Application of Combined Physical and Electrochemical Methods for Conditioning Diamond-Containing Raw Materials to Improve the Efficiency of Sticky and Foam Separation Processes

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Abstract. This research work contains a new solution to the urgent scientific issue of increasing the diamond extraction under terms of sticky and foam separations based on combined electrochemical, thermal and ultrasonic effects providing increased technical and economic indicators for enrichment of diamond-bearing kimberlites due to the increased -5 mm-class diamond extraction into concentrates of sticky and foam separation at the average 5%.

1. Introduction

The prospective method to solve the issue of supporting the achieved diamond extraction level on AK ALROSA enterprises is intensification of small diamond extraction procedures (-5+2 mm, -2+1 mm, -1+0.5 mm) that is the main contents of the useful component in the ore. The enrichment and upgrading technologies applied to these classes of diamond-containing products use sticky and foam separation processing applying natural water-repellency of the diamond surface.

Involvement of alluvial and technogenic deposits as well as the deposits which kimberlites were subject to the active secondary modification into the industrial recycling results into modification of the physical and chemical characteristic of recycle waters and affects technological indicators of considered separation processes [2].

Losses of diamonds with considered dimensions are close to 20% or $20 mln in a year. Taking into account this fact, the issue to boost up their extraction in technological schemes of enriching diamond-extracting plants is relevant [3].
2. The purpose and objectives of the study
As a result of interaction with water phase components, the secondary contamination of mineral complexes happens due to formation of technogenic films and compounds completely modifying water-repellent and water-retaining characteristics of crystals which use is the basis of methods for enrichment of -5 mm-class diamond-bearing raw materials. Therefore, before sticky and foam separation processes applied to the diamond-bearing material, methods of its preliminary processing are to be used in order to recover and to enhance contrast ratio of separated minerals' features.

The prospective method to solve the issue for increased extraction of diamonds of the considered dimensions out of kimberlites is application of combined physical and physical and chemical methods of impact on solid and liquid pulp phases that provide for removal of water-retaining surface films from the diamond surface and the increased intensity of their new formation.

In order to solve the task, the contents of mineral formations and mechanism of impact of external energetic factors on the heterogenous diamond-mineral film-aquatic environment system is to be determined. At this, thermo-mechanical and chemical dissolution-crystallization processes are to be taken into account. The modern method to manage them is simultaneous application of ultrasonic, thermal and electrochemical effects on mineral components, ore pulp and recycle water of considered separation processes.

3. Principal part
Results obtained after the RFE spectroscopy of mineral formations on the surface of water-retaining diamonds showed that the view of surface formation is various and may be roughly divided into large slurry coverings (Figure 1 a, b), massive embossed formations (Figure 1c), mixed mineral formations (Figure 1 d).

![Image](a)

![Image](b)

![Image](c)

![Image](d)

Figure 1. The mineral substance on the surface of diamonds where: a, b – location of the slurry material on diamonds; c – location of the coalescent material; d – mixed formations.
Surface films on supergene modified diamond crystals have the form of multiple embossed formations with dimensions of up to 30 µm and up to 0.7 µm thick, consisting of slurry classes of aluminium silicate-type host rocks firmly bound with the diamond crystal surface ferruginized by the calcium-magnesium carbonate cementing substance. Massive formations mostly include carbonate-phosphate minerals with the high relative percentage of ferrous minerals (up to 15%) and are concentrated in cracks and on geometrically uneven areas of the crystal surface. Filmy formations are wide-spread on all types of surfaces and are mostly characterized by the carbonate contents with the weight ratio of oxides and iron carbonates that is from 2.3 to 4.0%.

The presence of the mineral film on the diamond crystal significantly modifies its surface features. The decreased value of the crystal wetting contact angle (up to 50.8 – 52.6°) due to the mineral film formed after the contact with the recycle water shows that the diamond surface becomes more water-retaining that results into losses of these crystals during sticky and foam separation procedures.

The technology for removal of water-retaining formations from the surface of diamond crystals was made developed using electrochemical, thermal and ultrasonic effects on liquid and solid components of the ore pulp in the diamond-bearing material used for sticky and foam separation processes.

The first stage of studies, taking into account well-known difference in the thermal expansion ratio of the diamond and host rocks took as a base the method for thermo-mechanical destruction of diamond clusters with mineral formations due to disruption of the mechanical link between the diamond and the surface mineral formation for the reason of relative shift in their crystalline grids [4, 5]. The term for rejection of the film will be the shift into nodes of grids L for the value of more than , 20% from the constant grid of the alloy:

$$\frac{L_{\text{a}}}{a} \geq 0.2$$

The analysis of the data on the Figure 2 shows that at the temperature of 650°C the value of difference between the linear expansion of the diamond and the film will exceed 20% at the linear size of the filmy formation, e.g, 0.4-0.6 µm for CaCO₃.

