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Controlling close boundary of a technogenic placer through changes in technological parameters of washery refuse storage

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Abstract

Purpose is to assess the potential to control boundaries of a technogenic placer through changes in the parameters of washery refuse storage process taking into consideration both size and density of particles of each fraction of the granulometric composition.

Methods. The research has applied approaches developed by V.A. Melentiev and M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine relying upon the condition of a critical flow origination. Problems to control close boundary of a technogenic placer have been considered in the process of hydraulic washery refuse storing in artificial tailing ponds at the expense of changes in technological factors involving characteristics of dry fraction particles of the hydraulic fluid.

Findings. Limitations have been obtained in the form of intervals of changes in technological influence coefficient values; relative velocity of a hydraulic liquid delivery; relative beach slope; and concentration of the hydraulic liquid flowing to the storage. It has been demonstrated that average beach slope is limited by the particle friction coefficient of the fraction on the beach surface; the abovementioned makes it possible to vary the inwash parameter value from 1.56 to 0.22. It has been identified that in the context of the calculations performed using engineering precision dependence of the inwash parameter upon the coefficient number in Pavlovskyi formula may be ignored since relative error of average value of the parameter use is not more than 1%; hence, its average value depending upon a relative beach slope can be approximated by a decreasing linear function.

Originality. For the first time, formulas have been proposed to identify the boundaries of intervals of changes in a set of technological parameters of storing process depending upon the required value of a close boundary of the technogenic placer. The abovementioned helps assess both concentration and velocity of hydraulic liquid getting to the inwash beaches; the beach slope; and particle parameters of solid fraction of the stored washery refuse providing the wanted distance from inner slope of a flood wall to a close boundary of the technogenic placer.

Practical implications. Using the research findings, it becomes possible to control geometry of technogenic placers formed in artificial washery refuse dams in the process of its hydraulic storing. Moreover, it helps avoid location of a flood wall of following levels above technogenic placers of lower inwash formations; construct covering between technogenic placers at two neighbouring levels; achieve separation of the technogenic placer from the fractions containing no valuable components while arranging them within different beach areas, and move closer to selective mining of useful mineral.

Keywords: *beach, inwash, critical flow, hydraulic size, friction coefficient, technogenic placer*

1. Introduction

The opportunity to mine technogenic placers formed in the artificial washery refuse dams is the global tendency. It is based upon following prerequisites [1]-[3]: an inwash beach formation makes it possible to separate certain share of valuable components being accumulated in the dike zone improving the efficiency as for merchant concentrates; and mining of technogenic placers makes space for new waste extending the life of the available storage facilities. Since the early 20th century, many domestic and world specialists have been engaged in the problem of technogenic placer mining; in the development of potential procedures for their extraction; and in the substantiation of the parameters of relevant surface mining operations [4]-[8].

For example, results of technical and economic assessment as for potential mining of critical raw materials (i.e. rare-earth metals, vanadium, and antimony) from washery refuse performed for Chilean storages show investment riskiness if the available techniques are applied [9]. Studies described in [10] define engineering as the key factor of successful valuable component mining from washery refuse storages which use helps restrict and avoid technogenic environmental impact. Publication [11] concerns vanadium extraction from washery refuse; it proposes a procedure of

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vanadium alkaline leaching under pressure; analyzes raw materials; examines influence by temperature, sodium hydroxide concentration, time of response, liquid-solid ratio, and mixing rate per leach rate of vanadium, chrome and silicium in the refuse. Authors of paper [12] who have produced eco-friendly cement mortar through partial sand substitution for graphite waste activated during its utilization, demonstrate potentials of utilization of graphite by-products. It has been defined that in such a way the recovered graphite waste better the mortar strength owing to the improved distribution of particle sizes; and the decreased "microzone flow" as well as "boundary effects". Admixture of iron-ore washery refuse in concrete is the key approach to sustainable development of Chinese industry [13]. It is pointed out that low pozzolanic activity of such admixtures needs their activation owing to which it is possible to achieve satisfactory produceability; mechanical characteristics; and longevity of concrete. Paper [14] has analyzed influence of waste rock inclusions in the bulk of washery refuse on safety coefficient of slopes. Results show minimal effect of waste rock impurities on the stability for one to two years; in the following, they provided less than 5% of increase in safety factors. Paper [15] has considered practices of fine low-grade iron ore processing from mines; waste from iron ore washing houses; and solid waste of iron manufacturers in Ballary, Karnatka District (India). It has been shown that low-grade ore waste dumps and amount of the plant refuse may be decreased down to 25 and 50%, respectively, reducing the costs for waste management and generating the profitable concentrates. There is an opportunity to manufacture brick from a tunnel-like furnace using clay waste from iron ore mines or waste storages as well as solid waste of iron making plants. Paper [16] proposes a new classification of different waste types resulting from iron ore mining; rational waste management methods have been proposed. The necessity to separate and sort waste according to its nature is mentioned to provide environmental safety and further reuse as a construction material.

Paper [17] considers prospects for application of the "condensed waste recycling". It is pointed out that waste storage in the form of highly concentrated hydraulic fluid makes it possible to increase water extraction from refuse; decrease the involved areas; reduce the risk of physical instability; avoid construction of high dams; and minimize infiltration from storages. Nevertheless, the paper does not consider difficulties connected with the development of washery refuse from technogenic deposits. Attempts were made to analyze numerically sedimentation of solid particles differing in their size in the non-Newtonian hydraulic fluid inside semiround open channel helping simulate a process of waste refuse storage within an inside slope of a waste dam [18]. Such an approach helped authors study influence of particle size as well as water channel slope on the process of particle sedimentation inside the water channel. Works are known as for the condensed watery refuse temperature impact on a liquid limit and some other parameters influencing both storing process and further development [19].

It is clear from the above review that all the available procedures of waste management and disposal face the problem of its recovery. The majority of expert ideas is reduced to the necessity to sort the waste. We believe the process should take place at the storing stage while controlling boundaries of the technogenic placer taking into consideration particle size of each fraction of granulometric composition.

Results of the studies demonstrate difficulties in the mining of technogenic deposits since flood walls of following levels are placed above technogenic placers of lower inwash levels [20] (Fig. 1); moreover, technogenic placers at two neighbouring levels are spaced apart (Fig. 2) [20] Obviously, from the viewpoint of mining it will be more convenient not to arrange flood walls of following levels above technogenic placers of lower inwash levels (Fig. 2). The most efficient way is when technogenic placers at two neighbouring levels cover each other (Fig. 3) [20]. In addition, under the current techniques (when classification process is not available), valuable material components are distributed over significant beach share (Fig. 4). The fact also stipulates large mining amount, and retards implementation of accompanying extraction of technogenic placers.

