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INVESTIGATION OF THE INFLUENCE OF FLOODED BENCH HYDRAULIC MINING PARAMETERS ON SLUDGE POND FORMATION IN THE PIT RESIDUAL SPACE

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Abstract. The research aim is establishment of effective parameters for mining of flooded bench by a hydro-mechanized complex with dumping of enclosing rocks in a sludge pond of pit residual space. The established research results make it possible to choose the effective width of the dredger mining cut at the hydromechanical method, taking into account the volume of the excavation and dump pipeline movements. Two technological schemes for the formation of a sludge pond in the pit residual space are proposed, they differ in the direction of the sludge pond movement relatively to the pit front. The established dependence of the number of movements of the sludge pond pipeline on the width of the dump pass allows to choose its effective value, taking into account the number of discharge pipes. Based on the dependence of the average monthly excavation volume and the number of movements of sludge pond pipeline on the width of cut face, the optimal number of discharge pipes is established. The research results allow establishing the effective dredger width of the sludge pond and the number of discharge pipes provided that a transverse or longitudinal pass at the internal sludge pond formation is applied during the mining.

Introduction.

The use of hydromechanized method for developing flooded benches of titanium zirconium deposits is comparable in effectiveness with the use of mechanical excavation equipment and in some cases even exceeds it. This is due to the relatively small capital costs and operating costs for mining as well as the use of the most efficient hydraulic transport to move the rocks [1, 2].

In the case of using the hydromechanized method, drags and dredgers are used as mining equipment, and rock mass in the hydraulic mixture form is transported by pipelines to a processing plant. The use of hydromechanized equipment at the development of flooded titanium-zirconium deposits has a significant drawback which consists in the need to move the entire volume of the ore to the processing plant located on pit top [3, 4]. At the same time the percentage of heavy minerals in the ore is only up to 5 %, therefore, the haulage of 95 % of the host rocks to the processing plant is a costly but necessary process.

The authors offer to solve this problem by using a hydromechanized mining complex (HMC), which includes dredges and a floating processing plant [5, 6], which allows to divide ore into heavy minerals, clay and sand in a pit cutting trench [7, 8]. The sand rocks can be stored in the mined-out pit area by a hydromechanical method. However, this solution requires justification of the effective mining and dumping parameters [9, 10].

Analysis of basic research and problem statement. The research works [11, 12] present the study results of the floating hydromechanized mining complex operation parameters during the development of flooded titanium ore deposits in Mozambique. However, the focus of the works is on the issue of titanium ore mining, at the same time, the question of host rocks storage is not considered.

The authors [13, 14] devote their research to determining the effectiveness of the hydromechanized mining complex usage in comparison with the development of ore sands by dredgers with the subsequent ore haulage to the processing plant outside the pit. At the same time the research does not address the further issues of handling sand rocks, also the question of their placement in the pit mined-out space has not been studied enough.

Studies performed in [15, 16] are devoted to establishing the optimal parameters of sludge ponds in the pit. The effective length and width of the sludge pond are established during its formation in special places bounded by dams. At the same time, there still remains the question of establishing the effective parameters of sludge ponds constructed in the developed space of the flooded pit bench.

The analysis of the studies has shown that the issue of sludge ponds formation in the residual quarry space is insufficiently studied while the main attention is given to the formation of sludge ponds in unusable territories near the pit: gullies, ravines, and other lowlands [17]. In this regard it is necessary to carry out research which will allow to establish the effective parameters for the formation of sludge ponds in the pit residual space, due to which a reduction in mining haulage work can be achieved, thus the question of the need to find additional land for the placement of external sludge ponds will be resolved [18].

To establish the influence of excavation parameters developed by the HMC on the internal sludge pond parameters of the trench it is necessary to solve the following tasks: 1) to establish the influence of the ore bed thicknesses on the volume of the excavation with different widths of the cut face; 2) to establish the effective width of the discharge pipes and its number at the storage sand rocks in sludge pond; 3) to determine the effective mining face cut width of the dredger in the transverse and longitudinal dumping cut of the internal sludge pond formation.

Method. The analytical research method is used to establish the dependence of the excavation volume and the movements number of the sludge pond pipeline, on the basis of which the effective width of the dredger mining face cut is determined with a transverse and longitudinal dumping cut at the internal sludge pond formation. The graphical research method is used to determine the effective number of discharge pipes during sludge pond formation and the distance between them.

