# SUBSTANTIATING THE POSSIBILITY AND EXPEDIENCY OF THE ORE BENEFICIATION TAILINGS USAGE IN SOLIDIFYING MIXTURES PRODUCTION

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## Quintessence of the contents of the article

The article is devoted to the substantiation of the possibility and disposal conditions of the ore beneficiation tailings of the metal-containing mineral raw materials, the storage of which is globally dangerous. Mining technology optimality criterion is justified as its humanity guarantor being the condition for the preservation of the Earth's surface during deposits development. The grounds for the geomechanical balance control of the mountain mass preserving the Earth's surface by way of dividing it into safe areas according to their stress rate are indicated. Brand new process of the substance activation by large mechanical energy has been characterized. The practical use of technology for the first time in the world practice has been described. Experimental evidence is given on the mechanical-chemical technology of using the tailings of the nonferrous and ferrous metals and coals of Russian deposits. The model of defining the economic and ecological efficiency of the technology is suggested. The technology is recommended for the enterprises of KMA of Russia in conversion to the underground ore mining.

## Key Words

Deposit development, mineral raw materials, metals, ore beneficiation tailings, the Earth's surface, geomechanics, tension, activation, mechanical energy, mechanics and chemistry, ecology, underground ore mining.

## Introduction

Mineral extraction is characterized by the increase of the amount and area of the mining development, caused by the dynamic progress of the human community's demands. It has long become the leader of the nature destruction technologies, first of all, because of the Earth's surface damage in the regions of mineral extraction. Drastic damage of the lithosphere is followed by the degradation of all environment spheres.

Therefore, the main purpose of the mountain mass state control must be preservation of the Earth's surface from destruction. Ground pressure control comes to ensuring the optimal parameters of the system "natural mountain masses – artificial mountain masses – surface" to meet the Earth's surface preservation criterion [1].

The wide-spread criterion of the efficient mountain mass state control is the cost value of the works connected with it or the amount used on 1 cubic meter of filled voids. This criterion makes most preferable the failure of ore and rock with raw materials loss, ore dilution and ecological balance change on the Earth's crust plot. Estimating the efficiency of this method may include the systematic error as the actual cost of land, raw minerals and ecological environment change cannot yet be expressed in material measurement.

Kotenko E.A., Kulikov V.V., Dyomin N.V., Golikov V.I. et alias suggested the optimality criterion as the condition of the Earth's surface preservation from destruction. The mentioned criterion is introduced while making the technical-economic comparison of technologies evaluating the final cost of the product.

Due to the Earth's surface preservation criterion the mountain mass state control methods are placed in comparable conditions meeting the humanity concept in using the subsoil and land. According to this criterion the number of possible control methods does not include those using the rock failure when going onto the Earth's surface, that brought ecological problems in the regions of KMA, Donbass, the Urals, and other mining regions of Russia and abroad [3].

To control the mountain pressure we use the discrete masses property to create stable constructions out of the rock destruction energy.

The broken rock bearing capacity is adjusted by the technology of working out the safe parameters of the breakage headings. Timbering is involved in the process of formation the stable zones with the output equal to the first meters around the mine workings.

The broken rocks do not lose their stability unless the limiting span is not exceeded (G.N.Kuznetsov, V.D.Slesarev, S.V.Vetrov, et alias). The rock construction existence condition is their self-locking in the layer adjoining the untouched mountain mass.

Usage conditions for the residual bearing capacity are created right along, but this phenomenon is not always used that leads to the ores dilution and metals loss. Strengthening the rigidity of the ore construction is performed by the injection of connecting materials between the rock parts, timbering and limiting the mine working span. But the drastic method of mountain mass control is the creation of artificial masses using solidifying mixtures.

So far as filling the gaps with solidifying mixtures is notable for the high cost, the problem is in justifying the possibility of using the cheap mixtures with small bearing capacity under the certain conditions.

