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Method for calculating the groundwater inflow into pit when mining the placer deposits by dredger

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Abstract. The research aims to increase the performance efficiency of hydromechanization equipment under the conditions of pit operation of the Motronivskyi Mining and Concentrating Plant by determining the dynamics of change in the water level in the mine workings when developing the overburden rocks and mineral. It has been generalized the world experience of determining the groundwater inflows into mine workings, which are mined by means of hydromechanization equipment. The methods have been developed for calculating the underground water inflow into the pit reservoir, when mining the placer ores by hydromechanization equipment. It has been proved that the dredger work in the conditions of the Motronivskyi MCP pit is possible without external source of water supply. The research results in determining the influence of underwater mining of overburden rocks and ore by dredger for decreasing the water level and its subsequent recovery in the reservoir of the Motronivskyi MCP pit, allow to develop a mode of mining operations without an external source of water supply. The dynamics of water level fluctuations in mine working during the working week have been established. The research results have shown that the dredger, taking into account the technical characteristics, can continuously operate for 9.5 days under the conditions of underground water inflow into the Motronivskyi MPP pit. It has also been established that after the dredging of the overburden rocks is stopped, the level of water in the pit for 2.5 days will recover.

1 Introduction

The floating properties of watered overburden and ore at the Motronivskyi titanium-zirconium placer deposit significantly increase costs of the mining by excavating complexes, and therefore underwater mining of ores by means of hydromining is more efficient from an

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economic point of view [1, 2].

Also, the use of hydromining during the development of placer deposits has a number of environmental benefits [3, 4]. First of all, there is no need to drain the pit, which reduces the costs of haulage and hydraulic washing-out of minerals [5, 6], there is no depletion of groundwater reserves. In addition, the application of underwater mining method eliminates the issue of pit water dumping into the hydrographic network. Therefore, the influence of mining works on the hydrogeological conditions of the area is minimal [7, 8].

However, the use of dredgers for ore sand excavation leads to a drop in water level in the pit reservoir [9, 10], after which begins the inflow of groundwater from the Sarmatian horizon. As the water level in the excavation decreases, the groundwater flow increases [11]. At the same time, if the water withdrawal is greater than the inflow, the water level in the excavation may drop to the roof of the ore, which will stop the work of the mining site and violate the schedule of the enterprise as a whole [12, 13].

At the Motronivskyi MPP pit, it is permissible to lower the water level to the mark of 95 m, after which the dredger operation must be stopped. The mining operations in the pit can resume only after the water level has restored. The water level in the pit rises due to the supply of underground sources [14, 15].

Taking into account the above, the problem of the research, which lies in the need to provide the required level of water in the excavation [16] mined by the dredger, is solved by calculating the time at which the water level in the excavation drops to the given mark and then restores [17].

The analysis of previous research shows that considerable attention is paid to the choice of methods for developing titanium ores, which are found both in hard rocks and in placer deposits [18, 19]. The authors provide a list of technological schemes that can be used in the development of placer deposits. However, when selecting mining equipment for placer deposits, the authors proposed to use a criterion for water availability on the surface of the deposit [20, 21]. Only in this case they recommend the use of hydromechanical equipment. In case of developing the Motronivskyi MPP pit, this criterion can not be applied, because water is available not on the surface of the ore deposit, but in aquifers [22, 23]. Therefore, the use of dredgers causes the need to justify the balance of water in the pit, which will ensure the continued operation of mining equipment.

The authors also proposed to use a dynamic programming model with two uncertainties to determine simultaneous optimal modes of mining operations, which is developed by hydraulic mechanization, taking into account the water requirements for the operation of mining equipment and the sediment rocks washing [24]. However, the issue of providing the given productivity of hydromechanization equipment in the development of watered alluvial ores is still unresolved, when the performance depends on water supplies only from underground horizons [25, 26].

Identification of previously unsettled parts of the general problem shows that issues of water supply in excavations developed by dredger is one of the most important in the conditions of low water-bearing aquifers. The problem is intensified in the absence of additional water reservoirs near the pit [27 – 29].

In general case, the inflow of underground water into the pit depends on the filtration properties of the aquifers, the size of the pit, the reduction of the level and water loss. Also, the crucial role is played by the time period for which the water level in the pit is restored. A generally accepted method for determining the underground waters flow in excavation is the method of a “large well”, where the radius r_k is given in formula:

$$r_k = \frac{P}{2\pi}, \text{ m},$$

where P is perimeter of a pit on the outline of water supply, m.