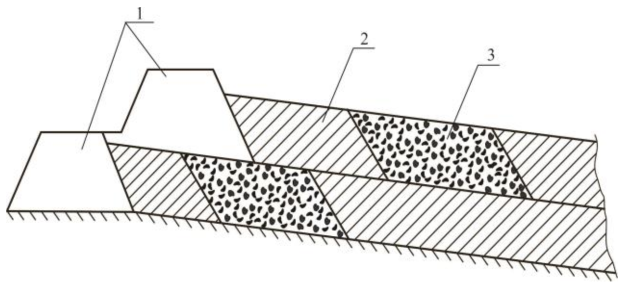

Figure 1. ***The most complicated option of technogenic placer occurrence from the viewpoint of its mining [20]: 1 – flood wall; 2 – waste rock; and (3) – technogenic placer***

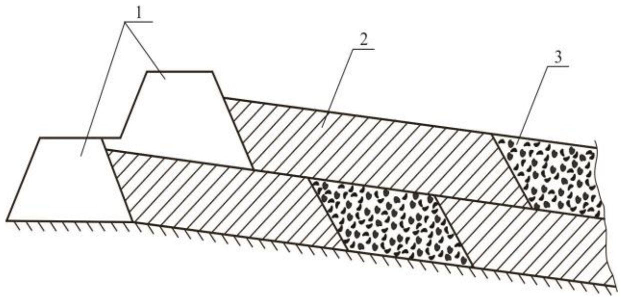

Figure 2. ***Medium-complexity option of technogenic placer occurrence from the viewpoint of its mining [20]: 1 – flood wall; 2 – waste rock; 3 – technogenic placer***

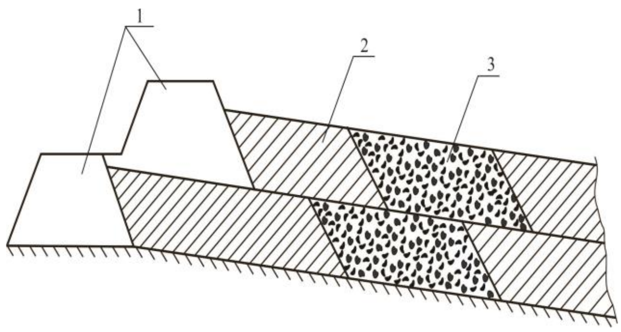

Figure 4. ***The most appropriate option of technogenic placer occurrence from the viewpoint of its mining [20]: 1 – flood wall; 2 – waste rock; and (3) – technogenic placer***

Traditional techniques for the classification process calculation (among other things, the most popular method by V.A. Melentiev) help define only distant boundary of a technogenic placer (L_{II}) so-called center of particle dispersion; nevertheless, they ignore difference in density of particles belonging to different size fractions.

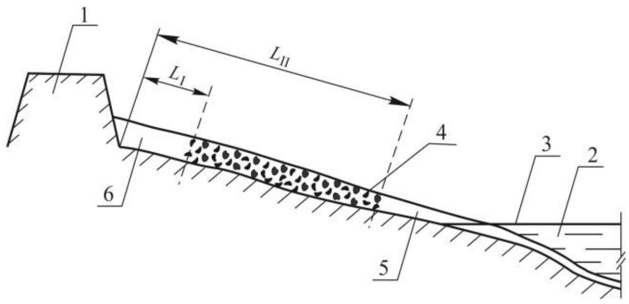

Figure 4.** **Technogenic placer boundaries within an inwash beach: 1 – flood wall; 2 – clarification pond; 3 – free surface; 4 – technogenic placer; 5 – near-pond beach share; 6 – near-dam beach share; L_I – beach length up to a point when solid particles achieve their critical velocity, m; L_{II} – beach length up to the center where solid parts experience their dispersion, m

A technique by IGM of NAS of Ukraine is also known; it relies upon the definition of a point where critical velocity is achieved. The technique considers change in velocity of a gravity flow along the beach, and compares the value with a critical point. The condition helps identify upper boundary of a technogenic placer (L_I). However, the procedure does not consider the opportunity to control the upper boundary position. The known methods to calculate parameters of classification identification were developed to define distribution of solid particle size along a beach length. The possibility to control the process was not considered. The matter is that when the waste storages were put into operation, nobody had the idea to mine technogenic placers, which would be formed inside them. Currently, life cycle of the majority of the storages is almost over and certain part of them operates with floodwalls which height exceeds design values. Hence, the opportunity to control the classification process parameters becomes more and more topical since it opens new possibilities.

In such a way, a technique is known to extend an operation period of artificial storages of washery refuse of minerals involving accompanying mining of technogenic placers [20] L_I value defining the possibility of mining equipment arrangement within the upper share of a flood wall or at its foot (Fig. 4) and L_{II} value characterizing risk of a technogenic placer waterlogging from a clarification pond are critically important for the technology. The difference between the two values defines placer excavation scope as well as storage capacity of the additional washery refuse.

Ultimately, control of a classification process is the possibility to separate technogenic placer from fractions containing no valuable components while placing them within different beach areas and move closer to selective mining of useful technogenic mineral.

Consequently, the research purpose is assessment of the possibility to control technogenic placer boundaries through the changes in parameters of washery refuse storage taking into consideration both size and density of each of granulometric composition fraction.