Results and discussion. The ore layer development in condition of flooded titanium-zirconium deposit using a hydromechanized mining complex (HMC) allows to separate the host mineral rocks into sand and clay components inside the pit. This leads to a direct change in the haulage scheme of the host rocks from the pit since sand separated from the ore can be stored in internal sludge pond.

The results of preliminary studies show that the distance between the mining and sludge pond openings is directly dependent on the thickness of the ore bed and the physical and mechanical properties of the rocks in sludge pond. At the same time the width of the face cut is taken according to the technical characteristics of the dredge and the safety conditions for mining operations when using HMC.

Another important factor for the stable operation of hydromechanized mining equipment is the condition for supplying the quarry mining zone with ground and industrial water, as in case of shortage, the dredger is forced to wait a certain time until the excavation (pit) is filled with water to the required balance. In this regard, it is necessary to establish the dependence of the excavation volume on the mining bench thickness, width of the mining cut and flooded excavation length.

The studies to determine the excavation volume considered the pit parameters in the following range: the thickness of the ore body from 5 to 15 m; width of face cut from 20 to 80 m; the downward length of the excavation was assumed to be constant– 200 m.

The following expressions are proposed by authors according to mining excavation parameters:

- average flooded excavation length:

$$L_{M.SR} = L_{M.MIN} + \frac{h_Y(ctg\alpha + ctg\beta)}{2} \text{ , m,} \tag{1}$$

- flooded excavation volume:

$$V_M = L_{M.SR} \cdot h_Y \cdot \left(A_3 + \frac{h_Y(ctg\alpha + ctg\beta)}{2} \right) \text{, m,} \tag{2}$$

where $L_{M.MIN}$ is the length of the excavation, m; h_Y is the height of the bench, m; A_3 is the width of the cut face, m; α is the working bench slope angle, 40, deg.; β is the slope angle of the sludge pond underwater part, 27, deg.

The results of the study to determine the influence of the mining bench height on the excavation parameters during the hydro-mechanized mining of titanium ores are shown in Figure 1.

According to the obtained research results (Fig. 1), when the thickness of the mining bench from 5 to 15 m, the volume of the excavation increases from 29,000 to 348,000 m^3 depending on its width. The maximum volume of the excavation is observed at the increase of bench height regardless of the mining cut width. The established dependences of the excavation volume on the mining bench height allow further studies to establish limit values for the length and width of the excavation taking into account the minimum required water level to ensure stable dredges operation.

Another important factor influencing the mining operations organization at the hydromechanical method in the pit is the production capacity. The speed of moving the cut face relatively to pit mining front depends on it. When performing studies to determine the impact of the pit production capacity on the annual and monthly movement of the cut face relatively to pit mining front, development parameters were considered in the following ranges: pit production capacity from 0.5 to 3.0 million m^3, width of the face cut (excavation) from 20 to 60 m, the number of working months in year – 9, length of pit mining front – 1800 m.

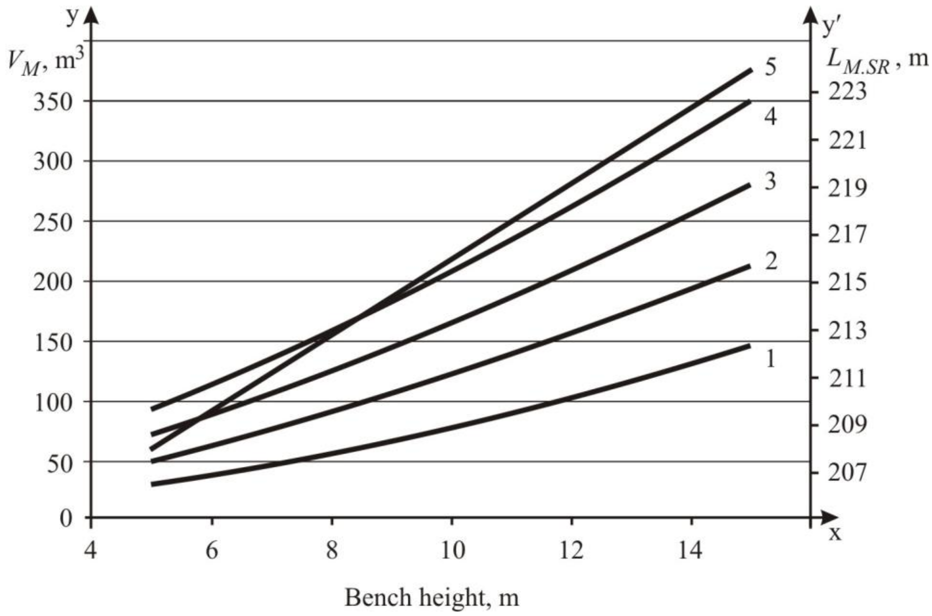


Figure 1 – The dependence of the excavation length and volume on the ore bed thickness:
1, 2, 3, 4 – face width (A_3) – 20, 40, 60, 80 m, accordingly; 5 – length of excavation