In practice geomechanical balance control of the mountain mass preserving the Earth's surface is ensured by dividing the masses into the plots meeting the following conditions:

$$Lf < Lu \text{ and } H > hr,$$

Where H, hr – is the depth of the mine working from the surface and the height of the mine working influence, m;

Lf, Lu, Lo – respectively, factual spans, utmost on condition of natural balance vault formation and preserving the flat top (fig.1).

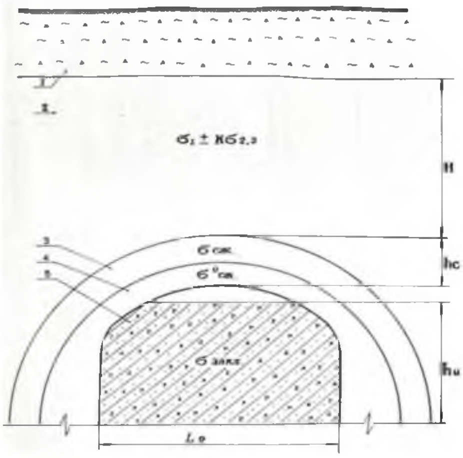


Fig.1: the scheme of tensions in geomechanical system: 1 – alluvia; 2 – rock; 3, 4 – respectively, the upper and bottom layers of the broken rock; 5 – artificial mountain mass made of solidifying mixture; H

– the depth of mining working; $h_c$ – the height of the natural balance vault; ha – the height of the artificial mountain mass; $\sigma_1$ – vertical tensions in the mountain mass; $\sigma_{сж.}$ – tensions in the upper layers of the natural balance vault; $\sigma_{сж}{}^{o}$ – tensions in the bottom layer of the natural balance vault; $\sigma_{закл.}$– tensions in the artificial mountain mass; $L_o$ – the width of the mine working.

The plots are divided into spans with the stable flat top. The ensuring of the mountain mass stabllity is brought to fixmg the technology parameters under which the tensions in the system elements do not exceed the critical ones. This task is solved by cutting the deposit into geomechanically balanced plots with the help of the pillars: the ore ones or those made of solidifying filling. The construction stability is checked for the possibllity of overlying rock failure by bullding the mine working zones of influence (fig.2).

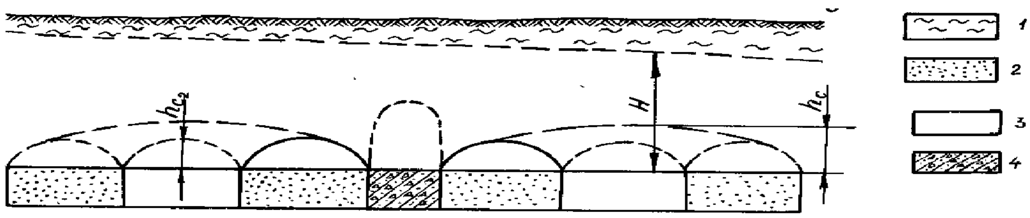


Fig. 2: The scheme of cutting the deposit into geomechanically balanced plots:

1 – alluvia; 2 – undurable filling mixture; 3 – mine working; durable filling mixture; H – the distance from the mine working to the Earth's surface; $h_{c1}$ –the height of the rock layer moving into the mine working; $h_2$ – the height of the rock layer moving into the mine working after filling with the solidifying mixture.

Within the geomechanically balanced plots one can use the compositions of solidifying mixtures of reduced stability minimized by the labor and material costs. The approach of this kind permits using the mixtures made on the basis of the low activity components, most often, ore beneficiation rejects, for the mountain mass control as well as the Earth's surface over it [2].

The storage of the minerals mining and processing waste is followed by the chemical influence on the environment of the toxic waste components, among which heavy metals are the most dangerous.

Combining the traditional ore beneflciation methods allows utillzing rejects quite rarely. Only complete disposal of the dangerous and at the same time valuable raw materials is the radical measure of decreasing the global danger of the chemical pollution of the environment.