2. Methods

Based upon the recommendations listed in methods by V.A. Melentiev and M.S. Poliakov Institute of Geotechnical Mechanics of NAS of Ukraine, coordinates of distant and close boundaries of technogenic placer along a beach length (Fig. 4) can be identified using the Formulas [20]-[23].

$$x_0 = \left[\sum_{j=1}^{N-1} \Phi_{0j} + \frac{1}{2}\Phi_{0N}\right]^{\frac{3}{5}};\quad x_I = \frac{1}{\sqrt[5]{C^3}}\, e^{-0.627\frac{C_w}{\sqrt[5]{C^2}}}; \tag{1}$$

$$x_0 = \frac{L_{II}}{L};\quad x_I = \frac{L_I}{L};\quad C_w = \left(\frac{K}{v}\right)^{\frac{3+2m}{1+2m}}; \tag{2}$$

$$K = \sqrt[3+2m]{\frac{(1-\sigma)^{1.5+m}}{\sigma}};\quad v = \frac{u_0}{w_\mu}; \tag{3}$$

$$u_0 = \sqrt[3+2m]{\frac{q_0^{1+2m}}{n^2}};\quad w_\mu = w\mu^{\frac{0.5+m}{3+2m}};\quad \sigma = \frac{I}{\mu}, \tag{4}$$

where:

x_0 – relative coordinate of center of dispersion of j^{th} fraction;

x_I – relative coordinate of a point where j^{th} fraction particles achieve their critical velocity;

Φ_{0j} – weight part of j^{th} fraction in granulometric composition of a solid phase, unit fractions;

N – number of fractions in granulometric composition of a solid phase;

L – beach length, m;

L_I – beach length to the point where j^{th} fraction particles achieve their critical velocity; m;

L_{II} – beach length to a dispersion center of j^{th} fraction particles, m;

C_w – technological influence coefficient;

C – volume concentration of hydraulic fluid delivered to a beach from a pipe, unit fractions;

K – inwash parameter;

v – relative velocity of hydraulic fluid delivery;

w_μ – efficient hydraulic size of j^{th} fraction particles, m/s;

u_0 – conventional velocity of hydraulic fluid delivery, m/s;

q_0 – hydraulic fluid consumption dispersed along a beach length, m^2/s;

σ – relative beach slope, $\sigma < 1$;

w – hydraulic size of j^{th} fraction particles, m/s;

μ – generalized friction coefficient of j^{th} fraction particles;

m and n – coefficients in Pavlovskyi formula;

I – average beach slope.

The technological influence coefficient used to define x_I value takes into consideration influence of the basic technological factors on a distance from internal slope of a floodwall to a close boundary of technogenic placer, i.e. a rate of hydraulic fluid delivery; a beach slope; and characteristics of solid phase particles. However, technological influence coefficient ignores the distance dependence upon the volume concentration of the hydraulic fluid delivered through a pipe to an inwash beach since its value is a component of an exponent as well as a coefficient before it. Relying upon analysis of the formula for x_I value (Expression two in (1)), it becomes possible to identify following factors helping regulate distance from the internal slope of a floodwall to a close boundary of technogenic placer, and optimize parameters of future surface mining operations: hydraulic liquid consumption distributed along a beach length; average beach slope; and volume concentration of the hydraulic fluid delivered to an inwash beach.

The hydraulic fluid consumption distributed along a beach length may vary quite widely. The parameter value is determined primarily through volume consumption of washery refuse, which should be removed from the preparation plant and stored. The parameter value can be controlled varying the number of depositing sites as well as using a procedure of a hydraulic fluid condensation [17], [24] or separate storing [20].

Average beach slope is limited by friction coefficient of the considered fraction particles on the beach surface. Research data on free-flow hydraulic fluid streams in channels show that the hydraulic slope and therefore flow velocity in such streams is identified by means of difference in a coefficient of solid fraction particle friction on the stream bed and geodetic slope of the channel [25]-[27]. Numerous recommendations and reference data are available to define friction coefficient under such conditions [28]. However, there are no recommendations concerning free flow along the beach if solid particle friction takes place not on the pipe wall but on similar particles or particles differing in their characteristics. For such conditions, several researchers propose apply coefficient of internal friction of granular material instead of a sliding friction coefficient [29], [30].

In the context of the domestic MPCWs, the value of volume concentration of hydraulic fluid delivered to an inwash beach is not regulated; it is defined through ratio between amount of solid and liquid waste delivered from a process cycle. The only way to control the parameter is through the use of hydraulic fluid condensation (as in the case of its consumption) [24] or separate storage [20]. Nevertheless, storage of washery refuse through a beach inwash is possible only for hydraulic fluids having no pseudoplastic characteristics which restricts their volume concentration from above [17], [20], [24].

Coordinate of particle dissipation center limits a point of critical velocity achievement from above (Fig. 4) (the possibility to control the boundary has not been studied). Consequently, while varying technological factors within the considered theories, it is possible to increase or decrease only lower boundary of a technogenic placer

$$x_P \le x_I \le x_0 ; \tag{5}$$

$$x_P = \frac{L_P}{L} ,$$

where:

x_p – relative coordinate of the required point of a critical velocity achievement for j^{th} fraction particles;

L_I – beach length up to the required point of a critical velocity achievement for j^{th} fraction particles, m.

In such a way, at the expense of control over a point of a critical point achievement it is possible on the one hand to exclude floodwall of following levels above technogenic placers of lower inwash levels (Fig. 1). On the other hand, it helps provide a situation when technogenic placers at two neighbouring placers cover each other (Fig. 3).

Technological influence coefficient is limited by values of relative coordinates of technogenic placer boundaries as well as by a hydraulic fluid concentration. The idea is supported by simultaneous consideration of (5), (2), and (1) Formulas. After suitable transformations, the abovementioned results in such a two-sided inequality:

$$S_0 \le \left(\frac{K}{v}\right)^{\frac{3+2m}{1+2m}} \le S_p ; \tag{6}$$

$$S_0 = 1.6\sqrt[5]{C^2}\,\ln\left(\frac{1}{x_0\sqrt[5]{C^3}}\right);$$

$$S_p = 1.6\sqrt[5]{C^2}\,\ln\left(\frac{1}{x_P\sqrt[5]{C^3}}\right),$$

where:

S_0 – the minimum of the technological influence coefficient defined through a dispersion center coordinate;

S_P – the maximum of the technological influence coefficient stipulated by a coordinate of critical velocity achievement point.

If inwash parameter value remains constant then it is easy to transform the two-sided inequality (6) into limitations for relative velocity of a hydraulic fluid delivery:

$$V_p \le v \le V_0 ; \tag{7}$$

$$V_p = \frac{K}{S_p^{0.684}} ; \text{ and } V_0 = \frac{K}{S_o^{0.684}} ,$$

where:

V_p – the minimum of relative velocity of a hydraulic fluid delivery stipulated by a coordinate of critical velocity achievement point;

V_0 – the maximum of relative velocity of a hydraulic fluid delivery defined by a dispersion center coordinate.

The both inequalities of system (7) are uniform, and nonlinear; they can be solved only numerically.

