Показана ефективність використання техногенних розсипів для вилучення важких металів, які накопичуються на об'єктах переробки мінеральної сировини. Доведено, що розподіл металу в техногенному розсипу нерівномірний. Основна маса металу концентрується в центральній частині розсипу і формує область важких металів у формі ядра з процентним вмістом від 60 % до 85 %

Ключові слова: корисні копалини, важкі метали, свердловинний гідровидобуток, техногенний розсип, технологічний цикл

Показана эффективность использования техногенных россыпей для извлечения тяжелых металлов, которые накапливаются на объектах переработки минерального сырья. Доказано, что распределение металла в техногенной россыпи неравномерное. Основная масса металла концентрируется в центральной части россыпи и формирует область тяжелых металлов в форме ядра с процентным содержанием от 60 % до 85 %

Ключевые слова: полезные ископаемые, тяжелые металлы, скважинная гидродобыча, техногенная россыпь, технологический цикл

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EXAMINING FEATURES OF THE PROCESS OF HEAVY METALS DISTRIBUTION IN TECHNOGENIC PLACERS AT HYDRAULIC MINING

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1. Introduction

Active mining of mineral resources for many years has led to the accumulation of mineral resources in technogenic deposits, which are an alternative to natural native sources of mineral resources.

Technogenic placers, which are formed as a result of deposit's industrial development with the use of open and hydraulic means of mining are the most expedient.

Because of the lack of reliable technology of enrichment or a failure to keep to a technological cycle, a part of the valuable component is dumped into the concentration tails. Tailings are formed on the Earth's surface, the relief of which determines the shape of future technogenic deposits. Filling of gullies, ravines, lowlands with wastes or forming piles in the shape of a cone are the most common. In each of these cases, zones of heavy metals concentration, or the so-called "cores" of technogenic placers are shaped differently. Parameters of such zones and their location will also be different. Knowledge of the location of these zones and their parameters is crucial for the development of technogenic deposits because it provides an opportunity of mining in the areas with the increased content of the useful component.

In terms of industrial development, the most promising are the technogenic placers of TOV "Zakarpatpolymetaly" (Ukraine), not far from the village of Muzhiyevo of Beregivsky District, Vilnogirsk (Dnipropetrovsk Region) and Irshansky (Zhytomyr Region) concentrating mills, as well as Kvasivsky and Sauliatsky (Transcarpathia), Rafalivsky (Rivne Region) deposits. A significant percentage of precious metals (gold, platinum, silver, copper, titanium and others) are contained in tailings of these deposits.

Because only certain zones of technogenic placers with the increased concentration of heavy metals are expedient to be used for the industrial development, it is relevant to establish indicated regularities. It is also important to substantiate parameters of the zones with increased concentration of heavy metals at different pulp concentration to extract valuable mineral raw materials.

2. Literature review and problem statement

The possibility of obtaining gold concentrates out of technogenic wastes of concentration of iron and manganese ores was proved by results of the research, conducted over recent years in Ukraine; secondary titanium concentrate was obtained from the wastes of concentration at Vilnogirsky ore mining and concentration plant (Dnipropetrovsk Region, Ukraine). In the process of mining and concentration of manganese ores, products of processing mineral raw materials that occurred as a result of their losses during concentration were accumulated in the tailing. In the slime depository named after Maximov in Dnipropetrovsk Region

(Ukraine), the reserves of manganese ores were assessed in the volume of 1.09 mln. t with an average content of manganese at 13.6 %. This technological deposit was registered in the state balance of stocks and attributed to the reserve of the State Fund of Subsoils [1].