Nature conservation concept of treating the minerals processing waste proceeds from its being the unused and dangerous resource in storage, the usage of which can ensure the ecological and economical effect.

The used methods of ore mining and processing are characterized by the loss of the part of valuable components in rejects at all the land repartitions (fig.3).

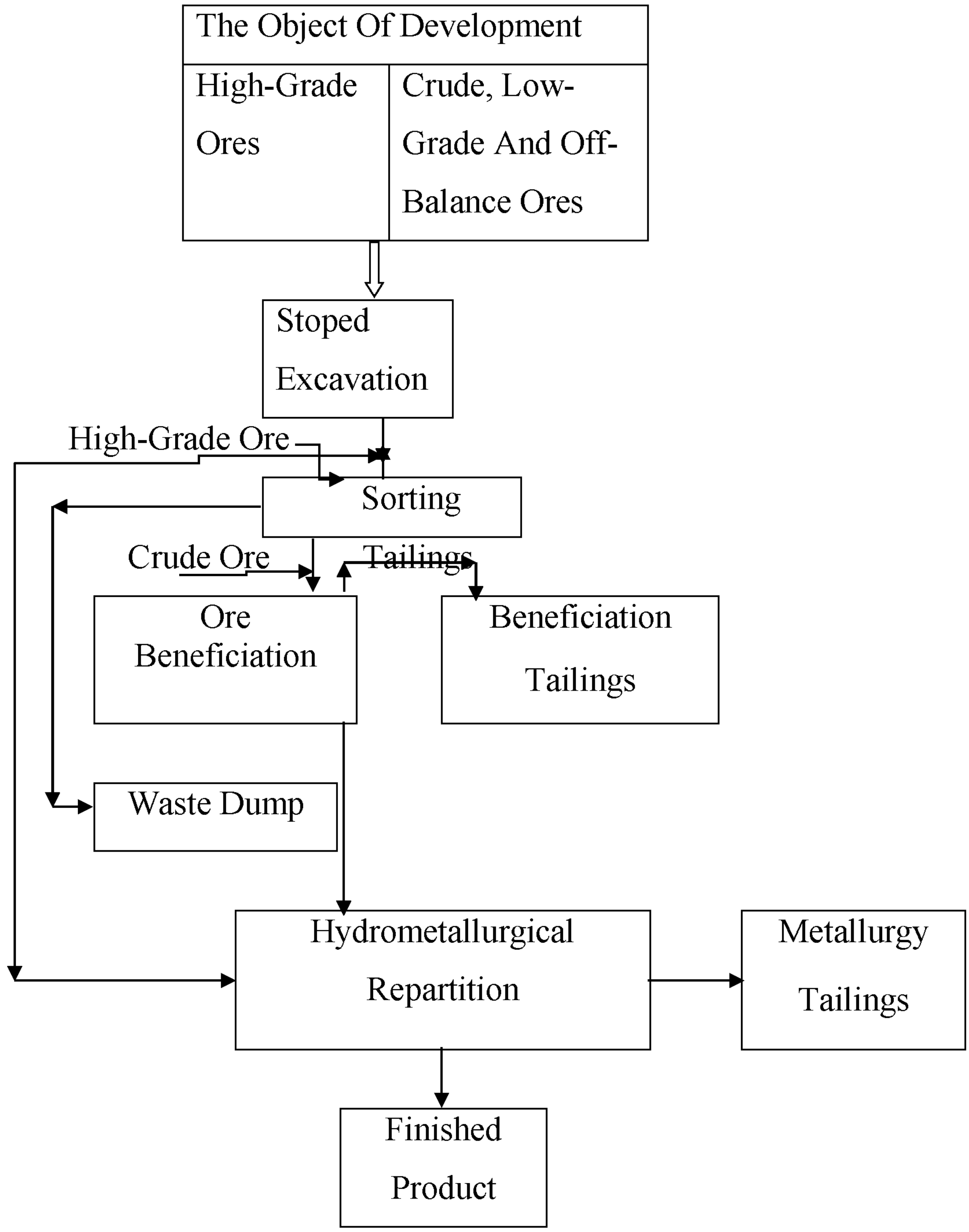


Fig.3: The principal scheme of metal extraction

So, combining the methods of magnetic, gravitation, and electrochemical concentration allows the extracting of iron, manganese, titanium, sulphur, and other components from high-grade tailings of the complex ores beneficiation into the selective produced commodities.