For an aquifer unlimited in the plan, without taking into account infiltration feed, the flow of water Q into excavation is determined by the formula:

$$Q = \frac{2.73TS_{\kappa}}{\lg \frac{r_k + \sqrt{\pi a t}}{r_k}}, \text{ m}^3,$$

where T is transmissivity, $T = k{\cdot}$m, where k is the coefficient of filtration, m is the thickness of the ore body, m; S is decrease in the level, m; a is the hydraulic diffusivity, $1{\cdot}10^3$ m^2/day.

In the given formula it is considered that the reduced radius of the pit is unchanged, that is, the well is cylindrical. However, the walls of Motronivskyi MPP pit are sloping, and therefore the application of the above equation in practice is incorrect. Therefore, when carrying out research, it is necessary to take into account the fact that the decrease in water level during mining is accompanied by a decrease in the area of the water mirror, the perimeter of the pit and the reduced radius, accordingly.

Preliminary studies of methodological approaches showed that problem does not have the analytical solution as to determining the influx of groundwater in excavation with the form of a pit with very gentle slopes and mined by dredgers [30].

Therefore, it is proposed to solve the problem of determining the water flow of groundwater in the excavations of very gentle slopes by the method of finite difference, dividing the process into elementary segments of time.

To solve this problem it is necessary to establish: volumes of water and mined rocks that is developed for the time unit; reduction of water level in the drainage and water inflow caused by this; determining the time for the water in the drainage to drop by 6 m, after which the dredger operations will be stopped; time for the restoration of water level in excavation during dredging; it is also necessary to develop recommendations for using dredger for a five-day working shift.

2 Development of the calculation method for groundwater inflow in the pit during dredging

The steady operation of a pit with underwater mining of minerals is significantly complicated in the event of groundwater shortage for excavation developed by hydromining equipment. In the development of flooded titanium-zirconium ores deposits, the mining of bed is carried out directly without the involvement of additional sources of water supply in the excavation [31, 32]. For a given technological scheme, it is necessary to first ensure the filling of the reservoir, located in a working trench, with water, after which there is an underwater mining of titanium-zirconium ore. Since the performance of the dredger exceeds the water flow of groundwater in the excavation, it is necessary to perform the calculation of the working parameters and the organization of ore mining by the dredger, in order to ensure the annual capacity of the pit. The development of watered pits, without taking into account the influx of groundwater, may lead to unexpected stops of mining equipment and, as a result, to a failure to achieve a given capacity, as well as failure of dredgers.

The task of determining the dynamics of water level reduction in excavation is solved by the method of making summation for the time units. During the research, the time of the work is divided into segments of time with the identical period. When performing calculations, the time interval was ΔT = 0.1 days. In subsequent calculations, the value of ΔT was determined in the days, the filtration factor was taken into account in meters per day, and the water supply in m^2/day. The volume of water and mined rocks ΔV taken out for the time unit was defined as:

$$\Delta V = Q_0 \cdot \Delta T \text{, m}^3,$$

where Q_0 is the volume of the excavated rock and water per time unit, m^3.

The proposed method of calculating the water inflow of underground water in mining excavation has the following sequence:

1. In case when the groundwater does not flow into the pit, the water level in the excavation falls down by the value:

$$\Delta S_0 = \frac{\Delta V}{F} = (const) \text{, m}^3,$$

where F is the area of the water mirror in the pit, which is determined by the mine surveying documentation, m^2.

Reduction in the water level in the excavation leads to water intake, which is determined by the formula:

$$Q_1 = \frac{2.73 \cdot k \cdot m \cdot \Delta S_0}{\lg \dfrac{r_k + \sqrt{\pi a \Delta T}}{r_k}} \text{, m}^3\text{/day,}$$

where k is filtration coefficient, 12.7 m/day; m is the thickness of the watered part of Sarmat, 6 m; r_k is equivalent radius of the pit, m; a is hydraulic diffusivity, $1 \cdot 10^3$ m^2/day.

At the same time, the actual decrease in water level is:

$$S_1 = \frac{(Q_0 - Q_1) \cdot \Delta T}{F} \text{, m.}$$

2. After lowering the water level in the pit for the first period of time, provided that there is no more groundwater in the pit, the water level in the excavation will decrease by the value $S_1 + \Delta S_0$.

