Removal of fine suspended solids from mine waters of the Udachny underground kimberlite mine by sedimentation

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Abstract. This paper presents the main results of theoretical and experimental studies on the removal of suspended solids contained in the mine waters of the Udachny underground kimberlite mine before their filling into well completions.

1. Introduction
Highly saline mine waters pumped out of the mine workings of the Udachny underground kimberlite mine of ALROSA are removed back into the subsoil by completing them into the permafrost areas and the collector of the Lower Cambrian Aquiferous Complex (LCAC) [1]. Practice shows that, due to their porous-cavernous structure, LCAC reservoirs are characterized by intense clogging with suspended solids entering the completion wells while filling; it negatively affects the completion of the latter. Taking into account the fact that suspended solids mainly belong to carbonate rocks in terms of material composition (figure 1). Due to their feature that they dissolve well in acids, they are systematically carried out with hydrochloric acid treatment (HAT) in order to maintain the productivity of completion wells [2].

Figure 1. Substance composition of suspended solids.
Frequent hydrochloric acid treatment in the long term can negatively affect the state of the environment [3]. One of the ways to reduce the amount of HAT is the removal of suspended solids from mine waters before they are poured into wells completion.

The paper presents the main results of theoretical and experimental studies on the control of suspensions contained in the mine waters of the underground kimberlite mine "Udachny" carried out within the framework of contractual work No. 052-20/04 "Justification of technology and technological equipment for effective clarification of mine waters and dehydration of sludge contained in mine waters in relation to the conditions of the main drainage of the Udachny underground mine.

2. Materials and methods
According to the collected data, about 86% of all suspended solids contained in the mine waters of the Udachny underground kimberlite mine have a size of less than 0.07 mm (table 1).

| Class | Class content |
|-------|---------------|
| > 1.2 mm | 1 % |
| – 1.2 mm … + 0.16 mm | 13 % |
| – 0.07 mm … + 0.02 mm | 56 % |
| < 0.02mm | 30 % |

The smallest possible size of the boundary grain while operating spiral classifiers and hydro screens is 0.1 mm and 0.3 mm. It indicates that there is no benefit from using this equipment in a particular case.

In the paper [4] the author notes that suspended solids of 0.02÷0.06 mm in size can be removed applying hydrocyclones with a diameter of \( D_g = 75 \) mm. In the conditions of the Udachny underground mine, the use of hydrocyclones of this diameter is an inexpedient solution. It is explained by the high risk of their systematic clogging with large inclusions and the need to apply them in large volume due to their low productivity. Moreover, it will be necessary to maintain the operating pressure at the inlet to the hydrocyclones constantly. It is quite difficult when pumping equipment operates on highly mineralized mine water under conditions of systematic fluctuations in water inflow. In the conditions of the daytime surface, the use of hydrocycloning technology, in addition to the previously indicated disadvantages, aggravates the harsh natural and climatic conditions of the region. It is necessary to construct a separate building for the application of hydrocyclones as it must be constantly heated in a cold season, so that mine waters do not become excessively viscous, i.e., additional significant expenditures. Moreover, the application of hydrocyclones or other technological equipment on the daytime surface will not solve the urgent problem of intensive hydroabrasive wear of expensive pumping equipment for the main drainage unit of the Udachny underground kimberlite mine.

It is possible to remove suspended solids of less than 0.07 mm in size by using radial thickeners with flocculants. According to the calculations given below, to extract the predominant proportion of suspended solids, a thickener with a deposition area \( F \) of at least 72.7 m\(^2\) is required [5]:

\[
F = f \cdot G = 12.98 \cdot 5.6 = 72.7 m^2
\]

where \( f \) is required sedimentation surface of 1 ton of the daily capacity of the thickener, \( m^2/t \cdot day \); \( G \) is thickener solid performance, \( t/h \) \((\dot{G}=5.6,\) based on the suspension content in water 16 g/l and water inflow into the mine \( Q = 350 m^3/h \)). A parameter \( f \) was calculated according to [5]:

\[
f = \frac{R_1 - R_2}{86.4 \cdot \alpha \cdot k} = \frac{75 - 1}{86.4 \cdot 0.11 \cdot 0.6} = 12.98 m^2/t \cdot d
\]
where $R_1$ and $R_2$ is ratio of $L:S$ (by mass) in the pulp and the thickened product, ($R = 75$, based on the mass of the liquid $m = 1200 \text{ g}$ and the solid phase $m = 16 \text{ g}$ in 1 liter of mine water; $R = 1$, predicted value) ; $v$ is sedimentation rate of the largest particles leaving the drain, mm/s, ($v = 0.11 \text{ m/s}$, according to field tests); $k$ is coefficient that takes into account the ratio of the effectively of the applied deposition surface to the total deposition surface of the thickener ($k = 0.6÷0.7$ for thickeners mounted in heated spaces).

Thickeners of the model STs-12A2 and STs 12AS1 with the following dimensions correspond to such requirements: external diameter $D = 12.17 \text{ m}$ and $12.2 \text{ m}$; width $B = 12.52 \text{ m}$ and $12.6 \text{ m}$; height $H = 11.22 \text{ m}$ and $11 \text{ m}$ [16].