During the research, the thickness of the ore bed was assumed 10 m, which corresponds to the average value for typical titanium zirconium deposits in Ukraine. To establish the speed of face cut movement relatively to pit mining front in the hydromechanical mining method the following expression was used:

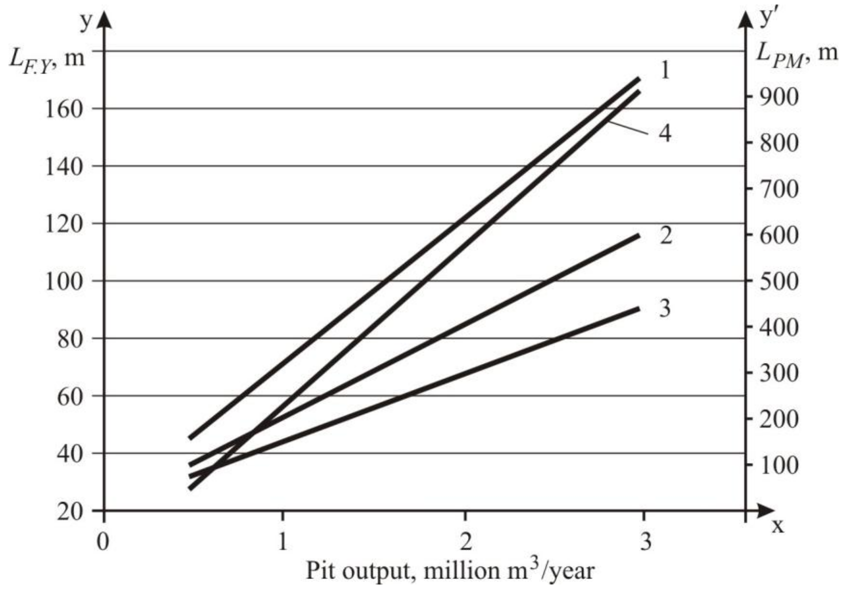
$$L_{PM} = \frac{Q_K}{h_Y \cdot \left(A_3 + 0.5 h_Y \cdot (ctg\alpha + ctg\beta)\right) \cdot N_{MM}}, \text{ m/month,} \quad (3)$$

where Q_K – is the pit production capacity, m^3; N_{MM} – the number of working months in year.

The study results at establishing the influence of the pit production capacity on the face cut movement relatively to pit mining front are shown in Figure 2. As we can see from the obtained dependences (Fig. 2) at the increase of pit productivity by 6 times from 0.5 to 3.0 million m^3, the monthly movement of the cut face increases by 13 times from 55 to 698 m, depending on the width of the mining bench face cut. The minimal monthly movement of 55 m was recorded with a pit productivity of 0.5 million m^3/year and a maximum face width 60 m, while the maximum movement is 698 m at the productivity 3.0 million m^3/year and a face cut width 20 m.

The results of conducted research are necessary for further studies to establish the dynamics of the internal sludge pond formation in the excavation for one-month period with different dump cut lengths and the method of its formation.

Previous studies have shown the feasibility of using a hydromechanized mining complex, which includes a floating processing plant for separate sand from the host ore rocks that allows further storage in the pit internal sludge pond. Since such placement has a direct impact on the pit mining efficiency it is necessary to establish the parameters of the technological scheme for the sludge pond formation.



1, 2, 3 – cut width (A_3) – 20, 40, 60 m, accordingly; 4 – pit mining front movement ($L_{F.Y}$)

Figure 2 – The dependence of the pit mining front ($L_{F.Y}$) and face cut movement (L_{PM}) relatively to pit mining front on the production capacity

The formation of the sludge pond is carried out by delivering sand pulp from the processing plant to the internal sludge pond using hydraulic haulage. The number and diameter of pipes for sludge pond forming is determined according to pit production capacity, the sand content in the ore, the pumps output for the hydraulic mixtures, the speed of rock hydraulic haulage, the pipes diameter, etc.