The next stage of the ore beneficiation technologies is using the second type of energy – chemical one – for metal extraction. In the course of chemical leaching metals are extracted from ore beneficiation tailings into solutions, and from them – into the produced commodities sediment. This way gold is leached out of the ore concentration rejects containing 0,6-0,3 g/t, unobtainable for traditional technologies, as well as copper and uranium.

In the process of sorption leaching metals extracted from the ore beneficiation tailings are precipitated on the ion-exchanging mineral pitch, and are extracted from it in the process of desorption. Crushed-ore extraction from the liquid stage increases in the counterflow of crushed ore-mineral pitch by superimposition of electric field.

Brand new technology exploits previously unknown phenomenon of activating the substance with the help of big mechanical energy at processing speed of more than 250 m/s [6].

Mechanical activation is increasing the catalyst properties of substances at ore reduction, accelerating the speed of chemical reactions, hardening. Mechanical activation effect is shown in disintegrators (fig.4).

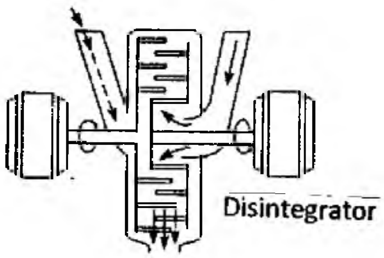


Fig.4: Disintegrator scheme

The material is put into the central part of the labour body and is subjected to numerous strokes of impact bars on the disks, circulating at the speed of 1000 rpm in the opposite directions. Being overcharged it stores the energy of special kind and changes its structural state. The stroke speed in disintegrator is by order of magnitude greater than in vibrating or bead mills, and the acceleration comes up to the millions of accelerations of gravity.

Activation creates in the material electric unequally charged centers, and by the accumulation borders of admixtures the material is being destroyed, so the phase separation processes are stirred up and preparation plant output increases.

## Experimental Results and Discussion

Disintegrator usage in mining was put into practice for the first time in the world in "Shokpak" deposit in North Kazakhstan as a part of the filling complex.

Plant DU-65, completed with universal naves, 4- and 3-rowed rotors and engines of 200 - 250 kilowatt ensured the active class output up to 55%, and combined with the vibrating mill – up to 70%, that allowed the activated slag to compete with finished cement [7].

The plant was situated in the separate building with the basement square of 5-7 m in three levels. The material was delivered to the upper level and let into the plant through the sieve with mesh width of 20mm. From the disintegrator ore reduction products went to the quieting bin and were directed to the technological series. Under the wet scheme of ore reduction the water is sent into the disintegrator, and the activation products are directed in the form of the crushed ore.

The presence of non-extracted metals is the problem in using ore beneficiation tailings. As a rule, the title metals are extracted, and the accompanying ones remain, complicating the following use of tailings. The total cost of metals non-extracted from tailings and lost in filling mixtures can exceed the cost of extracted ones.

Mechanic-chemical technology allows extracting metals and increasing mixture components activity simultaneously.

Experimental substantiation of this phenomenon is made on the basis of ore beneficiation tailings of nonferrous and ferrous metals and coals. The uniform leaching methods are applied in the following modes:

1. Raw tailings agitation leaching.

2. Agitation leaching of pre-activated tailings.

3. Tailings leaching in disintegrator.

4. Agitation leaching of tailings activated in disintegrator.

5. Multiple tailings leaching in disintegrator.

The experiments are performed using the mathematical planning of Venken-Boxa plan. The independent factors were:

- sulphuric acid contents in leaching solution ($X_1$) 2-10 g/l;
- sodium chlorides contents in leaching solution ($X_2$) 20-160 g/l;
- weight relation between the mass of leaching solution and the leached mass ($X_3$) in the unit experiment (50g) 4-10;
- the time of leaching ($X_4$) is within the range of 0,15-1,0 hour.