The biggest problem that prevents the increase in capacities of TOV "Zakarpatpolymetaly" in the Muzhiyevo gold-bearing mine in Beregovo district of Ukraine is the imperfection of technology. The thing is that by using a gravitation method it is possible to extract from rocks from 40 to 60 percent of gold. The rest remains in the so-called "tails" (in the Muzhiyevo deposit, their role is performed by a lake near the concentration workshop). Here, under a 15-metre pulp layer, more than half a ton of precious metal, which has not been obtained, is buried. Muzhiyvsky deposit is polymetallic, that is, there is silver, lead, zinc, and cadmium in the rock. They are not extracted, but rather stored in tailings where there is 40 % of gold, which is not extracted from the ore, and is waiting for the implementation of modern technologies [2].

According to data by "Ukrainian polymetals" (Ukraine) [3], in order to outline the near future of "Zakarpatpolymetaly" (in addition to Muzhiyvsky, gold is found in Kvasivsky, Saulatsky and other deposits), it is necessary to increase mining capacity at least twice, that is up to 120 thousand tons of ore per year. It is necessary to apply the complete technological processing cycle, expand resource base through the geological exploration of tailings. It is expedient to reveal places of the largest accumulation of polymetals of the gold ore area, as well as to conduct technical modernization of the concentration factory in order to avoid the loss of precious metals. Systematization of technogenic deposits is important from the perspective of their evaluation and reuse. Methods for the development of industrial mineral resources may differ from the partial or complete replacement of primary mineral raw material with waste. To do this, within the framework of existing enterprise, it is important to predict the creation of new production based on effective techniques and technologies. The indicated features of technogenic mineral objects define appropriate tasks for their geological-industrial and geoecological assessment [4]. As an example, paper [5] examines the formation of a technogenic placer in the process of concentration of ores at the Norilsky mining and metallurgical plant. A work for the purpose of revealing and exploration of technogenic placer with industrial parameters was conducted in the promising section in the basin of the river Shchuchia, in the upper part of which the waste tails of the Norilsky concentration plant were formed. The tails (containing 1.7 g/t of platanoids and 0.27 g/t of gold) are located on the left bank near current bed and cover the distance of 3.5 km along the river with practically continuous cover. The calculation of reserves of the deposit was conducted based on temporary conditions with the aim of engaging them into technological process in the long term, and their role will become more important with the depletion of mineral raw materials base.

Article [6] illustrates existing experience in the formation and engagement in operation of technogenic deposits of Kazakhstan, Uzbekistan, Russia, Tajikistan and Armenia. The authors investigated the process of flotation of tailings of concentration on the machines of the "Mehanobr" type and found that gold is extracted from the initial product into a 34.7 % concentrate and silver – into a 33.3 % concentrate. In other words, processing of underlying tailings by the flotation method is not expedient because of low indicator of metal extraction and it requires more advanced technologies for their extraction.

In Turkey [7], more than 6 million tons/year of technological production waste in the form of slag are found in storages and are not used. In the world, technogenic slag storages that are necessary to recycle are calculated in billions of tons. For these deposits to acquire practical-production character, and for valuable mineral raw materials to be extracted, it is necessary to apply new technologies. Despite the fact that companies/corporations in India are using modern technologies of extraction and processing copper ore, a lot of copper and other metal compounds, which are accumulated in technogenic placers, are lost. Many types of waste are a valuable source of secondary raw materials, which are suitable for using in various industries. With the efficient development of tailing, the slag, obtained in this process, can be used for manufacturing cement and tiles [8].

In China, because of violations in the production standards at concentrating mills, several serious accidents happened that caused contamination through the break of levees at tailings. Wastes of mining and concentrating plants with significant content of polymetals need studying and development [9]. Research into recent tailings was carried out using geochemical and mineralogical analyses in the vicinity of the mine Dabaoshan in Guangdong. The results showed a relatively high acid production potential of metals such as Si, Zn, Pb in recent waste. The Dabaoshan mine tailings possess much larger potential of heavy metals [10]. The source of wastewater of Desin tailing contains copper, which is lost at flotation at the factory and at leaching. The content of Zn, Si, Fe and Mn and other heavy metals in tailings require additional geological studying with the aim of using them in the production process [11].