If the control is performed under the constant value of relative velocity of hydraulic fluid delivery at the expense of change in the inwash parameter then (6) inequalities transform into following limitations of the value:

$$vS_0^{\frac{1+2m}{3+2m}} \le K \le vS_p^{\frac{1+2m}{3+2m}} .$$

While substituting expression one from (3) in them and performing relevant transformations, we obtain following system of inequalities restricting the value of relative beach slope:

$$(1-\sigma)^{1.5+m} - A_p\sigma \le 0 ;\ (1-\sigma)^{1.5+m} - A_0\sigma \ge 0 ; \tag{8}$$

$$A_p = S_p^{1+2m} v^{3+2m} ; \text{ and } A_0 = S_0^{1+2m} v^{3+2m} .$$

The both inequalities of (8) system are uniform and nonlinear tangibly. It follows from system (8) equations that they can be reduced to equations helping derive analytical solution in the two cases: if m is equal to 0 and if m is equal to 0.5. In the first instance, equations of (8) system amount to incomplete cubic equations relative to a square root of relative beach slope; they can be solved with the help of Cardano formulas. In the latter case, system (8) equations are the second-degree equations; they can be solved using the known formulas. However, earlier calculations show 0.009-0.212 variations in m value; i.e. neither of the both considered cases can be implemented. Thus, system (8) equations can be solved only numerically.

If control of upper boundary of the technogenic placer is performed at the expense of change in a hydraulic fluid concentration then the two-sided inequality (6) transforms into the system of two inequalities:

$$1.6\sqrt[5]{C^2}\,\ln\left(\frac{1}{x_P\sqrt[5]{C^3}}\right) \ge \left(\frac{K}{v}\right)^{\frac{3+2m}{1+2m}} ; \text{ and}$$

$$1.6\sqrt[5]{C^2}\ln\left(\frac{1}{x_0\sqrt[5]{C^3}}\right)\le\left(\frac{K}{v}\right)^{\frac{3+2m}{1+2m}}.$$

using transformation of a variable, they amount to a numerical solution of one non-linear equation with different coefficient values:

$$\ln(z)-B_p z^2\ge 0;\ \ln(z')-B_0 z'^2\le 0; \qquad (9)$$

$$z=\frac{1}{\sqrt[3]{x_p}\sqrt[5]{C}};\quad B_p=\frac{\sqrt[3]{x_p^2}}{4.8}\left(\frac{K}{v}\right)^{\frac{3+2m}{1+2m}};$$

$$z'=\frac{1}{\sqrt[3]{x_0}\sqrt[5]{C}};\text{ and } B_0=\frac{\sqrt[3]{x_0^2}}{4.8}\left(\frac{K}{v}\right)^{\frac{3+2m}{1+2m}},$$

where:

z – reverse efficient relative coordinate of the required point for critical velocity achievement;

z' – reverse efficient relative coordinate of particle dispersion center;

B_p – coefficient involving value of the required point for critical velocity achievement;

B_0 – coefficient involving coordinate of particle dispersion center.

Analysis of system (9) equations shows that use of numerical algorithms will be the most appropriate technique to solve them. Since values in the denominator of the used variables are much less than unity then it is impossible to decompose natural logarithms in the equations into the exponential series. In this regard, the variable substitution for inverse values makes it possible to apply such decomposition. However, such formulas resulting from transformation will be cumbersome; in addition, the final equation will be at least quartic. The approach not only prevents from analytical solution obtaining; it also adds extra roots since initial equations have two roots as minimum as it is seen from their type.

3. Results and discussion

The abovementioned formulas were used to perform calculations within characteristic intervals of changes in values being their part. Preliminary calculations demonstrate weak dependence of inwash parameter value upon coefficient value m in Pavlovskyi formula; while using the averaged value, relative error is not more than 1%. In this regard, a beach slope cannot exceed μ coefficient value; hence, taking into consideration the last Formula from (4) $\sigma < 1$. With this in mind, the first of (3) formulas was taken as a basis to analyze dependence of the inwash parameter generalized in terms of m coefficient value upon relative beach slope (Fig. 5). Results numerical processing of the dependence (Fig. 5) denote the possibility of its approximation with $R^2 = 0.9956$ accuracy being sufficient for engineering analysis, and linear decreasing function being $K = 1.38\text{-}1.18\sigma$.

It follows from Figure 5 that control of relative beach slope makes it possible to vary inwash parameter value from 1.56 to 0.22 (Fig. 5). Analysis of the two-sided inequalities (6)-(8) should take into consideration that both minimum and maximum of technological influence coefficient depend equally on a relative coordinate of the technogenic placer coordinate as well as on a hydraulic fluid concentration (Fig. 6).

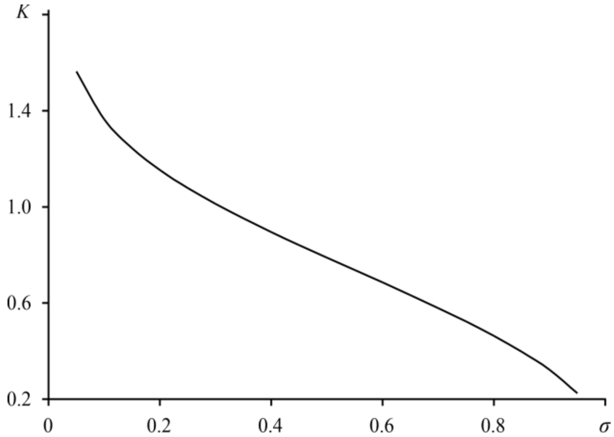

Figure 5. Dependence of the inwash parameter generalized in terms of m coefficient upon the relative beach slope

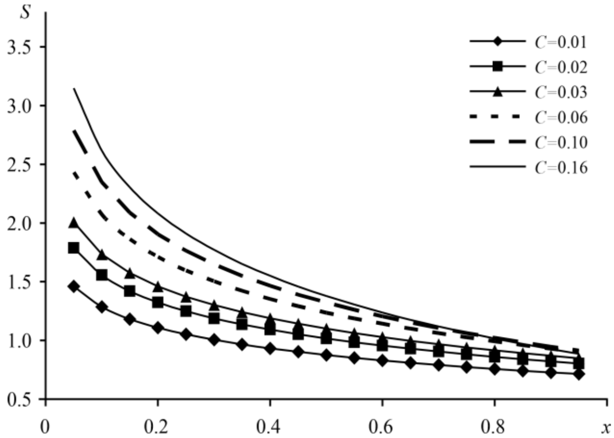

Figure 6. Dependence of the boundary value of a technological influence coefficient upon the relative coordinate of technogenic placer boundary under the varying hydraulic fluid concentration

The abovementioned has been taken into consideration while analyzing dependence of boundary value of relative velocity of hydraulic fluid delivery on the relative coordinate of technogenic placer boundary under the varying hydraulic fluid concentration for several values of the relative beach slope (Fig. 7).