**Complex ores** of Sadon deposit (Russia, the North Caucasus) are leached in hard suspensions with the extraction of lead and zinc – 80-85 %, silver –60%, cadmium – 56%, bismuth –30 %, and the rejects output of 25-50% from the processed ores volume. Rejects chemical composition, %: $SiO_2$ – 31,4; Fe – 4,4; CaO – 1,96; S – 1,88; Ag – 0,015; Cu – 0,18; Mn – 0,015; $K_2O$ – 3,5; $Al_2O_3$ – 0,8; $TiO_2$ - 0,03; Zn – 0,95; Pb – 0,84.

Metal extraction into the solution is given in table 1.

Table 1: The results of metal extraction into the solution

| Series | Lead, % | Zinc, % |
|---|---|---|
| 1st | 24,8 | 39,2 |
| 2nd | 33,9 | 44,4 |
| 3d | 35,7 | 46,1 |
| 4th | 13,2 | 10,3 |
| 5th | 21,5 | 21,6 |
| 6th | 21,6 | 21,9 |

The results of the research allow concluding that:

- activation in disintegrator and leaching outside it multiplies the extraction from ore beneficiation tailings: lead – up 1,4 times, zinc – up 1,1 times;

- leaching in disintegrator compared with the variant of separate activation and leaching ensures approximately the same extraction, but reduces in-process time from 15 – 60 minutes to seconds, i.e. by 2 digits.

The results of the experiment allow asserting that:

- leaching the crushed ore tailings using the activation in disintegrator is substantially more efficient than agitation leaching;

- the top-down prioritization of influencing the process includes: the contents of reagent in the leaching solution, disintegrator rotor speed; the number of disintegrator processing cycles and the ratio L:S (Liquid:Solid) [4].

## Jaspilites of KMA.

Ore beneficiation tailings of the wet magnet separation of jaspilites present the fine dispersed powder with aggregate fractions size less than 0,071 mm 40 - 70%.

Tailings analyses: $SiO_2$ – 64%, Fe – 8%, $Al_2O_3$ – 5,2%, Mn – 3,2%, $K_2O$ – 0,7%, P – 0,1%, Ca – 0,8%, MgO – 0,2%, Cu – $5 \cdot 10^{-3}$%, Ni - $4 \cdot 10^{-3}$%, Zn - $5 \cdot 10^{-4}$%, As, Ba, Be, Bi, Co, Cr, Li, Mo, Nb, Pb, Sb, Sn, Sr, Ti, V, Y – within the range of $(30\text{-}50) \cdot 10^{-5}$%.

Having the initial iron content of 8% in the analyzed sample the one-time leaching extracts about 1% of iron, and after the triple passing of the tailings through disintegrator 3% of iron is leached into the solution. The sanitary safe level of iron content can be reached by further increasing the processing cycles number.

The chemistry of the tailings initial sample is characterized by the content of As, Ba, Be, Bi, Co, Cr, Li, Mo, Nb, Pb, Sb, Sn, Sr, Ti, V, Y within the range of $(30\text{-}50) \cdot 10^{-6}$%. After the mechanic-chemical processing the content in the recycled tailings does not exceed the building materials rating.

The mechanic-chemical activation at one-time processing multiplies metal extraction into the solution up to 25% compared with the basic rate, and has the growth reserve while increasimg the processing cycles number.

Processing during the same time is characterized by the following results (table 2).