Paper [12] examines acidity and salinity of the mine in Central Manitoba (Canada) with wastes of concentration factory. The zones of high conductivity, caused by acids of mine drainage, were established in the course of previous electromagnetic research in the section. Laboratory saturation measurement in the array of polymetals tailing were performed from the samples, taken from the upper 2-meter tailings along the profile. Results of the study indicate a possibility of using electromagnetic geophysical research into tailings and mine piles for their development in future.

According to data from the State Department of environment and natural resources in Rivne Region (Ukraine) [13], considerable stockpiles of technological waste were accumulated on the territory of Rafalivsky basalt career because of imperfection in the technology that is used for basalt and tuff production [14]. These stockpiles contain a high percentage of heavy metals (copper, polymetals, silver, titanium-magnetite, etc.) that are not used, but represent industrial interest.

With the purpose of developing technogenic deposits of Ukraine and, in particular, Rafalivsky deposit in Rivne Region, it was necessary to conduct detailed research. The pattern of forming a zone of concentration and distribution of valuable component in the process of forming technogenic placers throughout the world has not been sufficiently studied.

3. The aim and tasks of the study

The aim of present work is to set the parameters of the area of high concentration of heavy metals at different percentage content of metal in tuff hydromix. Hydromix is put into a placer at different density, on a specially designed experimental stand to study formation of zones of heavy metals concentration in the placers of conical type.

To achieve the set goal, the following tasks were to be solved:

– examining features of the process of distribution of heavy metals in the body of a placer and defining patterns that affect parameters of the areas of concentration of heavy metals in a placer;

– determining percentage content of metal in the core of a placer;

– establishing a mathematical model for the process of forming a placer and the zone of increased metal concentration in technogenic placers.

4. Procedure for conducting the experiment and experimental measurements

Experimental studies were performed under laboratory conditions on tuffs of Rafalivsky career of Rivne Region, Ukraine. The carriers of copper mineralization are basalts, basaltic tuffs and lavocluster breccia at non-uniform content of copper in the rocks. In the tuffs, native mineralization with copper content from 0.4 % to 1.2 % is observed, in lavocluster breccia it ranges from 0.004 % to 8 %; in basalts, it ranges from 0.4 % to 5 % [15].

Recently extracted tuffs were found to be quite cemented, but under the influence of moisture, they decompose with the formation of loose mass. After crushing these rocks at the jawbreaking mill, the tuff flour was obtained, which in granulometric composition contains particles with dimensions >2 mm – 25 %; 1–2 mm – 32 %; 0.5–1.0 mm – 9 %; 0.25–0.5 mm – 14 %; 0.1–0.25 mm – 11 %; <0.1 mm – 9 % of the total mass of air-dry material. After crushing at a ball mill, tuff material contains around 50 % of physical sand, 33 % of dusty fraction and 17 % of clay substance, it has a number of plasticity 5–7 and by these parameters corresponds to low plastic dusty sandy loam. Weight density of crushed tuff is within $0.96–1.22·10^3$ kg/m^3, and specific surface is 120–150 m^2/kg. Total porosity of dispersed tuff material reaches around 30 %; swelling in water – 36 %. Water absorption by weight is around 18 %, and that by volume is 33 %.

Before the experiment, a portion of tuff, water and metal with different consistency of water to tuff (liquid to solid) P:T and various contents of native copper were loaded into the mixer. When using the hydromining, the optimal ratio P:T is 80 % to 20 %; 85 % to 15 %; 90 % to 10 % [15]. The stopwatch was started as soon as the first portion of the hydromix appeared at the outlet of the pulp pipe, and was stopped at the moment the transportation was terminated, which allowed averaging hydraulic parameters of the mixture during formation of technogenic placer.

Percentage content of native copper in the study was accepted, respectively, 0.5 %, 0.75 %, 1.0 % relative to the weight of tuff. Since in tuffs copper is subtly disseminated with diameter of up to 2 mm, the size of metal balls in the experiments was in the range from 1 mm to 2 mm.

