Electrohydraulic technology of mineral disclosure

D V Avramov1,*, N V Martynov1 and V N Dobromirov2
1“NPF "Electrohidrodinamica", St. Petersburg, Russia
2Saint Petersburg State University of Architecture and Civil Engineering, St. Petersburg, Russia
E-mail: *dvavramov@gmail.com, nik_mart51@mail.ru, viktor.dobromirov@mail.ru

Abstract. The technology of mineral disclosure, based on the electrohydraulic effect, allows splitting the host rock along inhomogeneities, i.e. along the boundaries of inclusions of particles of useful minerals, leaving the degree of grinding within the limits of economic feasibility. The aim of the study was the experimental development of electro-hydraulic technology for energy-saving selective disintegration of finely disseminated ores of complex mineral raw materials. Research was conducted using a specially designed laboratory setup. As objects of research, previously crushed samples of various ores were used. The subject of the study was the process of the discovery of minerals from the action of factors of the electrohydraulic effect. Approaches to the calculated determination of electrical parameters that provide a high degree of mineral disclosure are described. As a result of a series of experiments on the discovery of minerals, the high efficiency of the proposed technology was confirmed.

1. Introduction
The active use of the Earth's mineral resources inevitably leads to their depletion. In this regard, the development of deposits, the development of which has been considered unprofitable until now, becomes relevant [1, 2]. In Russia, there are many deposits of finely disseminated ores of complex composition, the usage of which is impossible due to too high energy costs for ore preparation [3]. This is due to the fact that the opening of minerals by traditional mechanical methods requires grinding the host rock to a size commensurate with the size of the smallest inclusions of useful fractions, and this is where the energy-consuming unjustified over-grinding of larger inclusions occurs. In the processes of implementing traditional technologies for the beneficiation of mineral raw materials, about 70% of the energy is spent on crushing and grinding ore. The consumption of electricity for the grinding process, depending on the type of ore, ranges from 20 to 60 kWh/t, and often an increase in the fineness of grinding does not lead to an increase in the degree of mineral disclosure. An insufficient degree of mineral disclosure leads to the appearance of waste in the form of huge dumps containing valuable raw materials that have not been extracted. Analysis of the main losses of valuable components in primary processing shows that 35–40% of losses are associated with intergrowths and 30–35% - with fine particles less than 40 microns in size [4]. These losses can be reduced by using controlled selective disintegration of ores. The development of such methods for the disclosure of mineral raw materials is an urgent task [5,6,7]. Its solution is possible through the implementation of electric-discharge disintegration technologies based on the use of the electrohydraulic effect and ensuring the destruction of the material along the interphase boundaries.
due to the formation of microcracks as a result of the action of controlled impulse loads arising from high-voltage electrical discharges in a liquid [4,8,9]

2. Tasks, object and subject of research
In connection with the aim of the study, its tasks were: determination of the calculated dependences to justify the electrical parameters of ore processing; development and creation of a laboratory setup; experimental processing of ores of complex mineral raw materials. Pre-crushed samples of various ores were used as objects of research. The subject of the study was the process of mineral disclosure from the action of factors of the electrohydraulic effect.

3. Materials and methods
The essence of the electrohydraulic effect lies in the fact that when a high-voltage electric discharge occurs inside a liquid, an ultra-high hydraulic pressure is generated that can perform useful mechanical work. This is the simplest way of converting electrical energy into mechanical energy with high efficiency, [10]. Selectivity of disintegration is achieved by the ability to control the influencing force parameters of the process in accordance with the strength of ore raw materials. It is known that the strength of the interphase boundaries is inferior to the strength of the phases. Therefore, the pressure of compression and extension waves arising as a result of the instantaneous expansion of the interelectrode discharge channel should not exceed the ultimate compressive strength of the processed product, but should be greater than the ultimate tensile strength at the interphase boundaries [11]:

\[ \sigma_{\text{tens}} < P_{\text{w comp}} < \sigma_{\text{comp}} \] (1)

where \( \sigma_{\text{tens}} \) — tensile strength of ore material, MPa; \( P_{\text{w comp}} \) — wave pressure, MPa; \( \sigma_{\text{comp}} \) — ultimate compressive strength of the processed material, MPa.