Table 2: Metal leaching results

| Leaching type | Tailings content, % | | | | | |
|---|---|---|---|---|---|---|
| | $Al_2O_3$ | Mn | $K_2O$ | P | Ca | Mg O |
| Agitation leaching | 4,9 | 2,8 | 0,3 | 0,07 | 0,25 | 0,16 |
| Activated rejects leaching | 4,2 | 2,5 | 0,2 | 0,07 | 0,23 | 0,14 |
| Leaching in disintegrator | 3,7 | 2,3 | 0,2 | 0,06 | 0,20 | 0,11 |
| Multiple mechanic-chemical activation | 3,5 | 2,2 | 0,2 | 0,07 | 0,18 | 0,11 |

Maximal extraction is achieved under mechanic-chemical activation of tailings and depends on the processes duration. Increasing the process duration one can extract the target components up to background content.

After metal extraction to the level of sanitary demands the ore beneficiation tailings can be used for manufacturing the fiiling mixtures and concrete commercial output, ensuring the necessary brand using the minimum cementing materials consumption.

Activation in disintegrator without leaching increases the mixture durability adding the cement from 1,30 to 1,52 MPa or at the ratio 1.17.

Mixtures activated in disintegrator without adding the cement can be used for fiiling the overwhelming majority of breakage headings.

## Russian Donbass Coals

The initial metal content in coal preparation tailings is shown in table 3.

Table 3: Metal content in coal preparation tailings g/t

| Element | Minimum | Maximum | Average |
|---|---|---|---|
| Manganese | 310 | 330 | 320 |
| Nickel | 10 | 40 | 25 |
| Cobalt | 5 | 10 | 5 |
| Vanadium | 60 | 130 | 95 |
| Chrome | 50 | 140 | 85 |
| Molybdenum | 1 | 2 | 1.5 |
| Zirconium | 60 | 90 | 75 |
| Lead | 20 | 90 | 55 |
| Zinc | 10 | 40 | 50 |
| Beryllium | 2 | 2.6 | 2.3 |

The results of the reduced samples analyses for the burnt and unburnt coal preparation tailings are given in tables 4 and 5.

Table 4: Metal extraction from the burnt coal preparation tailings

| Metal, % | Softened concentrate | Dry concentrate | Changes, times |
|---|---|---|---|
| Cr | 0.01 | 0.10 | 10 |
| Fe | 0.85 | 2.75 | 3 |
| Ni | 0.03 | 0. 30 | 10 |
| Mn | 0.01 | 0.10 | 10 |
| Co | 0.02 | 0.10 | 5 |
| Cu | 0.03 | 0.40 | 13 |
| Pb | 0.01 | 0.1 | 10 |
| Zn | 0.04 | 0.30 | 7 |

Table 5: Metal extraction from the unburnt coal preparation tailings

| Metal, % | Softened concentrate | Dry concentrate | Changes, times |
|---|---|---|---|
| Cr | 0.03 | 0.15 | 5 |
| Fe | 1.3 | 3.06 | 2 |
| Ni | 0.026 | 0.17 | 6 |
| Mn | 0.015 | 0.10 | 8 |
| Co | 0.03 | 0.12 | 4 |
| Cu | 0.03 | 0.30 | 10 |
| Pb | 0.01 | 0.10 | 10 |
| Zn | 0.02 | 0.14 | 7 |

The extraction into steamed and tempered product made, in percent: cobalt – 104,5%, nickel – 102,1%, lead – 43,5%, zinc– 36,6%, chrome – 18,0%, manganese - 1,4%. Metal extraction of more than 100% is explained by possible exceeding of their content in leaching materials over the content in analyzed samples of the initial materials. Metal extraction having very low content in solutions, mg/l: manganese – 1, nickel – 7, cobalt – 2, chrome – 4, lead – 3, zinc – 5 mg/l is rather high.

The tailings of mechanic-chemical activation of coal preparation rejects are the dispersed mass, made of the particles of about 0,1 mm in size, notable for more regular structure that improves the quality substantially.

The effect of it is illustrated by increasing the strength of the concrete manufactured ceteris paribus on the basis of slag, produced by different methods: grinded in a mill and activated in disintegrator.