In view of the fact that the examined zeolite-smectite tuff has considerable water absorbing capacity – up to 30 %, it is crushed when hydrotransported. Physical properties of the hydromix were determined by the particle dimensions of the entire hydromix mass. When processing experimental data, dimensional characteristics of the whole mass, rather than separate particles, were considered.

When modeling the formation of placer, special attention was paid to preserve the mode of hydromix flowing from the pulp pipe, as well as to reproducce the asignrf tuff hydromix concentration in a mixer.

To provide the required accuracy in establishing the percentage content of metal in the technogenic placer, formed on a laboratory stand, it was divided into separate volumes with dimensions of 10×10×5 cm. These samples were placed on the research table, after which the metal was extracted by magnetic induction 600 Mt with the help of magnetic core-type separator of the SMS 0.5-1-MN-0.2 type. The extracted metal was weighed by electronic scales VLKT – 500 g – M and VLKT – 2 kg – M.

The selected research section was equipped so that all parameters that characterize alluvium of technogenic placer could be measured; they included:

– consumption and consistency of the hydromix;

– granulometric composition of tuff;

– an increase in the height of aluviated sand over time;

– sifting and weighing the amount of metal in the core.

In the experiments, it does not seem possible to estimate quantitatively power consumption separately for cases of each interaction of solid particles in the falling pulp flow, as well as in the wash funnel. We used a method for total assessment of the work of flow, which was defined as the maximum transportation capacity of the falling flow into the body of a placer. Simulation of tuff by hydraulic dimensions was used in the study as it was more relevant than geometric modeling by particles' diameter as it takes into account the effect of gravity and inertia forces on the sedimenting rock at aluviation.

The process of formation of a technogenic placer with formation of the core, depending on the concentration of specific weight of the pulp, was studied in a three-dimensional tray by three series of 27 experiments each, which are presented in Table 1.

Table 1

Basic methodological indicators of experimental research

No. of experiment	Time t, min	Water volume W, l	Tuff weight M, kg	Metal weight m, kg		
				0.5 %	0.75 %	1.0 %
Series 1						
1	23,8	90	10	0,05	0,075	0,1
2	24,1	90	10	0,05	0,075	0,1
3	23,6	90	10	0,05	0,075	0,1
Series 2						
4	24,2	85	15	0,075	0,1125	0,15
5	24,1	85	15	0,075	0,1125	0,15
6	23,8	85	15	0,075	0,1125	0,15
Series 3						
7	24,0	80	20	0,1	0,15	0,2
8	23,7	80	20	0,1	0,15	0,2
9	24,1	80	20	0,1	0,15	0,2

Longitudinal profile along the axis of the core of a placer, formed in the course of experiment, is presented in Fig. 1.

The purpose of this experimental research was the substantiation of theoretical conclusion on that without a reliable concentration technology, a part of valuable component is dumped into waste. Technogenic placers with the core, in which a considerable metal part is concentrated, are formed.

The problem of quantitative metal distribution in the core and core shapes at different percentage content of metal and at different hydromix density was studied. Hydraulic tray for performing experimental aluviations was equipped with special net traps that retain metal and rock that go beyond the tray. The tray had a drainage system from a metal grid with a center of 0.5×0.5 mm and perforated holes of diameter 0.5 cm, located at the bottom of the tray.

