fixed VC content in separation tailings.
If $P_2O_5$ content in XLS tailings is at 2% level, the efficiency of separation for Partomchorr apatite-nepheline ore is

- $\varepsilon = 0.90$ in two-way survey;
- $\varepsilon = 0.84$–$0.89$ in one-way survey.

![Figure 4. Curves of contrast and concentration for Partomchorr apatite-nefeline ore.](image)

To conclude, negligible variations in technological parameters of X-ray luminescence separation prove feasibility of its realization with measurement of luminescence on only one surface of the test lump; possible application of XL separators with one-way algorithm for excitation and registration. Realization of one-way algorithm for excitation and registration in the separator can allow support of the admissible separation level, a reduced number of parts in the complete set, reduced overall dimensions of the separator, and feasibility to adjust specific separator performance and its cost.

References

[1] Tereshchenko S 2002 The Main Provisions of X-Ray Luminescent Separation of Mineral Raw Materials. Apatity: KFPetrGU (in Russian)

[2] Tereshchenko S, Marchevskaya V, Chernousenko E, Rukhlenko E, Pavlishina D and Smolnyakov A 2014 Ecological and technological aspects of ore quality management based on separation in: Ecological strategy for mining industry—shaping a new outlook for mineral mining: Collected Papers of the Russian Academy of Sciences, Institute of Mining, Kola Science Center RAS Saint-Petersburg: Renome (in Russian)

[3] Tereshchenko S, Marchevskaya V, Chernousenko E, Rukhlenko E, Pavlishina D and Smolnyakov A 2015 Integrated ore preparation in processing of low-grade apatite–nepheline ores GIAB No 1

[4] Tereshchenko S, Marchevskaya V and Pavlishina D 2016 Ways to reduce the negative environmental impact of mining industry Vestn. Kol. Nauch. Tsentra RAN No 4

[5] Lagov B, Tereshchenko S, Kaitmazova T, Yuriev V and Valshchikov A 1984 Studies into radiometric separation of Khibiny low-grade apatite ores in Laboratory and Proof Tests and Dressing of Minerals. Domestic and International Experience VIEMS Issue 5 (in Russian)

[6] Tereshchenko S, Marchevskaya V, Maslov A, Golovanov V and Pogrebnyak O 1998 High-
quality ore separation from diggings—one of the conditions of rational ore concentration

Vestn. Murmansk Gost. Tekh. Univer. Vol 1 No 3

[7] Tereshchenko S, Denisov G and Marchevskaya V 2005 Radiometric Methods of Sampling and Separation of Mineral Raw Materials Saint-Petersburg: MANEB (in Russian)

[8] Tereshchenko S and Marchevskaya V 2002 Rational Subsoil Use Based on Radiometric Preconcentration of Minerals Marksheider. Nedropolz No 3 (in Russian)

[9] Tereshchenko S, Marchevskaya V, Chernousenko E, Pavlishina D and Rukhlenko E 2015 Investigation of priority trends in mineral processing GIAB No 6

[10] JSC VNIIHT [official website]. URL: http://www.vniiht.ru

[11] Innovative Ecological Mineral Dressing Technologies [official website]. URL: http://www.egont.ru

[12] SouzCvetMetalAvtomatica [official website]. URL: http://www.scma.ru