Advanced Methods for Modifying the Properties of Separation Media and Mineral Components for More Efficient Separation of Diamond-Bearing Raw Materials

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Abstract. The results of this study proof the effectiveness of combining physical and electrochemical methods to intensify the processing of diamond-bearing ores as shown by:
– recovering more diamonds thanks to the synergistic effects of making the diamond crystal surface more hydrophobic in grease recovery and froth flotation;
– complete recovery of abnormally luminescent crystals thanks to modifying the spectral and kinetic properties of such crystals in separation by X-ray fluorescence;
– lesser use of ferrosilicon thanks to its greater resistance to corrosion induced by interfacing with corrosive water systems.

1. Introduction
Russia’s diamond producing facilities are currently concentrated in the west of Yakutia; they process hard-to-process kimberlite ores [1, 2], the composition of which makes the core processes below far less efficient [3]:
– grease recovery (GR) and froth flotation (FF), as diamond surface develops mineral films, making it hydrophilic [4];
– X-ray fluorescence separation (XRF), as diamond crystals are there that have abnormal X-ray fluorescence, making them unrecoverable in standard configuration of the separation unit;
– dense medium separation (DMS), as interfacing with the mineralized process water causes the dense medium (ferrosilicon) to degrade.

Recovered diamonds vary from 0.2 to 50 mm in size; coupled with the need to preserve the crystals, this factor necessitates using phased processing of diamond-bearing raw materials, which includes the separation processes above.

GR, FF, and XRF in total lose 22% of jewelry- and industrial-grade diamonds per annum (crystals of altered technological properties are considered lost).

Dense medium separation is associated with the following factors that diminish the corrosion resistance of ferrosilicon, resulting in a greater loss: physico-chemical properties and ion composition...
of the water system in use, and the ferrosilicon pellet properties that make it more or less resistant when interfacing with the corrosive mineralized waters running in the DMS process.

Therefore, hard-to-process kimberlite ores call for a reduction in diamond loss in XRF, GR, and FF processing of diamond-bearing products, and a reduction in the loss of ferrosilicon in DMS if such processing is to be efficient and cost-effective.

2. Subject matter of research
Based on the facts above, the research team has rationalized, developed, and recommended for industrial testing a set of novel innovative methods that modify the properties of separation media and mineral components so as to fully recover diamond crystals without jeopardizing the environment while reducing the loss of expensive ferrosilicon.

Therefore, this paper analyzes:
– the spectral and kinetic properties of diamond crystals subject to separation by X-ray fluorescence;
– the hydrophobic quality of diamond crystal surface as observed in grease recovery and froth flotation;
– the properties of water systems, ferrosilicon suspensions and pellets in dense medium separation.

3. Goals and objectives
Russian developments presented below sought to solve two problems at once: making the core processes of separating diamond-bearing materials more cost-effective; and extracting more diamonds from the processing tailings by using innovative methods to modify the properties of separation media and mineral components while fully recovering diamond crystals of +0.2 mm in size.

This new Russian approach thus ensures effective use of natural resources without jeopardizing the environment.

4. Research essentials
A team of specialists representing the Institute of Comprehensive Exploitation of Mineral Resources, Russian Academy of Sciences (ICEMR RAS), the Mirny Institute of Technology, North-Eastern Federal University in Yakutsk (MIT NEFUY), and ALROSA’s Geology Research Unit (GRU) has devised, developed, and validated a combined technology that intensifies the processing of hard-to-process diamond-bearing ores by applying innovative methods to modify the properties of separation media and mineral components [5].

Find the summary of these developments and implementation results below.

4.1. Intensifying Grease Recovery and Froth Flotation
Research into the surface of diamonds not recovered by GR or FF identified mineral inclusions sized 0.01 to 5 mm linearly, 5 to 350 μm in thickness, see Figure 1.
Figure 1. Mineral inclusions on the diamonds that grease recovery (a, b) and froth flotation (c, d) failed to separate from the diamond-bearing ore.

The researchers further identified how the composition of such altered kimberlite and surficial mineral inclusions in diamonds recovered from such ores correlated [6]. The team further classified these mineral inclusions by composition, properties, and type of attachment to the crystal surface [7], see Table 1.

| Surficial mineral inclusion type | Occurrence | Percentaage | Carbonates | Phosphates | Iron hydroxide | Layered aluminum silicates (AS) | Clays |
|---------------------------------|------------|-------------|------------|------------|---------------|---------------------------------|------|
| 1. Sludge conglomerate: silicates, carbonates, and phosphates | 176 | 49.5 | 4-26 | 13-24 | 0.5-1.9 | 17-32 | 16-45 |
| 2. Sludge conglomerate: talcum and smectite | 34 | 9.6 | 3-7 | 3-7 | 0.1-1.5 | 33-73 | 16-28 |
| 3. An aggregate of rock minerals and a diamond | 67 | 18.9 | 23-44 | 13-33 | 1.5-6.5 | 12-24.5 | 6-18 |
| 4. Anthropogenic film formation | 78 | 22.0 | 53-80 | 2-16 | 1.5-4.5 | 3-12 | 3-12 |
To make the separation processes under consideration more efficient, the research team proposed, validated, and tested experimentally in production combined power methods capable of modifying the hydrophobic-hydrophilic state of the crystal surface. These tests showed the methods were effective, as they increased diamond recovery thanks to the synergistically stronger hydrophobization of diamond crystal surface [8].