The considered thickeners have significant dimensions, primarily height, and therefore, their application in the cramped conditions of an underground mine is impossible.

If we take into account a problem of saving money, the application of a radial thickener on the day surface will reduce the financial costs for carrying out the HAT and cleaning of injection wells by approximately $15÷20$ million rubles per year (the cost of the HAT and cleaning of one well is the same and amounts to $1.8$ million rubles). At the same time, the total expenditures for purchase, delivery and assembly of the thickener alone will be approximately at least $100$ million rubles. Moreover, as in the case of hydrocyclones, a separate building must be erected for the thickener, only of a much larger size than in the case of hydrocyclones. It is necessary to take into mind that the completion of flocculants into the subsoil together with mine waters will also lead to additional financial expenditures.

According to Figure 2, the concentration of $K$ suspended solids contained in highly mineralized mine water decreases from $26 \text{ g/L}$ to $16 \text{ g/L}$ as it moves in the clarification tank and water collection place. Thus, the problem of effective control of suspended solids in the conditions of the Udachny underground kimberlite mine can be solved by traditional sedimentation of water in mine workings. For this it is necessary to drill the clarification tanks No. 5 and No. 6.

![Figure 2](imageURL)

**Figure 2.** Concentration of mechanical suspended solids in mine workings accumulating mine water: 1 is in front of the clarification tank; 2 is in front of the water collection place; 3 is behind the water collection place.

3. **Research results and analysis**

The geometric capacity of the developed clarification tank $V_g$ can be calculated as follows [6]:

$$V = Q \cdot t \ (3)$$
where $Q$ is average hourly water inflow into the mine, m$^3$/h; $t$ is settling time of mine water in the clarification tank, required for sedimentation of suspended solids, h.

The water inflow $Q$ in the coming years will increase to 400 m$^3$/h based on the collected hydrogeological data.

According to [6], the time $t$ can be represented as a function of the water level $h$ in the clarification tank. To establish the time $t$, field studies were carried out on settling mine water at various values of $h$ in measuring containers simulating a clarifying tank. According to the dependence between the movement of suspensions in the measuring tanks $S$ and the time $t$, the prevailing proportion of suspended particles (about 80%) contained in the mine waters entering the clarification tanks of the main drainage of the underground kimberlite mine "Udachny" pulp after 17 minutes at $h = 10$ cm; after 30 minutes at $h = 15$ cm; after 45 minutes at $h = 30$ cm (figure 3: a, b, c). Then, the rate of sedimentation of suspended solids and compaction of the sediment drops sharply.

On the basis of the linear trend approximation of the relationship between the above values of the parameters $h$ and $t$, a regression model of the following type was built: $t = 1.3077 h + 6.6923$ (figure 4). The predicted time $t$, calculated on the basis of the regression model, was 268.23 min or 4.47 h in accordance with the accepted value $h = 200$ cm (it is the most optimal variant of the depth of the design clarification tank).

It is necessary to introduce a correction factor $k_1$ into expression (3) to calculate the capacity of the latter, which allows to effectively precipitating suspended solids since in the process of field studies the mine water was at rest, unusual for it when a real clarifying tank is located. The water velocity in the clarification tank is relatively low (it is about 7 mm/s, i.e., calculated data). So, the considered coefficient was taken equal to 1.1.
Figure 4. Dependence $S = f(t)$ and its approximation by a linear trend.

The following requirements were put forward by the management of the Udachny mine to the capacity of the developed clarification tanks:

1) The operating time of the clarification tank (before cleaning) must be at least 27÷30 days;
2) The clarification tank continued to clarify the mine water effectively at the moment of its removal from service.

These requirements were taken into account by introducing a correction factor $k_2$ into expression (3), the size of which, according to calculations carried out earlier within the framework of the contractual work, was 2.05.

Taking into account correction factors, the capacity $V_g$ was 4032 $m^3$:

$$V_g = k_1 \cdot k_2 \cdot Q \cdot t = 1.1 \cdot 2.05 \cdot 400 \cdot 4.47 = 4032 m^3$$  (3)

According to the calculations performed, the approximate payback period for the penetration and subsequent operation of clarification tanks No. 5 and No. 6 will be approximately 4.8 years. The expected economic effect after payback will be about 70 million rubles in each subsequent year.

4. Conclusion
The most expedient solution to combat suspended solids contained in the highly mineralized mine waters of the Udachny underground kimberlite mine is their traditional settling in clarification tanks. It is dictated primarily by the particle size distribution of suspended solids. The most optimal dimensions of the design clarification tanks were established for the conditions of the main drainage of the Udachny underground kimberlite mine. They help to remove suspended solids less than 0.07 mm in sediment in highly mineralized mine waters, and, accordingly, to reduce the number of HAT completion wells in the conditions of LCAC water collection place. The performed technical and economic calculations confirm the efficiency of driving clarification tanks No. 5 and No. 6 in conditions of the Udachny underground kimberlite mine.

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