To determine the required number of pipelines in the sludge pond, it is proposed to transform expression for determination of pipe diameter [18]:

$$D_T = \sqrt{\frac{4 \cdot Q_{PP}}{3600 \cdot \pi \cdot V_{KP}}}\ , \text{ m}, \tag{4}$$

it follows that

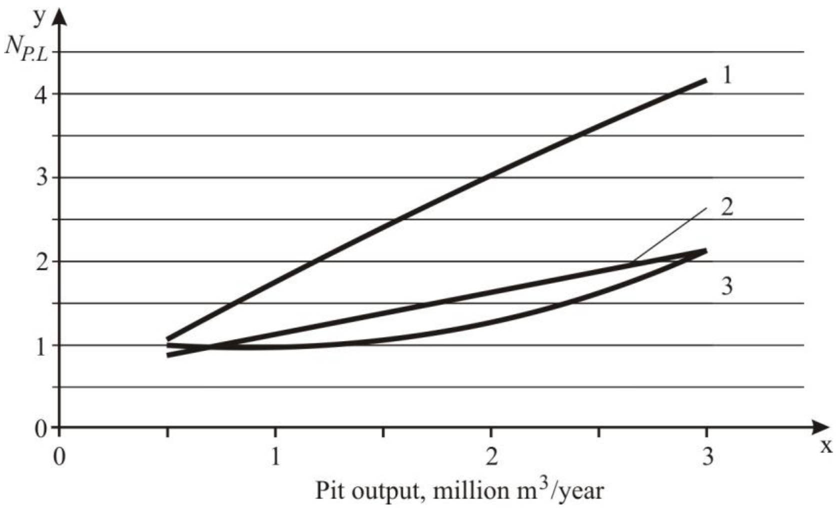
$$N_{P.L} = \sqrt{\frac{4 \cdot Q_{PP}}{3600 \cdot \pi \cdot V_{KP} \cdot D_T^2}}\ , \text{ pcs.}, \tag{5}$$

where Q_{PP} is output of processing plant by sand, m^3/h; V_{KP} is the critical speed of rock haulage depending on the pipe diameter and the rock type, m^3/s; D_T is the pipeline diameter, m [18].

The production capacity of the processing plant in previous studies was taken in the range of 0.5 – 3.0 million m^3. The average content of sandy rocks in the ore is 80 %, which corresponds to the development parameters of the Motronovsky MPP pit (Dnipropetrovsk region). Previous studies [2, 13] made it possible to establish that the output of the dredge ZMD-200-50l for sandy hydraulic mixtures is 1882 m^3/h and this value is taken in further studies.

During the research, three possible pipe diameters of 0.4, 0.5, and 0.6 m were considered, with a critical sand hydrotransport speed of 2.4, 3.0 and 3.2 m/s, respectively.

The results of studies to establish the connection between pit output and hydraulic haulage pipes diameter taking into account pipelines number are presented in Figure 3.



1, 2, 3 – pipeline diameter (D_T) – 200, 400, 600 mm, accordingly

Figure 3 – The dependence of the pipelines number for placing sand in the internal sludge pond from the production capacity of the quarry

The established dependences show (Fig. 3) that the increase of pit output 6 times from 0.5 to 3 million m^3/year leads to the increase 4 times of the required number of pipelines for sand rocks hydraulic haulage to a sludge pond, depending on the diameter of the selected pipes. The maximum number of pipelines is observed at the pit output 3.0 million m^3/year. In this case, if the diameter is increased 1.5 times from 400 to 600 mm, the required number of pipelines decreases 4 times at the pit output 2.5 million m^3. It is also determined that when the pit output is up to 2.0 million m^3, it is recommended to accept pipes for hydrotransport with a diameter of 500 mm and when the output exceed to 2.0 million m^3 – 600 mm.

The next objective of the research is to determine the dumping parameters during the formation of sludge pond in the mine flooded excavation. For this, first of all, the effective amount of haulage discharge pipes is determined at the placed sand in sludge pond.

The main factors that affect the dynamics of the cut face movement relatively to the pit front are: the pit output, the number of discharge pipes and the distance between them. Due to the significant number of initial parameters for the research, the pit output equal to 2.7 million m^3 is assumed to be constant, which corresponds to the development of Motronovsky MPP pit. In this case, the annual movement of the mining face corresponds to the indicators in Figure 2.