The value of the wave pressure is determined by the ratio of electrical parameters: the voltage of the discharge circuit, the capacity of the capacitor banks, the inductance of the discharge circuit, \( l_{\text{dg}} \) — the length of the discharge gap, as well as the distance of the wave from the epicenter (radius of destruction).

The pressure of compression waves generated by an electric discharge in a liquid is expressed by the relationship [12]:

\[ P_{\text{w comp}} = \frac{4 \sqrt{U_0^5 C}}{\sqrt{r^8 L^3 l_{\text{dg}}^4}} > \sigma_{\text{tens}} \] (2)

where \( P_{\text{w comp}} \) — pressure at the front of the compression wave, MPa; \( U_0 \) — discharge circuit voltage, kV; \( C \) — capacity of capacitor banks, \( \mu \)F; \( r \) — radius of destruction, m; \( L \) — discharge circuit inductance, \( \mu \)H; \( l_{\text{dg}} \) — discharge gap length, m; \( \sigma_{\text{tens}} \) — tensile strength of the material, MPa.

In [4], an empirical coefficient of proportionality \( k \) is proposed, equal to 1.3 and taking into account the excess of pressure at the front of the compression wave \( P_{\text{w comp}} \) over the ultimate tensile strength of ore materials \( \sigma_{\text{tens}} \). When introducing the proportionality coefficient \( k \), dependence (2) is transformed into the expression:

\[ P_{\text{w comp}} = \frac{4 \sqrt{U_0^5 C}}{\sqrt{r^8 L^3 l_{\text{dg}}^4}} = k \sigma_{\text{tens}} \] (3)

On the basis of expression (3), knowing the value of \( \sigma_{\text{tens}} \) of the ore material and determining the required pressure \( P_{\text{w comp}} \), it is possible to select the electrical parameters of processing \( U_0, C, l_{\text{dg}} \) with the structurally specified parameters of the setup \( r \) and \( L \), which ensure the obtaining of the required pressure at the front of the compression wave. The frequency and number of discharge pulses supplied to the processed medium determined the degree and speed of raw material crushing.
A schematic diagram of the functioning of the laboratory electro-hydraulic setup created for the study is shown in Figure 1. The starting material enters the working area from above through the loading opening. In the discharge chamber in the zone of a pulsed high-voltage discharge in water, solid materials are crushed into fractions. The material crushed to the required fraction passes through a slotted classifier and enters the setup drip pan. The slotted classifier sets the size of the fractions of the disclosed minerals. The circulating pump ensures the circulation of the working fluid (process water) in the system.

![Diagram of the laboratory setup for electrohydraulic disclosure of minerals.](image)

**Figure 1.** Laboratory setup for electrohydraulic disclosure of minerals.

Pre-crushed ore samples from the Akkarginsky, Diabazovy, Kuldursky and Snezhnoye deposits were processed by electrohydraulic crushing to a given size. The initial samples prepared for grinding and brought to the required size as a result of processing were examined in VIMS Research and Production Association to determine the disclosure of valuable components of materials.

### 4. Results and discussion

Preliminary determination of the ultimate compressive strength of rocks [13, 14] and experimental refinement of electrical parameters made it possible to adjust the operation of the setup for grinding each of the crushed ore samples to the required size. In particular, the values of the electrical parameters of the setup for grinding a sample of crushed ore from the Kuldursky deposit for the size -2+0 and -1+0 were: \( U_0 = 36 \text{kV}; \ C = 2.7 \text{ kF}; \ l_{dg} = 20 \text{ mm}; \) the number of pulses is 500. The energy of one discharge is 1750 J in both cases. The discharge frequency determines the performance of the process and depends on the power of the high-voltage power supply. The higher the power supply capacity, the higher the frequency of discharges in the same mode. Usually the discharge frequency does not exceed 2 Hz. Taking this into account, the processing time was 250 seconds, and the required power of the power supply was 1750 \times 2 = 3500 \text{ W} or 3.5 kW.

Below are the results of the study of the disclosure of target minerals in the sample of the Kuldursky deposit. Initial material - crushed ore sample with a size of -10+0 mm, which is a mixture of minerals (hardness on the Mohs scale): brucite - 65-70\% (2.5); magnesite - 10-15\% (3.5-4.5); dolomite - 5-10\% (3.5-4); serpentine - 5\% (2.0-4.0); calcite - 45\% (3.0); deweylite - 1-3\% (2.0-4.0). A useful mineral is brucite.