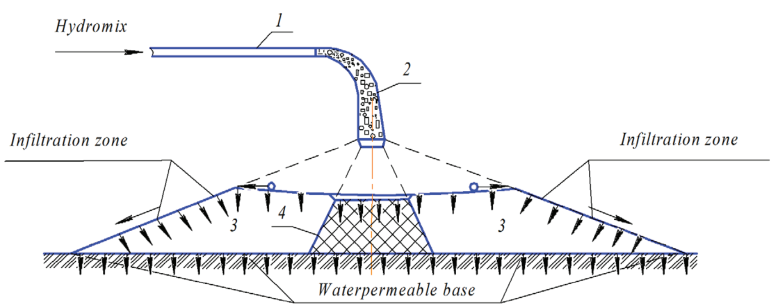

Fig. 1. Schematic of motion of water flows in the body of aluviating placer with the core: 1 – pulp pipe; 2 – falling pulp stream; 3 – body of a placer; 4 – core of a technogenic placer

5. Results of examining the pattern of heavy metals distribution in technogenic placers

By the results of research, the graphs of changes in the height of a placer on the length of its base at different density of hydromix were plotted. The amount of metal in the cross-section and by the height of the body of a placer was defined. Due to a considerable volume of experimental data, data for series 2 are presented in this article (Fig. 2–4). Similar graphs were obtained for experimental research in series of experiments 1 and 3.

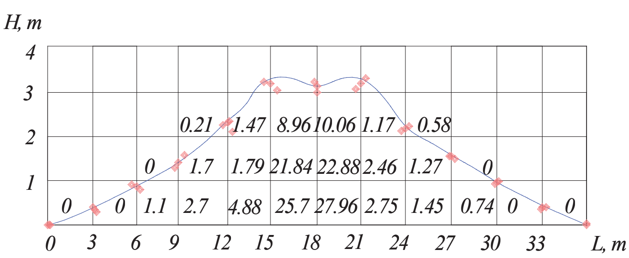

Fig. 2. Graph of change in the height of a placer depending on its length and distribution of heavy metals in the body of a placer for pulp consistency P: T/85 %: 15 % at metal content of 1 %

We may conclude, based on the analysis of experimental data, shown in graphs 2–4, that the distribution of metal in a technogenic placer is non-uniform, both in height and lengthwise of a placer. The bulk of metal is concentrated in the central part of a placer, which proves the assumption about the formation of heavy core-shaped area of heavy metals.

To establish the patterns of distribution of heavy metals and parameters of the placer's core, Tables 2–4 give the average values of metal content in the core of a technogenic placer. Averaged graphs of determining the basic parameters of both a technogenic placer and its core are shown in Fig. 5–7.

It is possible to conclude, based on analysis of the data, presented in tabular and graphical forms, that the bulk of metal is concentrated in the central part and forms the core of technogenic placer.

Table 2

Summary table of determining average metal content in a technogenic placer at tuff hydromix consistency P: T/85 %: 15 %

No. of entry	Height of bulk, H, m	Length of placer L, m	Average metal weight in core, g		
			m_1 1 %	m_2 0.75 %	m_3 0.5 %
1	0	0	0	0	0
2	0.3	3	0	0	0
3	0.75	6	0	0	0
4	1.5	9	1.16	1.03	0.45
5	2.25	12	4.32	3.23	4.4
6	3	15	7.8	7.65	5.84
7	3.2	18	58.38	41.10	24.73
8	3.2	21	61.63	37.07	19.9
9	3	24	5.63	8.45	9.31
10	2.25	27	3.7	4.22	4.8
11	1.5	30	0.84	0.97	0.79
12	0.75	33	0	0	0
13	0.3	36	0	0	0
14	0	37	0	0	0
Σ	–	–	143.45	103.8	70.23

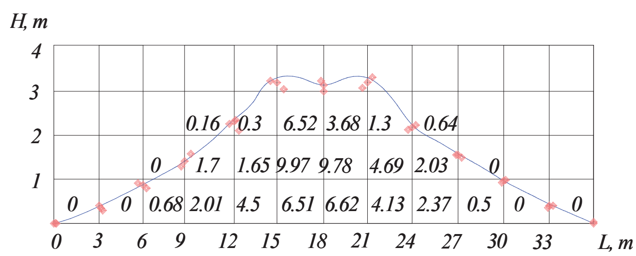

Fig. 3. Graph of change in the height of a placer depending on its length and distribution of heavy metals in the body of a placer for pulp consistency P: T/85 %: 15 % at metal content of 0.75 %