Combination of methods for the thermal treatment of the pulp and the electrochemical conditioning of the recycle water at this stage of studies turned to be the most effective technological solutions to increase diamond extraction due to removal and prevention of formation of water-retaining mineral films on the crystal surface.

The synergetic effect under conditions when thermal and electrochemical treatment of the ore pulp (Figure 3) is applied together is proven by the fact that the growth of the wetting contact angle of natural water-retaining diamonds (28-33%) is considerably more than the amount of wetting contact angle growth when these technologies are applied separately (18-21%).

The visual analysis of electronic and microscopic images from the surface of studied diamonds showed that up to 90% of embossed filmy formations are removed from it (Figure 4).
Figure 2. Dependences of the relative linear shift of nodes from grids of the diamond and the diamond film on the linear size of the filmy formation, where: 1 – when heated up to 650°C; 2 – when heated up to 450°C; a - the area where the film peels off the diamond; b – the stability area of the diamond unit.

Figure 3. Modification of the diamond water-repellency after treatment with the recycle water treated without a membrane, where: 1,2 – a naturally water-retaining diamond; 3,4 – a naturally water-repellent diamond; 1,3 – without a thermal treatment; 2,4 – with a thermal treatment.
The second stage of the study carries out similar studies of application of the ultrasonic technology for enhancement of the diamond surface's water-repellency due to removal of large water-retaining formations with the structure of conglomerates of thin grain classes of rock-forming minerals with the firm adhesive coupling with the diamond surface. These mineral formations mostly have the carbonate silicate contents and are not removed from the diamond surface when the diamond-bearing pulp is treated both in the mechanical devices and during thermal treatments reviewed above. The main objective of this stage of the study was to develop the mode for the ultrasonic treatment on surface formations without intensive impacts directly on diamond crystals that is mostly explained by the need to provide for their protection. At this, like in previous studies, main experiments are done when ultrasonic and electrochemical effects on the ore pulp of the diamond-bearing material are combined. Results of the study helped to set up parameters of ultrasonic impacts at which conditions are made for selective destruction of surface formations on the diamond. As seen on the scheme of the Figure 5, during interaction with the diamond at the set-up mode of the low-frequency ultrasonic impact (20-130 Hz) with the capacity of 3.75 W/cm² the reflected wave concentrates 85-90% of the source energy and 10-15% enters into the scope of the diamond. On the contrary, only 25% of the sound wave energy reflects from the surface of the water-retaining mineral formation and 75% enters into it.

On this stage of the study, the effect of both combined ultrasonic and electrochemical impacts and their separate application on the level of the diamond surface purification is studied [6, 7, 8].

Results of the quantitative IR-spectroscopy showed:
- application of the recycle water electrolysis (RWEL) product enables purification of the diamond surface on 19.1-25.5% in regard to silicate minerals and on 31.1-40.7% in regard of carbonate minerals;
- application of the ultrasonic treatment (UT) as the separate procedure enables purification of the diamond surface in regard of silicate minerals on 76-91% and in regard of carbonate minerals – on 52-64%;
- combined application of electrochemically prepared recycle water and the ultrasonic treatment (RWEL and UT) enables complete purification of the diamond surface that was 94.3% in regard of silicate minerals and 91.7% in regard of carbonate minerals.

Obtained results are confirmed by visualized images of studied items obtained by the method of electronic spectroscopy (Figure 4)
Figure 4. Microscopic images of alloys on the diamond surface under the studied treatment conditions where a – the source; b – after RWEL; c – after UT; d – combined application of RWEL and UT.

4. Conclusions
The completed set of experimental studies resulted into the fact that the most prospective method to solve the issue for the increase of the -5mm-class diamond extraction from kimberlites by sticky and foam separation methods is application of combined physical and physical and chemical methods of impact on solid and liquid pulp phases providing for removal of water-retaining surface films from the diamond surface and the decreased intensity of their recurrent formation.

The technological mode of the foam separation of the diamond-bearing material is confirmed. It consists of the thermal treatment of the initial feed by the jet steam, conditioning of the feed with reagents and the recycle water, feeding of the treated ore pulp on the foamy layer while the electrochemically treated recycle water is used inside the flotation machine. Enlarged trials of the developed foam separation mode showed the option to increase diamond extraction into the concentrate at 5.5%.

The technological mode for preparation to sticky separation of diamond-bearing products is proven. It includes the ultrasonic treatment of the source feed at frequency of 22-44 Hz and capacity of 5 – 7.5 Wt/cm² in the environment of the recycle water that has undergone electrochemical conditioning without a membrane. Completed enlarged trials of the developed sticky separation mode showed the option to increase diamond extraction into the concentrate at 5%.

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