Numerical analysis of the solution of system (8) equations shows that dependence of restrictions applied for a value of relative beach slope (from the minimum and maximum of technological coefficient) with an accuracy being sufficient for engineering calculations, i.e. $R^2 = 0.998$), may be approximated through a logarithmic function. Hence, it is possible to propose following inequalities:

$$\sigma_0-b(3+2m)\ln(S_0)\le\sigma\le\sigma_0-b(3+2m)\ln(S_p); \qquad (10)$$

$$\sigma_0=1+b(3+2m)\ln(v)+a,$$

where:

σ_0 – relative beach value not depending upon the technogenic placer boundaries;

a and b – approximation coefficients ($a = 0.5599$; and $b = 0.3453$).

While averaging the coefficients of (10) inequalities in terms of m coefficient value then we obtain (Fig. 8).

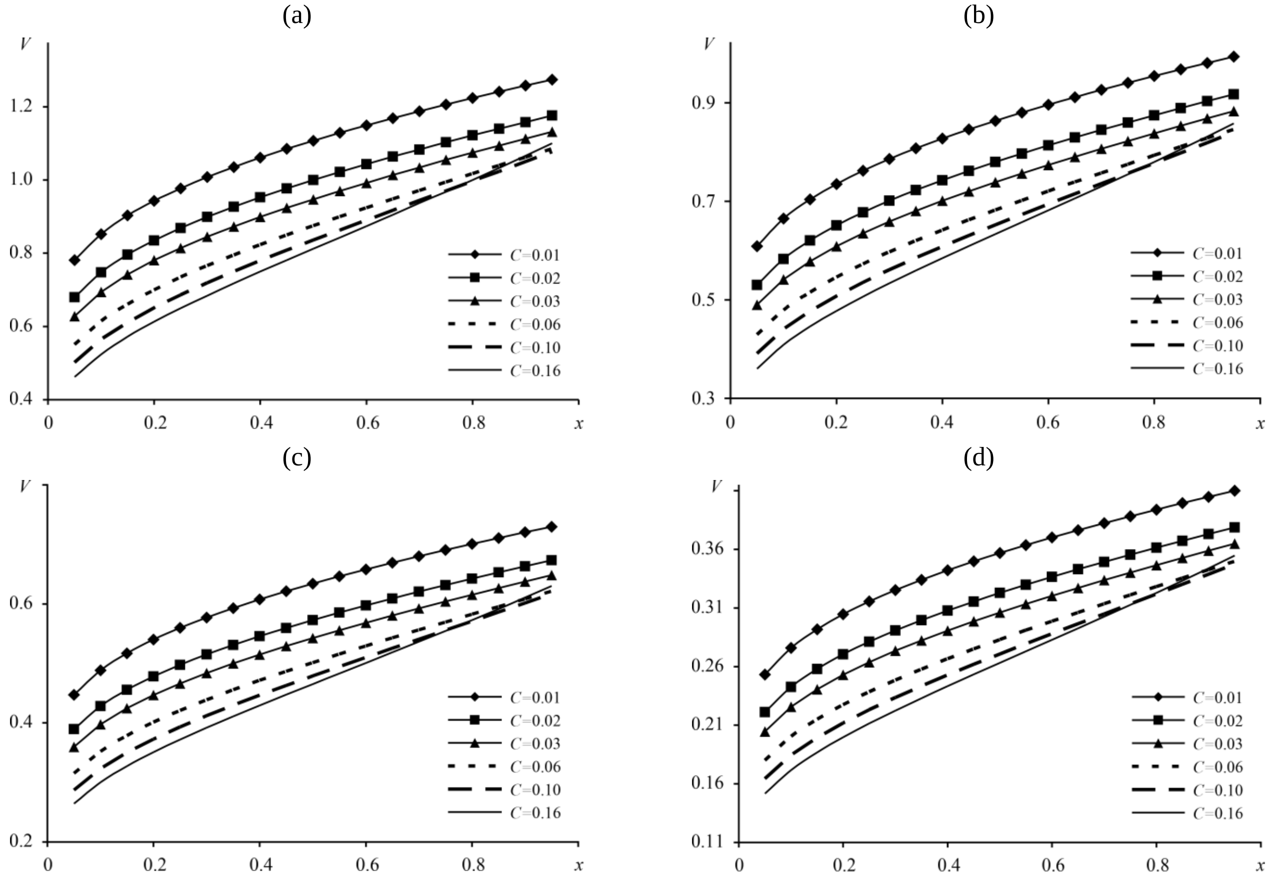

Figure 7. Dependence of the boundary value of relative velocity of hydraulic fluid delivery upon the relative coordinate of a technogenic placer coordinate under the varying hydraulic fluid concentration (C) for relative slope: (a) is σ = 0.3; (b) is σ = 0.5; (c) is σ = 0.7; (d) is σ = 0.9