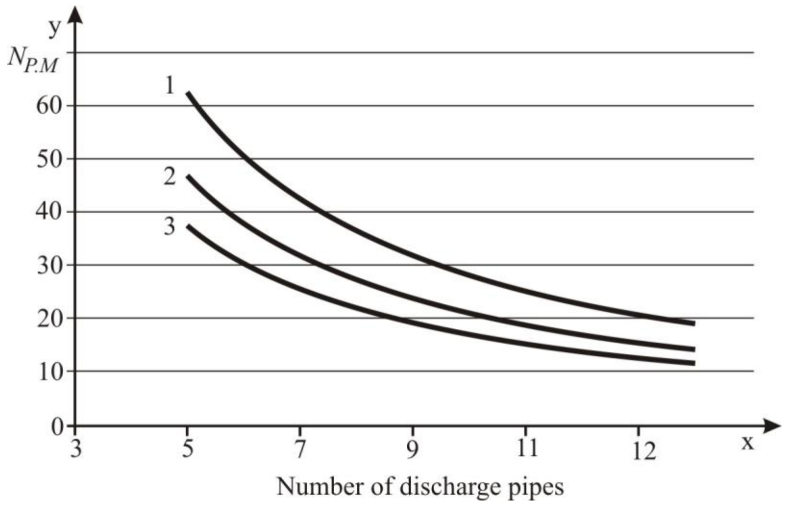
The analysis of scientific works [18] shows that in practice the distance between the discharge pipes of on the sludge pond is accepted in the range 6 – 10 m. Moreover, the number of discharge pipes can have a wide range and depends on the length of the sludge pond front. During the study, the number of discharge pipes was taken in the range from 5 to 15 and width of the sludge pond pass to be constant – 20 m. To determine the discharge pipes movement number proposed following expression:

$$N_{PM} = \left\lceil \frac{Q_K \cdot K_{I.P}}{A_{3.O} \cdot H_{Y.O} \cdot L_B \cdot N_{MM} \cdot (N_{HP} - 1)} \right\rceil, \text{pcs} \qquad (6)$$

where $K_{I.P}$ – is percentage of sand in ore formation,%; $A_{3.O}$ – is the width of the sludge pond pass, m; $H_{Y.O}$ – the height of the sludge pond bench, m; $N_{H.P}$ – is the number of discharge pipes of sand, pcs.; L_B – is the distance between discharge pipes on a sludge pond, m.

The results of studies to establish the effect of the discharge pipes number and the distance between them on the number of the sludge pond pipeline movements during the month are presented in Figure 4.

As can be seen from the research results (Fig. 4), the distance between the discharge pass has a slight effect on the number of pipeline movements, while the number of discharge pass is an important parameter. So with an increase in the number of discharge pass from 5 to 14, the number of pipeline movements will decrease from 62 to 12, depending on the distance between the discharge pass.



1, 2, 3 – distance between discharge pipes – 6, 8, 10 m, accordingly

Figure 4 – The dependence of the pipeline movement number in sludge pond on the discharge pipes number taking into account the distance between them

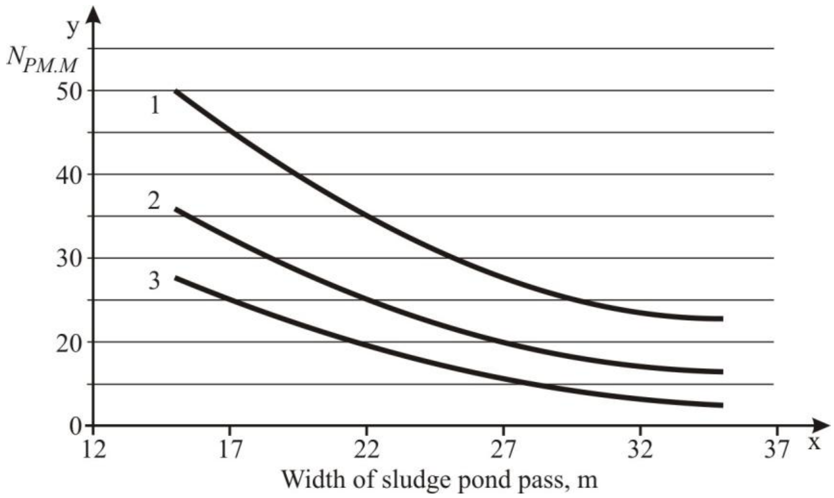
Since in the previously established dependencies the width of the discharge pipes was assumed to be constant 20 m, the question arises regarding the effectiveness of this parameter. It is necessary to establish the influence of the width between discharge pipes on the number of pipeline movements at the sludge pond, taking into account the number of discharge pass, the distance between which is accepted – 8 m. In the calculation, the values accepted earlier in expression (6) were used:

$$N_{PM.M} = \left\lceil \frac{Q_{PP} \cdot N_{DM} \cdot N_{CM} \cdot T_{CM}}{A_{3.O} \cdot H_{Y.O} \cdot L_B \cdot (N_{HP} - 1)} \right\rceil, \text{pcs.}, \quad (7)$$

where N_{DM} – is the number of working days per month; N_{CM} – is the number of shifts per day; T_{CM} – is the duration of the shift.