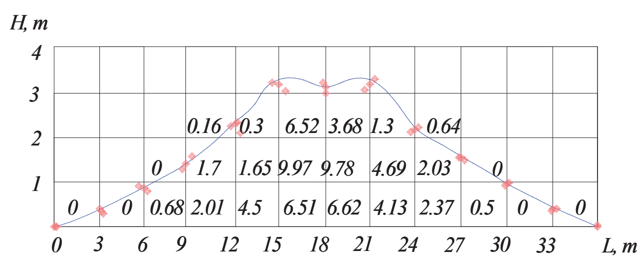

Fig. 4. Graph of change in the height of a placer depending on its length and distribution of heavy metals in the body of a placer for pulp consistency P:T/85 %: 15 % at metal content of 0.5 %

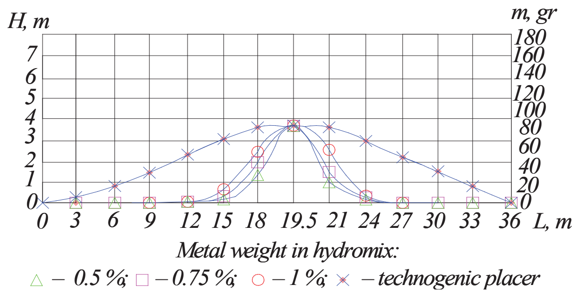

Fig. 5. Graph of dependence of change in average metal content in a technogenic placer and the formation of placer's core for tuff hydromix consistency P: T/85 %: 15 %

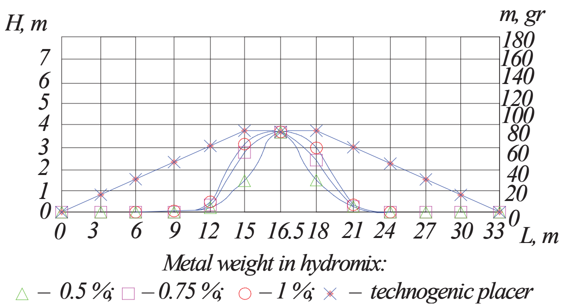

Fig. 6. Graph of dependence of change in average metal content in a technogenic placer and the formation of placer's core for tuff hydromix consistency P: T/80 %: 20 %

Table 3

Summary table of determining average metal content in a technogenic placer at tuff hydromix consistency P: T/80 %: 20 %

No. of entry	Height of bulk, H, m	Length of placer L, m	Average metal weight in core, g		
			m_1 1 %	m_2 0,75 %	m_3 0.5 %
1	0	0	0	0	0
2	0.75	3	0	0	0
3	1.5	6	0	0	0
4	2.25	9	2.11	2.03	1.04
5	3.0	12	11.08	7.48	6.1
6	3.75	15	89.7	69.6	38.8
7	3.75	18	74.4	58.4	36.6
8	3.0	21	9.05	6.09	8.92
9	2.25	24	1.11	1.12	1.38
10	1.5	27	0	0	0
11	0.75	30	0	0	0
12	0	33	0	0	0
Σ	–	–	187.47	144.72	92.6

Summary Table 5 gives comparison of experimental data on metal content in the core of a cone-shaped placer for different consistencies P:T and corresponding percentage content of metal.