Using the coal preparation tailings is profitable, the revenue position can be described by the model:

$$П = \sum_{p=1}^{P}\sum_{o=1}^{O}\sum_{n=1}^{П}\sum_{t=1}^{T}\sum_{f=1}^{F}\sum_{n=1}^{N}\{(М_{еу}Ц_{му} + Q_{у}Ц_{qу})\} - \sum_{з=1}^{З}[К(1 + Е_{ну}) + Е_{q} + Е_{х}] -$$
$$- [(М_{е}Ц_{м} + QЦ_{q}) + Q_{г}Ц_{г}]К_{с}К_{у}К_{т}К_{б}К_{г}К_{вр}К_{ч} \rightarrow \max$$

where P – is the tailings utilization products; O – the tailings types; П – tailings recycling processes; T – the recycling time; F – storage existence phases; N – tailings usage stage; $М_{еу}$ – metals amount from the tailings; $Ц_{му}$ – metals cost; $Q_{у}$ – restored effects quantity; $Ц_{qу}$ – utilized substances cost; $Е_{q}$ – percentage crediting rate factor for the utilization; $Е_{х}$ – percentage crediting rate factor for the metals production; $Е_{ну}$ – percentage crediting rate factor for the environment restoration; $М_{е}$ – lost metals amount; $Ц_{м}$ – lost metals cost; Q – lost effects quantity; $Ц_{q}$ – lost useful substances cost; $Q_{г}$ – the quantity of environmental damage effects; $Ц_{г}$ – compensation inputs for the global damage factors; З – management inputs; К – storages control inputs; $К_{с}$ – tailings self-organization ratio; $К_{у}$ – leaching products drain ratio; $К_{т}$ – solutions drain dlstance ratio; $К_{б}$ – biosphere influence ratio; $К_{г}$ – the pollution influence ratio in relation to neighboring regions; $К_{вр}$ – hazards implementation ratio in time; $К_{г}$ – the environment damage risk ratio of unrecorded factors.

## The conclusion

Mechanic and chemical tailings activation in disintegrator allows ensuring the mixture correspondence to the ecological and technological demands within the minimum of time.

Waste-free processing concept for the off-grade raw minerals combines the technologies of using the metalliferous natural resources, ensuring the inclusion of processing tailings into the natural cycle [5]. It is based on the following propositions:

1. The traditional concentration processes do not ensure the full mineral disclosure, so they cannot be called for the deep metal extraction from processing tailings.

2. The innovation methods of hydro-metallurgic and chemical processing increase the concentration efficiency by raising the number of used energy types.

3. The prospective course in metal extraction from the off-grade raw materials is combining the possibilities of chemical leaching and mechanical activation in disintegrator, when the leaching solution is intensively pressed into the cracks made by destruction.

The results of the experiment allow concluding that:

1. The traditional beneficiation technologies are bound by the extraction limit, the result of which is the tailings that cannot be further used for metal extraction by the known methods.

2. Metal extraction from the non-ferrous and ferrous metals tailings and coals is ensured by leaching in mechanic-chemical activation of raw materials.

3. The updating of the traditional beneficiation processes is to be performed by using hydro-metallurgic and chemical treatment processes applying the phenomenon of the large energy activation.

4. The results convergence of the processed tailings from different off-grade raw materials verifies the perfection of the method.

The basic effect of the processing tailings utilization that cannot be estimated objectively is the absence of necessity to store them on the Earth's surface and returning the lands to the economic use.

Storing the off-grade metalliferous raw materials on the Earth's surface has long formed the global problem, the radical solving of which is the utilization of dangerous and valuable anthropogenic raw materials barely.

Implementation of the present concept related to the waste-free utilization of the off-grade raw minerals ensures the possibility of using the processing tailings. The success of the concept implementation depends on the volumes of combining the processes of chemical leaching and mechanical activation in disintegrator within the sequence-linked operation.

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