The inflow of water in the excavation is determined by the formula:

$$Q_1 = \frac{2.73 \cdot k \cdot m \cdot (S_1 + \Delta S_0)}{\lg \dfrac{r_k + \sqrt{\pi a 2 \Delta T}}{r_k}} \text{, m}^3\text{/day.}$$

The actual decrease in water level during the time ΔT is:

$$\Delta S_2 = \frac{(Q_0 - Q_2) \cdot \Delta T}{F} \text{, m.}$$

The total decrease S_2 is $S_1 + \Delta S_2$, m.

3. After lowering the water level in the pit for the first and second periods of the time, in condition when ground water does not flow into the pit, the water level in the excavation will decrease by the value $S_2 + \Delta S_0$.

In this case, the inflow of water is determined by the formula:

$$Q_2 = \frac{2.73 \cdot k \cdot m \cdot (S_2 + \Delta S_0)}{\lg \dfrac{r_k + \sqrt{\pi a 3 \Delta T}}{r_k}} \text{, m}^3\text{/day.}$$

The actual decrease in water level for 0.1 hours is:

$$\Delta S_3 = \frac{(Q_0 - Q_3)\cdot \Delta T}{F}, \text{ m.}$$

The total decrease of S_3 is $S_2 + \Delta S_3$, m.

The experiment will continue until the level of water in the pit falls below $S_n = 6$ m.

As a result of the experiment, the time of dredger operation is determined:

$$T = n \cdot \Delta T,$$

where n is the number of calculation steps.

After decrease in water level by the 6 m, the dredger operation is stopped for technical reasons, until the water in the pit rises and reaches the required level.

The calculation of restoration of water level in the pit is carried out in the following sequence.

4. The inflow of water in the pit is determined by the formula:

$$Q_1 = \frac{2.73 \cdot k \cdot m \cdot S_n}{\lg \dfrac{r_k + \sqrt{\pi a T_n}}{r_k}}, \text{ m}^3\text{/day.}$$

At the same time the increase in water level in the excavation is:

$$\Delta S_1 = \frac{Q_1}{F}, \text{ m}$$

and the drop in water level in the pit is:

$$S_1 = S_n - \Delta S_1, \text{ m.}$$

5. After restoration of the water level in the pit for the first period of time, the water inflow in it for the second period of time is determined by the formula:

$$Q_2 = \frac{2.73 \cdot k \cdot m \cdot (S_n - \Delta S_1)}{\lg \dfrac{r_k + \sqrt{\pi a \cdot (T_n + \Delta T)}}{r_k}}, \text{ m}^3\text{/day.}$$

At the same time increase in the water level in the pit for the second period of time will be:

$$\Delta S_2 = \frac{Q_2}{F}, \text{ m.}$$

Decrease in water level in the pit during this time is:

$$S_2 = S_1 - \Delta S_2, \text{ m.}$$

3. The inflow of water into the pit for the third period of time is determined by the formula:

$$Q_3 = \frac{2.73 \cdot k \cdot m \cdot \left(S_n - \Delta S_2\right)}{lg \dfrac{r_\kappa + \sqrt{\pi a \cdot \left(T_n + 2\Delta T\right)}}{r_\kappa}}, \text{ m}^3\text{/day.}$$

Increase in water level in the pit for the third time period is:

$$\Delta S_3 = \frac{Q_3}{F}\text{, m.}$$

Decrease in water level in the pit for the third time period is:

$$S_3 = S_2 - \Delta S_3\text{, m.}$$

The calculation continues until the value of water level decrease in the pit reaches zero.

3 Results and discussion

To determine the dynamics of lowering the water level in the pit and its subsequent restoration, the task was initially solved with the continuous operation of the dredger until the water level dropped by the acceptable technical characteristics of the dredger – 6 m. Then the dynamics of water level restoration in the pit with standing dredger was determined.

The results of calculating the drop in water level in the pit and subsequent restoration of this level are presented in the graph shown in (Fig. 1).

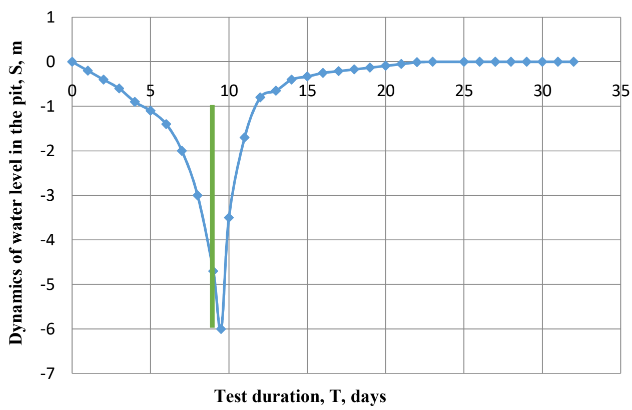

Fig. 1. Dynamics of lowering the water level and its subsequent restoration in a pit in dredging operations.