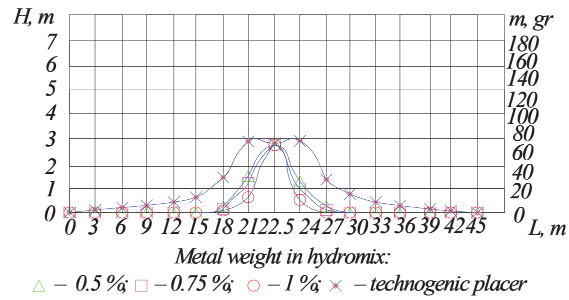

Fig. 7. Graph of dependence of change in average metal content in a technogenic placer and the formation of placer's core for tuff hydromix consistency P: T/90 %: 10 %

Table 4

Summary table of determining average metal content in technogenic placer at tuff hydromix consistency P: T/90 %: 10 %

No. of entry	Height of bulk, H, m	Length of placer L, m	Average metal weight in core, g		
			m_1 1 %	m_2 0.75 %	m_3 0.5 %
1	0	0	0	0	0
2	0.2	3	0	0	0
3	0.35	6	0	0	0
4	0.55	9	0	0	0
5	0.75	12	0.29	0.1	0.18
6	1.5	15	2.58	0.76	1.71
7	2.25	18	4.01	4.82	8.19
8	2.9	21	17	32.55	38.46
9	2.9	24	17.11	27.27	35.07
10	2.25	27	4.32	5.37	8.41
11	1.5	30	2.08	0.62	1.36
12	0.75	33	0.15	0.09	0.42
13	0.55	36	0	0	0
14	0.35	39	0	0	0
15	0.2	42	0	0	0
16	0	45	0	0	0
Σ	–	–	47.32	71.08	93.79

A comparison of percentage of metal in the core for 3 series and 27 experiments proved the hypothesis about the formation of heavy metals core of a conic placer with percentage of metal in the core from 59.46 % to 85.35 %. Maximum error when conducting the studies did not exceed 9.68 %.

It was also experimentally found that the height of the conic placer and its width depend on pulp consistency. The height of placer increases at an increase in the ratio P:T, and the width of its base decreases (Table 5).

Table 5

Generalized experimental data on determining percentage content of metal in the core of a placer

No. of entry	Hydromix consistency, P:T	Total weight of metalm, g	Length of the base L, m	Height of bulk H, m	Percentage content of metal in samples, %	Metal content in samples, g			Metal content core m_{co}, g	Metal content in core, %
						m_1	m_2	m_3		
1	90:10	50	45.0	2.9	0.50	48.45	45.16	48.33	34.11	68.22
		75	45.2	3.1	0.75	69.88	72.74	70.63	59.82	79,76
		100	44.7	3.0	1.00	95.3	92.01	94.05	73.55	73,55
2	85:15	75	37.3	3.7	0.50	70.84	69.55	70.31	44.6	59,46
		112.5	37.0	3.9	0.75	105.19	100.88	105.35	78.2	69.51
		150	37.9	3.9	1.00	141.05	141.52	147.08	120.34	80.22
3	80:20	100	31.8	5.5	0.50	91.35	92.75	93.72	75.46	75.46
		150	32.1	5.4	0.75	147.86	144.88	139.54	128.03	85.35
		200	33	5.5	1.00	189.64	184.7	188.07	164.1	82.05

Approximation and statistical processing of experimental data were performed in the software packagea MathCad and Microsoft Excel. Experimental data were approximated by third order polynomials.

Polynomic approximation of measurement data, which were formed as some vector Y at certain values of argument that form vector X of the same length as vector Y, were conducted with the help of built-in MathCad functions for cubic spline-interpolation. The meaning of spline-interpolation is that on the intervals between the points, the approximation was performed in the form of dependence $f(x)=ax^3+bx^2+cx+d$, where a, b, c, d are the factors that are determined independently for each interval, based on values of y_i y at neighboring points. This process is hidden from the user, because the meaning of the interpolation problem is to find function f(x) at any point x. To verify approximation reliability and its quantitative assessment, statistical data were processed, namely the value of correlation coefficient and root-mean-square deviation between experimental data and approximated dependences was calculated.