The research results for determining the effect of the pass width of sludge pond and the number of discharge pass on the pipeline movement frequency are presented in Figure 5.

The research results (Fig. 5) show that with the increase in the width of a sludge pond pass from 15 to 35 m, the number of pipeline movements per month will decrease from 50 to 12. It should be noted that the main decrease of the sludge pond pass number is in the range of 15 – 20 m. In the case when the width of sludge pond pass exceeds 20 m, the number of the sludge pond pipeline movements changes slightly. Therefore, the results of previous studies in which the width of the sludge pond pass was taken equal to 20 m, do not need additional adjustments.

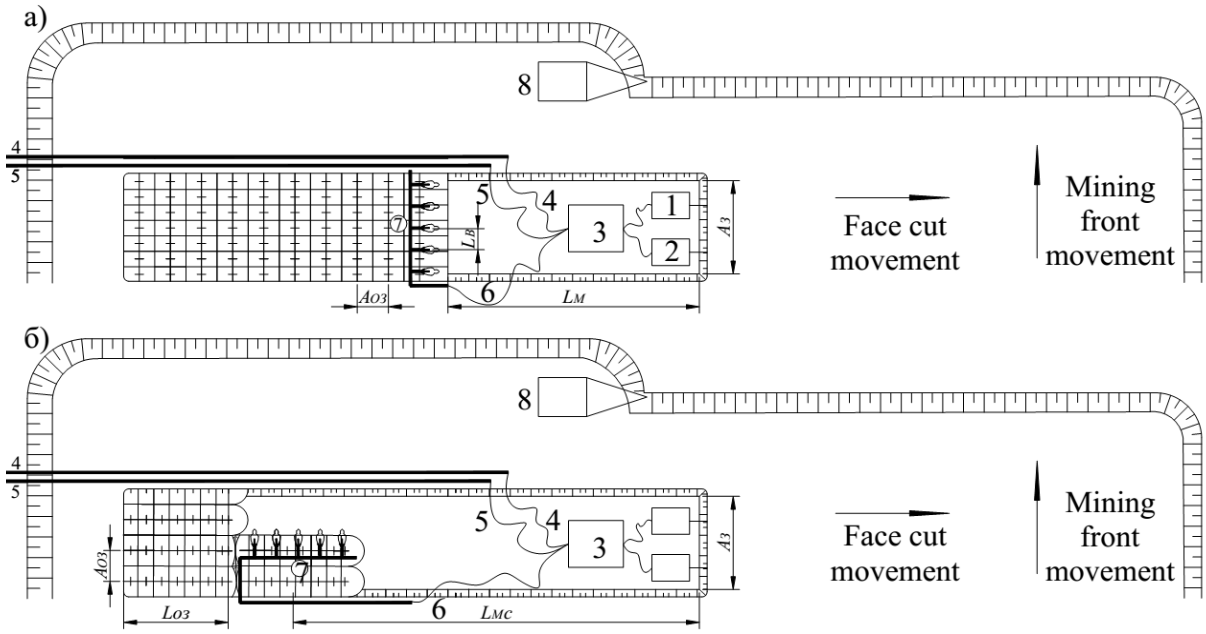


1, 2, 3 – distance between discharge pipes – 6, 8, 10 m, accordingly

Figure 5 – The influence of the sludge pond pass width on the number of pipeline movements with the discharge pipes per month

The last stage of the research is to establish the parameters of the sludge pond, which depend on the location of the pipeline position to the direction of pit front movement. During the research, two main technological schemes of the internal sludge pond formation in pit excavation were examined: transverse and longitudinal. The considered technological schemes are shown in Figure 6.