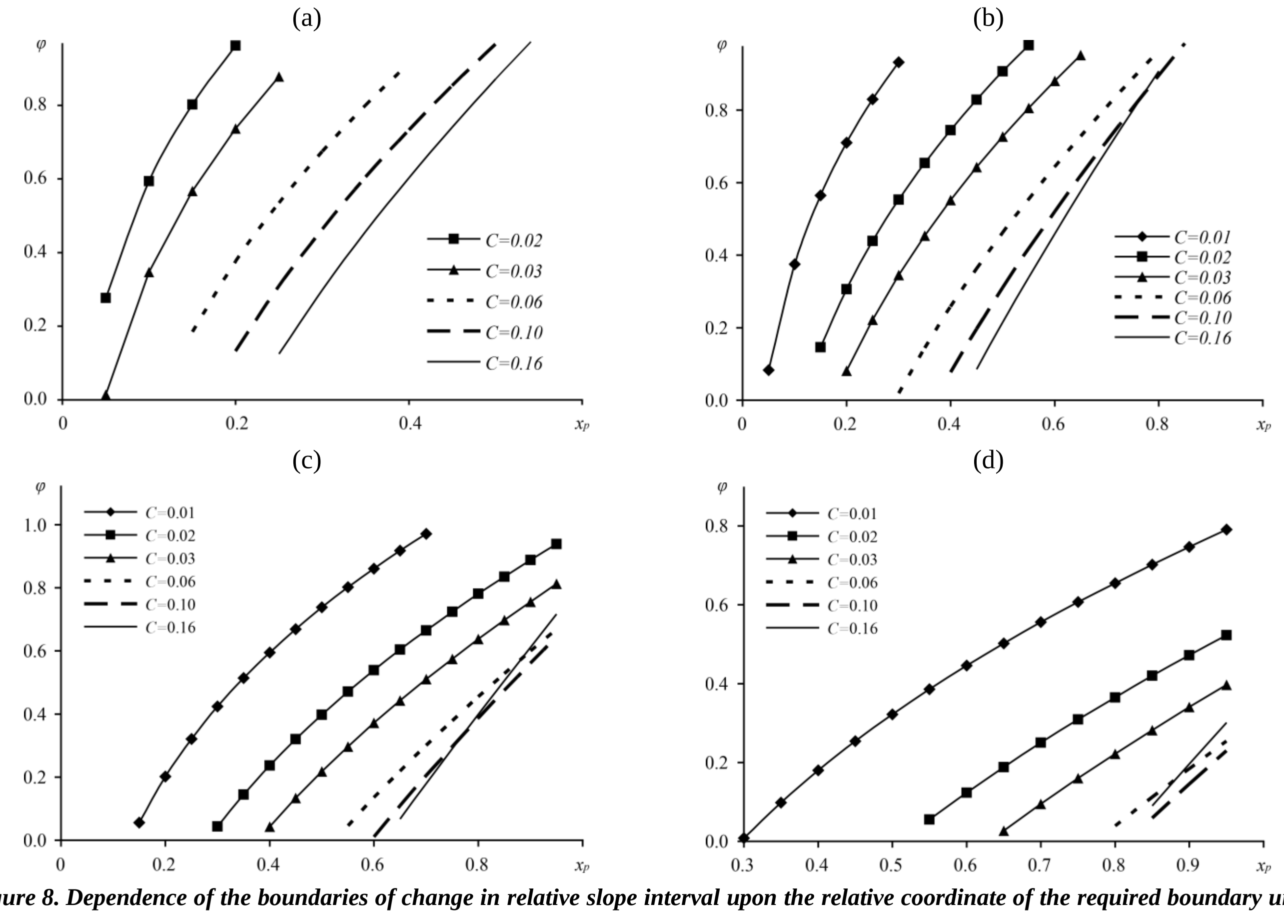

Figure 8. Dependence of the boundaries of change in relative slope interval upon the relative coordinate of the required boundary under varying hydraulic fluid concentration for (a) being ν = 0.6; (b) being ν = 0;8; (c) being ν = 1.0; (d) being ν = 1.2

$\varphi_0 \le \sigma \le \varphi_p$;

$$\varphi_0 = \ln\left(\frac{0.57}{\left(vS_0\right)^{2.28}}\right);\text{and } \varphi_p = \ln\left(\frac{0.57}{\left(vS_p\right)^{2.28}}\right),$$

where:

φ_0 – lower boundary of interval of change in a relative beach slope (Fig. 8);

φ_p is upper boundary of interval of change in a relative beach slope (Fig. 8).

Results of the calculations performed for numerical solution of system (8) equations show that their roots depend weakly upon *m* value, a coefficient from Pavlovskyi formula (Fig. 9).

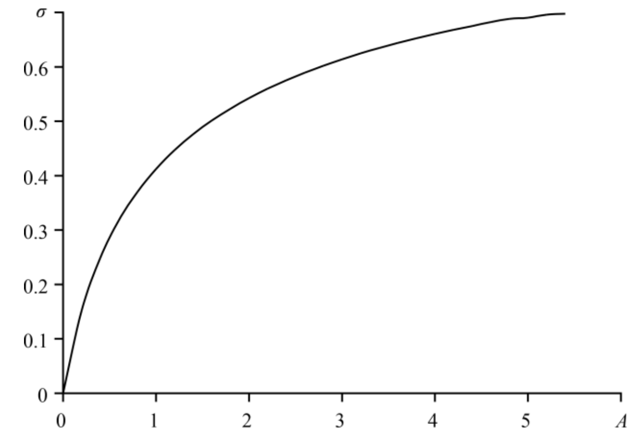

Figure 9. Dependence of a root of system (8) equation generalized in terms of m coefficient

Equation which corresponds to (9) inequalities has two roots separated by an abscissa of extreme point $z_* = \frac{1}{\sqrt{2B}}$, and exists on a real axis during implementation of following restriction on the coefficient:

$$B \le 0.184, \tag{11}$$

where:

z_* – abscissa of the function extremum (9).

If (11) condition is met then solution of (9) inequalities may be represented in the form of following inequalities:

$$z_1\left(B_p\right) \le z \le z_2\left(B_p\right); \tag{12}$$

$$z \le z_1\left(B_0\right);\ z_2\left(B_0\right) \le z, \tag{13}$$

where:

z_1 – smaller in absolute magnitude root of Equation (9) (Fig. 10);

z_2 – larger in absolute magnitude root of Equation (9) (Fig. 11).

The results of numerical processing of the obtained solutions shows that average value of Equation (9) root being smaller in absolute magnitude can be applied with engineering accuracy (Fig. 10); exponential function approximation is applicable for larger in absolute magnitude root (Fig. 11).

Taking into consideration the Inequality, (12) and (13) can be represented as follows:

$$1.5 \le z \le \frac{0.552}{B_p^{0.784}};\text{ and } z \le 1.5;\ \frac{0.552}{B_0^{0.784}} \le z.$$

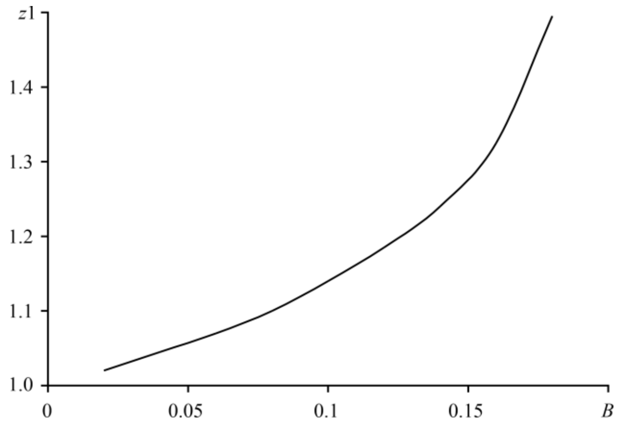

Figure 10. Dependence of Equation (9) root with smaller absolute magnitude upon B parameter value