Grinding of the material was carried out to a given size of 1mm and 2mm. The study of the fractional and mineralogical composition was carried out using three samples: sample 1 - initial material, samples 2 and 3 - after processing to a required size.
To assess the fractional composition, all samples were sieved into size classes. Sample sieving is shown in Table 1. The study was carried out using a ZeissAxio Imager.A2m optical microscope with an image analyzer and ThixometPro software. Specimens for optical analysis were made from the material of each sample.

**Table 1. Granulometric characteristics of samples.**

| Sample | Initial | -1+0 | -2+0 |
|--------|---------|------|------|
|       | Output  | Output | Output |
| Class | gram | % | gram | % | gram | % |
| +2   | 125.8 | 62.0 | 0 | 0 | 15 | 14.8 |
| -2+1 | 37.2 | 18.3 | 24.5 | 24.4 | 39.6 | 39.0 |
| -1+0.5 | 18.1 | 8.9 | 35.2 | 35.0 | 16.8 | 16.5 |
| -0.5+0.250 | 9.7 | 4.8 | 14.6 | 14.5 | 8.4 | 8.3 |
| -0.250+0.125 | 6.5 | 3.2 | 11.3 | 11.2 | 7.3 | 7.2 |
| -0.125+0.071 | 2.7 | 1.3 | 4.8 | 4.8 | 3.8 | 3.7 |
| -0.071+0.045 | 2.0 | 1.0 | 3.2 | 3.2 | 4.6 | 4.5 |
| -0.045 | 1.0 | 0.5 | 6.9 | 6.9 | 6.1 | 6.0 |
| Total | 203.0 | 100.0 | 100.5 | 100.0 | 101.6 | 100.0 |

Granulometric analysis showed that the material of the samples after electrohydraulic processing up to size grades -2+0 and -1+0 is different in the nature of the distribution by size classes. Thus, in terms of composition, the coarser-grained sample (-2+0) retained the bulk of the grains in grain size classes greater than 0.5 microns. At the same time, the output of classes less than 0.125 µm, where the material consists of a carbonate fine mass contaminating the target minerals (beryl), is approximately the same in both samples. In a sample with a particle size of -1+0, the material was divided into two main classes -2+1 and -1+0.5, which in total amounted to almost 60%. In both samples, all sludge fractions are noted with a size class of -0.125 microns. Target minerals are maximally contaminated with fine carbonate particles and partly with clay, creating compressed masses that move from class to class.

Mineralogical analysis was carried out using binoculars and an optical microscope according to size classes. Based on the results of the analysis, a table of the disclosure of mineral individuals was compiled, which shows the degree of disclosure by size class (table 2).

**Table 2. Disclosure of mineral individuals by size classes in the original sample and in the samples after processing.**

| Sample | Size class | +2 | -2+1 | -1 | -0.5 | -0.250 | -0.125 | -0.071 | -0.045 | Total |
|--------|-------------|----|------|----|------|--------|--------|--------|--------|-------|
| Initial | output 62 | 18.3 | 8.9 | 4.8 | 3.2 | 1.3 | 1 | 0.5 | 100 |
| disclosure 63.00 | 79.00 | 83.00 | 88.00 | 97.00 | 97.00 | 99.00 | 99.00 | 70.98 |
| -1+0 | output 0 | 24.4 | 35 | 14.5 | 11.2 | 4.8 | 3.2 | 6.9 | 100 |
| disclosure 0 | 81.00 | 85.00 | 88.00 | 92.00 | 98.00 | 98.00 | 99.00 | 87.25 |
| -2+0 | output 14.8 | 39 | 16.5 | 8.3 | 7.2 | 3.7 | 4.5 | 6 | 100 |
| disclosure 79.00 | 80.00 | 82.00 | 85.00 | 90.00 | 92.00 | 98.00 | 99.00 | 83.71 |

From the data in Table 2, it follows that, in general, the disclosure of mineral components in both samples is very high for all size classes, and almost evenly increases with decreasing class.

**5. Conclusion**

Analysis of the results of processing samples from the remaining deposits made it possible to draw identical conclusions on them. This gives reason to believe that the technology of energy-saving selective disintegration of finely disseminated ores of complex mineral raw materials, based on the use of the electrohydraulic effect, has prospects for industrial application.
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