In accordance with presented schemes, studies were carried out to establish the effective pass width A_3 for schemes with transverse and longitudinal movement of the sludge pond front relatively to pit mining front. To select the width of face cut, we analyzed the indicators of the pipe movements number on the sludge pond, as well as the volume of the excavation.



a) transverse; b) longitudinal; 1, 2, 3 – are the dredges and the floating processing plant as part of a hydromechanized mining complex; 4, 5, 6 – are the pipelines with heavy minerals, clay and sand rocks, respectively; 7 – is the sludge pond pipe with discharge pipes; 8 – is the shovel excavator

Figure 6 – The scheme for determining the sludge pond parameters in pit excavation

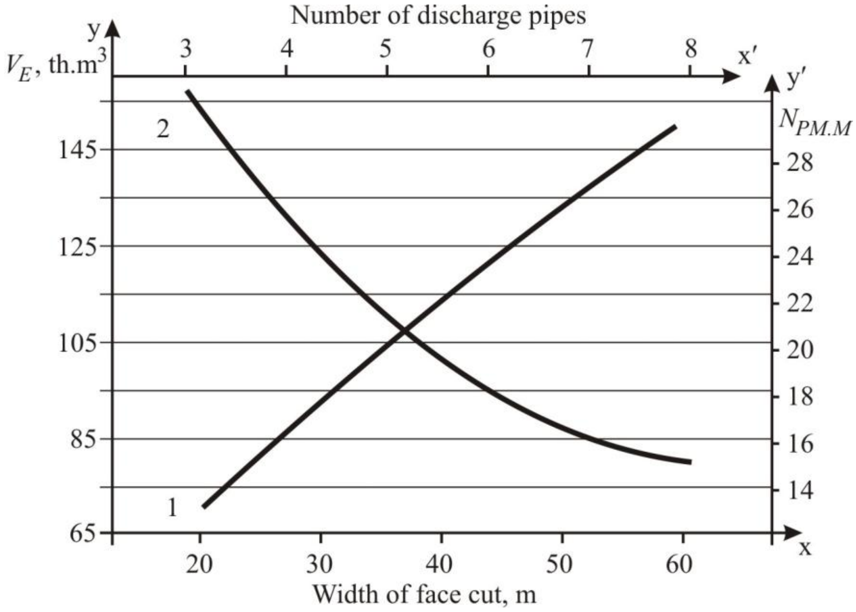
From the point of performing calculations, the simplest scheme is with the transverse movement of dumping passes, because, in this scheme, mining and dumping moves move in parallel and the number of discharge pipes on the sludge pond is proportional to the width of the excavation. When performing the calculations, the distance between the discharge pass at the sludge pond was assumed to be 8 m, according to previous studies, the pass of sludge pond pipeline was taken 20 m and the length of the excavation L_M – 200 m. To establish the effect of the width of face cut A_3 on the volume of the excavation, expression (2) is used and to determine the number of the sludge pond pipeline movements:

$$N_{PM}^{T} = \left\lceil \frac{Q_K}{h_Y \cdot \left(A_3 + 0.5 h_Y \cdot (ctg\alpha + ctg\beta)\right) \cdot N_{MM} \cdot A_{O3}} \right\rceil, \text{ pcs.,} \qquad (8)$$

where A_{O3} – is the width of the sludge pond pass, m.

Figure 7 shows the research results at the establishing dependence of the pipeline movement number with the release of slurry at the sludge pond on the width of the excavation face cut A_3.

As can be seen from the research results (Fig. 7), at the increase of face cut, the number of pipeline movements decreases while the volume of the excavation increases. During the application of this scheme, it is recommended to take the width of face cut 35 – 40 m. This allows avoiding the formation of excessive pit volume while the number of pipeline movements will be optimal.



1 – excavation volume; 2 – number of pipeline

Figure 7 – The influence of the face cut width on the excavation volume and the number of pipeline with discharge pipes movements at the transverse scheme of sludge pond formation

The last stage of the research is to establish the effective width of face cut at the longitudinal movement of the sludge pond passes (Fig. 6 b). The difference between this scheme and the scheme with transverse sludge pond formation is that the length of the sludge pond section of the pipeline with the discharge pipes does not depend on the width of the face cut A_3. This is because it does not affect the excavation length, so the length of the dumping L_{O3} may exceed it. However, as shown in previous studies (Fig. 4), an increase in the number of discharge pipes over 8 does not lead to an improvement in the technological parameters of the technological chart, while it leads to an increase in the excavation volume, therefore, we can operate this value.