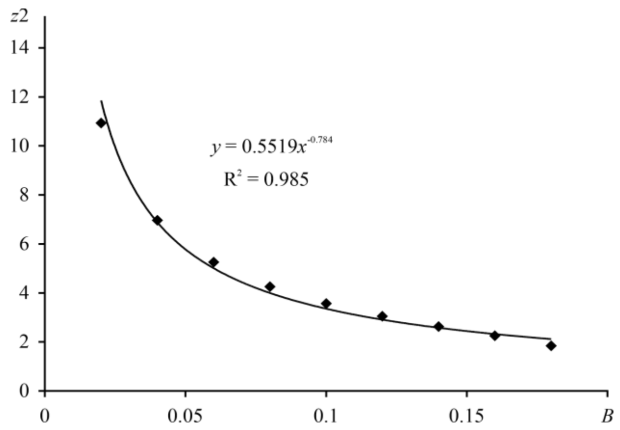

Figure 11. Dependence of Equation (9) root with larger absolute magnitude upon B parameter value

After return to original variables, they will look like:

$$Z \le C \le P;\ C \le \left(\frac{x_0}{X}\right)^{0.95};$$

$$X = 1.56\left(\frac{v}{K}\right)^{2.19};\ Z = \left(\frac{x_p}{X}\right)^{0.95};\text{ and } P = \frac{0.132}{\sqrt[3]{x_p^5}},$$

where:

X – value relative coordinate of the required point to achieve critical velocity under which the interval of change in a hydraulic fluid concentration degenerates into a point (Fig. 12);

Z – lower boundary of the interval of change in a hydraulic fluid concentration (Fig. 13);

P – upper boundary of the interval of change in a hydraulic fluid concentration (Fig. 14).

The results of numerical processing of graphs (Fig. 13) demonstrate the possibility to approximate the linear increasing function with an accuracy being sufficient for engineering calculations within the whole interval of changes in X value; and dependence of lower boundary of interval of change in hydraulic fluid concentration upon a relative coordinate of the required point of critical velocity achievement (Figs. 15, 16):

$$Z = a + bx_p; \tag{14}$$

$$a = \frac{0.0107}{X^{0.307}},\text{ and } b = \frac{1.0101}{X^{0.988}},$$

where:

a and b are approximation coefficients ((Figs. 15 and 16).

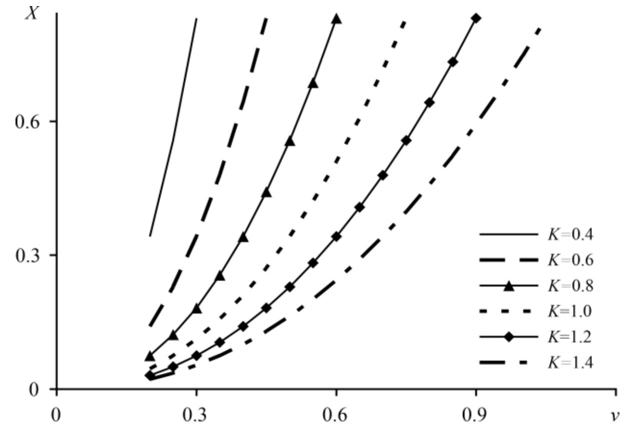

Figure 12. Dependence of a relative coordinate of the required point to achieve critical velocity under which the interval of change in a hydraulic fluid concentration degenerates into a point upon the relative velocity of hydraulic fluid delivery under different inwash parameter values

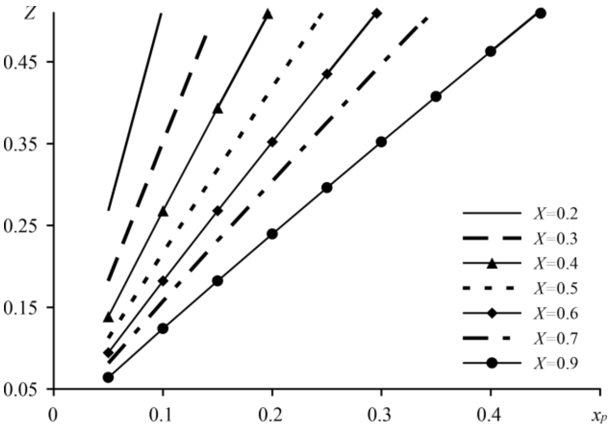

Figure 13. Dependence of the lower boundary of the interval of change in a hydraulic fluid concentration upon the relative coordinate of the required point to achieve critical velocity under different X magnitudes

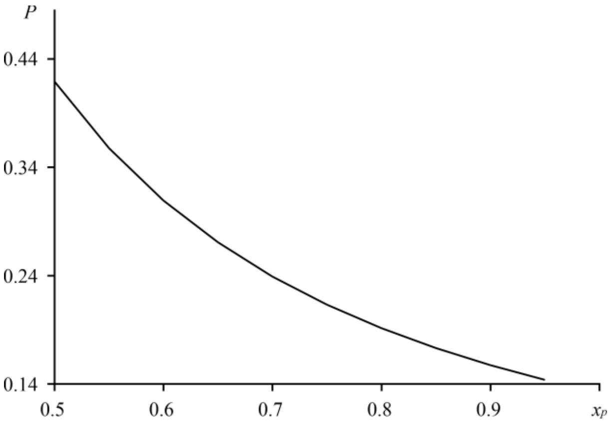

Figure 14. Dependence of the upper boundary of the interval of change in a hydraulic fluid concentration upon the relative coordinate of a point to achieve critical value

Consequently, relying upon the results of numerical calculations (Figs. 5-16), an approach has been proposed to identify boundaries of intervals of change in technological parameters of storing process depending on the required value of a close boundary of a technogenic placer. It helps assess concentration amounts; velocity of hydraulic fluid delivering to inwash beaches; beach slope.