The results of the research presented in the graph (Fig. 1) show that the dredger, taking into account the technical characteristics, can operate continuously for 9.5 days. After the dredge operations are finished, the water level in the pit will rise to a mark (-1.0) m from the starting level within 2.5 days and its absolute mark will be 100.5 m.

Subsequent filling of the pit with groundwater is very slow, asymptotically approximating the water level in the excavation to the initial mark of 101.5 m.

The obtained results of the conducted research confirm the necessity of changing the work schedule of the dredger, taking into account the dynamics of changes in the level of water in excavation filled by groundwater.

Indicators for the reduction and filling of the pit with groundwater must be taken into account when planning ore mining at Motronivskyi MPP pit, since up to 26% of the working time, dredgers should be in standby mode. The operation is resumed provided that the water level mark in the mining output is raised to the required value.

Let's consider one of the most widespread cases of organizing the operation of a hydromining equipment complex during the development of Motronivskyi MPP pit. The equipment complex operates at a 5-day working week. The duration of one working shift is

8 hours, followed by a 16-hour break.

In accordance with the developed method for determining the inflow of groundwater into excavation, a study was carried out to determine the dynamics of water level changes in mining operations during a working week with a previously established regime. The dynamics of water level changes in excavation during dredger operation in the conditions of Motronivskyi MPP pit is presented in the graph in Fig. 2.

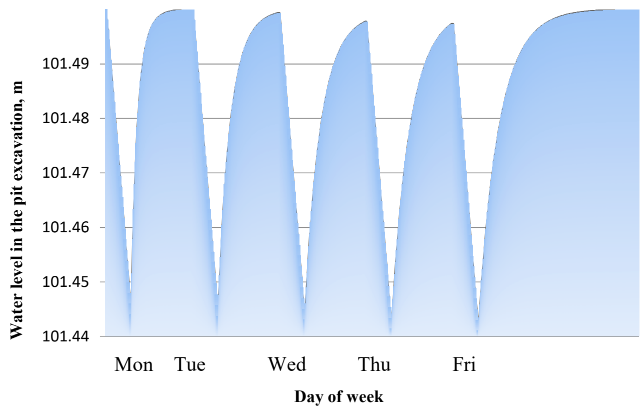

Fig. 2. Dynamics of water level fluctuations at the dredger operation Motronivskyi MPP pit during a working week.

As can be seen from the graph shown in Fig. 2, at the predetermined mode of mining operations during the 16 hour rest time, there is practically a complete restoration of water level in the pit during the day. That is, the extraction equipment, which is represented by dredgers, begins a new shift according to the schedule without violation of the operation regulations.

In the given operation mode of dredgers involved in stripping operations of the Motronivskyi MPP pit, within one month 164 000 m^3 of overburden is mined, while the productivity of hydromining equipment reaches up to 2000 m^3/hour.

Based on the facts given above, it can be concluded that underwater mining of titanium-zirconium deposits is possible provided by only the groundwater supplies to the mining excavation in the absence of a preliminary drainage of the pit. In case of determined inflow of groundwater, the planned productivity of the enterprise is ensured by the distribution of time of mining equipment without additional water supplies. It was established that ore mining is also possible with the involvement of additional water supplies, when it is necessary to increase the minerals output, depending on the market consumption. This allows to determine the measures preventing the adverse impact of reduced water level on the technology in mining excavations.

The research allowed to determine that, to ensure the established pit productivity, the extraction of minerals should be based on the developed weekly plan of hydromining equipment (dredgers) operation. The developed method of calculating the water inflow into excavation can significantly reduce the time of hydraulic calculations and ensure uninterrupted pit exploitation.

4 Conclusions

A methodology for calculating the inflow of groundwater into the pit at the extraction of placer ore deposits by hydromining equipment allows to determine the dredger operation mode.

It is proved that the dredger operation without external water supply in the conditions of the Motronovskyi MPP pit is possible, but with rather low productivity of the mining enterprise.

According to the results of the research, it is recommended to conduct stripping operations with productivity determined by the necessary inflow of groundwater into the pit.

Prospective studies are to clarify the operating conditions of the hydromining complex through conducting experimental and industrial works.

Other important studies are the establishment of possible modes of mining with a two-shift day and seven-day working week, which is relevant when increasing demand for products and production capacity of the enterprise in ore mining.

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