The core results shown in Table 2 prove these novel solutions effective, as they help recover 10% to 15% more diamond crystals on average.

### Table 2. Combined methods for modifying the properties of water systems and diamond surfaces in grease recovery and froth flotation.

| Method name and operation where it is used                                      | Diamond recovery, % | Increase recovery, % in | 
|---------------------------------------------------------------------------------|----------------------|-------------------------|
| co-use of electrochemically treated recycled water plus ore pulp attrition      |                      |                         |
| Froth flotation (standard configuration)                                        | 88                   |                         |
| Attrition                                                                       | 92.6                 | 4.6                     |
| Electrochemical treatment of recycled water                                    | 96.8                 | 8.8                     |
| Electrochemical treatment of water during attrition                            | 97.3                 | 9.3                     |
| combined electrochemical and thermal treatment of ore pulp                     |                      |                         |
| Froth flotation (standard configuration)                                        | 84                   | -                       |
| Thermal treatment                                                              | 90.4                 | 6.4                     |
| Electrochemical treatment of recycled water                                    | 92.1                 | 8.1                     |
| Combined thermal and electrochemical treatment                                 | 96.7                 | 12.7                    |
| combined electrochemical and ultrasonic treatment of ore pulp                  |                      |                         |
| Grease recovery (standard configuration)                                        | 81.7                 | -                       |
| Ultrasonic treatment of ore pulp                                               | 89                   | 7.3                     |
| Electrochemical treatment of recycled water                                    | 91.2                 | 9.5                     |
| Combined ultrasonic and electrochemical treatment                             | 95.7                 | 14.7                    |

4.2. **Intensifying Separation by X-Ray Fluorescence**

In recent years, diamond processing facilities started receiving a lot of kimberlite ores where 5% to 10% of diamond crystals have abnormal natural luminescence outside the controlled range that XRF units use to detect diamonds, making these crystals unrecoverable by such methodology.

The research team behind this paper has developed a novel approach to recovering weakly or abnormally luminescent diamonds by experimentally optimizing a luminophore-containing emulsion and a method for applying it to diamond crystal surface so that the spectral and kinetic characteristics of the material match the existing XRF technology [9].

Using an experimental separation unit named POLUS-M at Yakutniproalmaz, the laboratory’s specialists tested the selectivity of applying the luminophore-containing composition to the surface of abnormally luminescent synthetic diamonds and kimberlite minerals. Tests showed that using a specifically composed luminophore-containing mixture as a diamond luminosity activator resulted in the activating components (luminophores) being selectively attached to the crystal surface.

These tests confirmed that the method was effective, as it enabled full recovery of such abnormal crystals by modifying their spectral and kinetic properties so that the experimental separator could detect them in a standard configuration, see Figure 2.
4.3. Intensifying Dense Medium Separation

The research team theoretically and experimentally prove the effectiveness of using physical and electrochemical methods to modify the process properties of ferrosilicon used in dense medium separation of diamond-bearing materials. This approach had two effects:

– it modified the properties of the corrosive water phase so that it would not oxidize the interfacing ferrosilicon pellets;

– it also modified the properties of the ferrosilicon pellet surface so that it would not oxidize.

A method based on removing air oxygen from the water phase of the ferrosilicon suspension was tested on an experimental stand. For this method, air was replaced with inert nitrogen gas for mixing the suspension during its preparation and storage. As a result, ferrosilicon loss was cut by a factor of 2 to 2.5.

Another method based on applying an anticorrosive coating was tested on an experimental bench. The tests showed this method was able to reduce the ferrosilicon surface corrosion rate by a factor of 5 to 6, effectively reducing the loss of the material by 5% to 8%, see Figure 3.

These results prove the developed solutions effective in terms of reducing the loss of ferrosilicon in dense medium separation.
Figure 3. Corrosion rates of the original (1) and nitrogenated (2) ferrosilicon pellets interfacing with a mineralized water system.

5. Conclusions
Thus, the research covered core approaches to intensifying the processing of hard-to-process diamond-bearing raw materials; as a result, the research team was able to experimentally validate, develop, and test in an industrial setting several innovative methods for modifying the properties of separation media and mineral components. According to what the process needs, these methods can:
– adjust the spectral and kinetic properties of diamond crystals so that XRF could fully recover them;
– restore the hydrophobic properties of diamond crystals for grease recovery and froth flotation to increase the recovery rates by 10% to 15%
– improve the corrosion resistance of ferrosilicon pellets interfacing with corrosive water systems to reduce the loss of ferrosilicon by 5% to 8%.

6. References
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