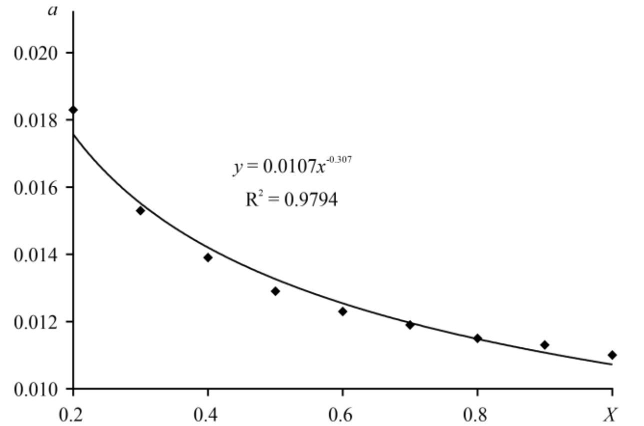

Figure 15. Approximation of the free terms of Formula (14) dependence upon X value

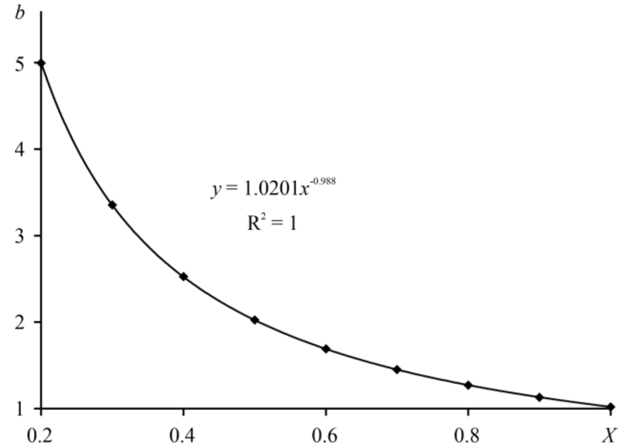

Figure 16. Approximation of the linear term of Formula (14) coefficient dependence upon X value

Parameters of solid fraction particles of washery refuse being stored providing the required distance from internal slope of a flood wall to a close boundary of a technogenic placer.

4. Conclusions

Analysis of the obtained calculation results listed in the paper has helped draw following results:

– it is possible to regulate both distance from internal slope of a flood wall to a close boundary of technogenic placer while varying volume concentration of a hydraulic fluid delivering to an inwash beach and technological influence coefficient which involves wholistically change in hydraulic fluid consumption distributed along the beach as well as average beach slope;

– it has been identified that boundary values of a technological influence coefficient from the relative coordinate of technogenic placer boundary (under each value of hydraulic fluid concentration) are described using decreasing functions where larger values of technological influence coefficient correspond to larger concentration values;

– boundary values of technological influence coefficient vary from 0.7 to 3.2. In this regard, the largest difference in the values being 1.46-3.15 different concentration values is observed under smaller values of relative coordinate of the technogenic placer. In terms of values of relative coordinate of the technogenic placer boundary seeking to 1, the difference becomes minimal and varies from 0.72 to 0.89;

– the minimum of a hydraulic fluid concentration within the control interval stipulated by a close boundary of the technogenic placer is in direct proportion to the required coordinate of a point of critical velocity achievement and to an inwash parameter to 0.95 power; and is in inverse proportion to relative velocity of a hydraulic fluid delivery to the same power;

– the maximum of a hydraulic fluid concentration within the control interval stipulated by a close boundary of the technogenic placer is in inverse proportion to the required coordinate of a point of critical velocity achievement to 1.67 power;

– the average beach slope is limited by a coefficient of the considered fraction particle friction on the beach surface which makes it possible to vary inwash parameter value from 1.56 to 0.22. In this regard, a value of boundary interval of change in the inwash parameter depends little on coefficient value in Pavlovskyi formula; a relative error is not more than 1% if the averaged value is applied.

Author contributions

Conceptualization: OM; Investigation: OM; Methodology: YS; Project administration: OM; Supervision: BB; Visualization: VM; Writing – original draft: OM, YS; Writing – review & editing: VM, BB. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Керування ближньою межею техногенного розсипу шляхом зміни технологічних параметрів процесу складування відходів збагачення

О. Медведєва, Є. Семененко, В. Медяник, Б. Блюсс

Мета. Оцінка можливості керування межами техногенного розсипу за рахунок зміни параметрів процесу складування відходів збагачення з урахуванням крупності та густини частинок кожної з фракцій гранулометричного складу.

Методика. При умові виникнення критичного режиму течії в роботі застосовано методики В.А. Мелентьєва та наукових співробітників Інституту геотехнічної механіки імені М.С. Полякова НАН України. Розглянуто проблеми управління ближньою межею техногенного розсипу при складуванні відходів збагачення у штучні сховища гідравлічним способом за рахунок зміни технологічних факторів з урахуванням властивостей частинок твердої фракції гідросуміші.

Результати. Отримано обмеження у вигляді інтервалів зміни значень коефіцієнта технологічного впливу, відносної швидкості надходження гідросуміші, відносного ухилу пляжу та концентрації гідросуміші, що надходить у сховище. Показано, що середній ухил пляжу обмежується коефіцієнтом тертя частинок фракції по поверхні пляжу, який надає можливість змінювати значення параметра намиву від 1,56 до 0,22. Встановлено, що для розрахунків з інженерною точністю, залежністю параметра намиву від величини коефіцієнтів у формулі Павловського можна знехтувати, оскільки відносна помилка при використанні усередненого значення параметра намиву не перевищує 1% і розглядати його середнє значення, залежність якого, щодо ухилу пляжу, може бути апроксимована спадною лінійною функцією.

Наукова новизна. Вперше запропоновані формули визначення меж інтервалів зміни низки технологічних параметрів процесу складування залежно від необхідного значення ближньої межі техногенного розсипу. Це дозволяє оцінити величини концентрації та швидкості гідросуміші, що надходить на пляжі намиву, ухилу пляжу та параметри частинок твердої фракції відходів збагачення, що складуються, які забезпечують необхідну відстань від внутрішнього укосу дамби обвалування до ближньої межі техногенного розсипу.

Практична значимість. З використанням результатів, наведених у статті, стає можливим управління геометричними розмірами техногенних розсипів, що сформовані у штучних сховищах відходів збагачення при їх складуванні гідравлічним способом, та дозволяє виключити розміщення дамби обвалування наступних ярусів над техногенними розсипами нижніх ярусів намиву, забезпечити перекриття між техногенними розсипами на двох сусідніх ярусах, а також досягти сепарації техногенного розсипу від фракцій, що не містять цінних компонентів, шляхом укладання їх на різних ділянках пляжу, і тим самим забезпечити селективний видобуток техногенної корисної копалини.

Ключові слова: *пляж, намив, критичний режим течії, гідравлічна крупність, коефіцієнт тертя, техногенний розсип*

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