To establish the effect of the face cut width on the excavation volume and the required number of sludge pond pipeline movements in month period, the following expressions is used:

$$V_M = h_Y \cdot \left(L_{MC} + 0.5L_B \cdot N_{HP}\right) \cdot \left(A_3 + 0.5h_Y(ctg\alpha + ctg\beta)\right), \text{ m} \quad (9)$$

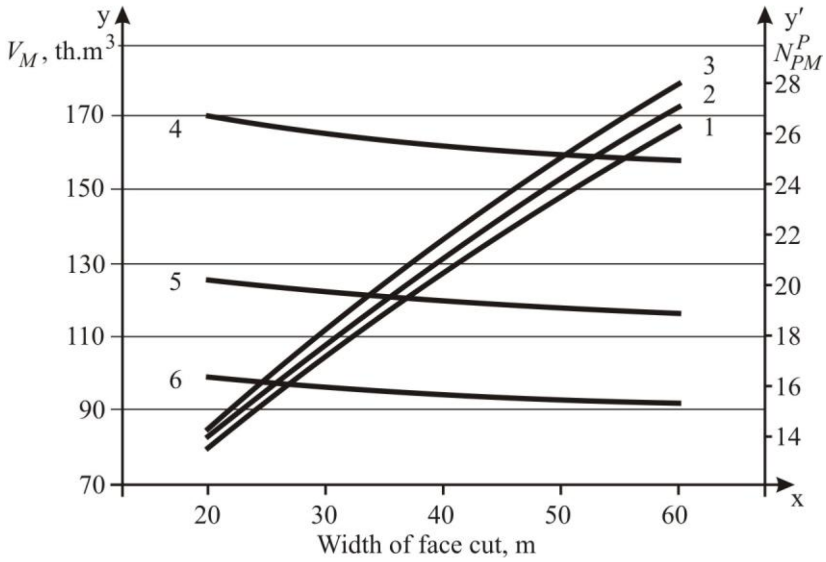
$$N_{PM}^{P} = \frac{\left(A_3 + A_{O3}\right) \cdot Q_K}{A_{O3} \cdot L_B \cdot N_{HP} \cdot h_Y \cdot \left(A_3 + 0.5h_Y \cdot (ctg\alpha + ctg\beta)\right) \cdot N_{MM}}, \text{ pcs} \quad (10)$$

where L_{MC} – is the average length of the flooded excavation, m.

While establishing the influence of the face cut width on the excavation volume and the number of pipeline movements, the following initial data were taken: the face cut width from 20 to 60 m; ore bench height – 10 m; the sludge pond pass width - 10 m; excavation length – 200 m; the distance between the discharge pipes in sludge pond – 8 m; the number of discharge pipes in sludge pond – 6, 8, 10. The results of the studies are shown in Figure 8.

As we can see from the graphs in Figure 8 with a longitudinal movement of sludge pound passes (Fig. 6 b) with an increase of face cut width 3 times from 20 to 60 m, the volume of the excavation increases 2.3 times from 75,000 to 175,000 m^3. At the same time, the number of movements of the pipeline with discharge pipes on sludge pond decreased by 10 %, provided that the number of discharge pipes is constant. With an increase in the discharge pipes number from 6 to 10 the number of sludge pond pipeline movement per month will decrease by 1.7 times from 25 to 15 at the face cut width – 60 m.

The established dependences (Fig. 8) allow to conclude that in the case of the parallel formation of the internal sludge pond, the face cut width of 25 m is most effective with 10 discharge pass of the slurry on the sludge pond. It allows to achieve the minimum number of the sludge pond pipeline movements per month – 17 times. With 8 discharge pass, the face cut width should be 36 m and the number of pipeline movements in month should be 19.



1, 2, 3 – volume of excavation at the number of discharge pipes – 6, 8, 10, accordingly; 4, 5, 6 – the number of discharge pipes movements in sludge pond at its number – 6, 8, 10, accordingly

Figure 8 – The influence of the face cut width on average volume of excavation and the number of sludge pond pipeline movements taking into account the number of discharge pipes

Conclusions. It has been established that at the increase of ore bench thickness from 5 to 15 m, the volume of the flooded excavation increases from 29 000 to 348 000 m^3 depending on its width, while the maximum volume of the excavation is observed with an increase in the capacity of the ore bench for any face cut width.

It was established that with an increase in the number of slurry discharge pipes at the sludge pond from 5 to 14 at the face cut width 20 m, the number of pipeline movements will decrease from 62 to 12, depending on the distance between the discharge pipes. Therefore, it is recommended that no less than 8 discharge pipes be accepted at the sludge pond while the distance between them from 6 to 10 m, depending on the existing width of the excavation.

Determining the face cut width of the ore bench in the transverse and longitudinal scheme of the sludge pond formation allowed to establish that for the first scheme, the most effective face cut width is 35 – 37 m, and for the second scheme – 25 – 36 m according to the ratio of the excavation volume and the number of the sludge pond pipeline movements.

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