Correlation coefficient was determined by the following formula:

$$r=\frac{\sum(x_i-x_{middle})(y_i-y_{middle})}{\sqrt{\sum(x_i-x_{middle})^2(y_i-y_{middle})}}, \quad (1)$$

where x, y are, respectively, the experimental and calculation data Root-mean-square was determined by formula:

$$\delta=\frac{\sqrt{\sum(x_i-y_i)^2}}{n-1}, \quad (2)$$

where n is the number of measurement points.

For quantitative assessment of reliability of the established mathematical dependences, the maximum relative error between experiments and calculated values for each point of measurement was determined:

$$\gamma_i=\frac{x_i-y_i}{x_i}\cdot 100\,\%. \quad (3)$$

Dependences, shown in Fig. 5–7, are described by equation:

$$H=f(L,m)=a(m)L^3+b(m)L^2+c(m)L+d(m), \quad (4)$$

where a(m), b(m) c(m), d(m) are the functions that are determined independently for each interval, and characterize dynamics of formation of a placer's core; m is the mass fraction of metal in a placer; L is the longitudinal coordinate of a placer.

Dependence (4) is the basis for analytic formation of prognostic methods for determining the dynamics of formation of the heavy metals core in a technogenic placer and its development.

Maximum rms deviation is 8.3 %, maximum relative calculation error is 2.88 %.

6. Discussion of results of examining effectiveness of using established patterns of heavy metals distribution in technogenic placers for their extraction

The research demonstrates expediency of using zones of heavy metals concentration in cores of a placer in the technological scheme of processing technogenic waste. A comparison of percentage of metal in the core for three series and 27 experiments have proved the hypothesis about the formation of heavy metals core with percentage of metal in the core from 59.46 % to 85.35 %. An analysis of experimental data reveals that the distribution of metal in a technogenic placer is non-uniform both in height and lengthwise of a placer. The bulk of metal is concentrated in the central part of a placer that meets our assumptions about formation of zones of high concentration (core) of heavy metals in a technogenic placer of the conic type. Further processing of experimental data proved the accuracy of this assumption. Fig. 5–7 shows averaged graphs of dependences of changes in metal content in a technogenic placer at different metal content in the hydromix. The resulting formula (4) provides the possibility to define parameters of zones of heavy metals concentration in the body of a placer.

The research results obtained indicate the need for waste recycling, which includes finding the zones of concentration of precious metals by the established pattern with the view to their extraction and further processing. It was shown that in the case of nonobservance of technology at mining, processing and metallurgical enterprises, a part of valuable component gets into waste with high percentage, which may present some industrial interest. Having analyzed results of the research, we can make a conclusion on the need for further research to identify areas of precious metal concentration in technogenic placers and tailings of concentration factories in the process of their formation in a ravine and lowland.

The results of the research make it possible to develop a technical task for carrying out industrial research and creation of an area of recycling technogenic tuff waste in order to extract copper and other accompanying metals on Rafalivsky career (Ukraine).

7. Conclusions

1. It was experimentally proved that distribution of metal in a technogenic placer is uneven, both in height and lengthwise in a placer. The bulk of metal is concentrated in the central part of a placer and forms the zone of heavy metals in the form of the core with percentage of metal in the core from 59.46 % to 85.35 %. Maximum error in the conducted studies did not exceed 9.68 %.

2. We substantiated the pattern of metal distribution and the shape of the core of a placer and basic parameters of both a placer and the core for the studied pulp concentration when placing it on the alluvium map. We also established regularities of heavy metals distribution in technogenic placers that allow identification of their location and calculation of parameters of zones of high metal concentration.

3. It was established that the height and the length of the base of a technogenic conic placer depend on the hydromix density. The height of a placer increases at an increase in the ratio P:T, and the width of its base decreases. Parameters of zones of high heavy metals content in a technogenic placer change by a dependence that is described by polynomial of third degree. Polynomial coefficients characterize the dynamics of formation of the core of a placer, where from 59.46 % to 85.35 % of heavy metals are concentrated.

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