

Shpylovyi K.L., Engineer
ORCID 0000-0002-9822-1500 geolog30@mail.ru

Shpylovyi L.V., PhD
ORCID 0000-0002-8053-8905 mineraltech.azov@gmail.com
LLC «Azov-Mineraltechnika», Mariupol

Biletskyi V.S., DSc, Professor
ORCID 0000-0003-2936-9680 ukcdb@i.ua

Komarova O.I., Lecturer
komarova.poltava@gmail.com
Poltava National Technical Yurii Kondratiuk University

TECHNIQUE AND TECHNOLOGY OF RARE-METAL ORES DESINTEGRATION AND GRAVITY-BASED BENEFICIATION

On the base of the analysis of centrifugal concentrators designs there has been justified the selection of apparatus for the rare-metal ores beneficiation. Process of pyrochlore ore grinding in mills of different types has been investigated and the expediency of use of impact-centrifugal action mills to ensure selectivity of minerals disclosure has been founded. Efficient technical and technological parameters of the centrifugal action mills have been justified on the base of active experimental method. The influence of disintegration methods on technological indication of rare-metal ore beneficiation of Mazurovske deposits in centrifugal Nelson concentrator has been analyzed.

Keywords: centrifugal concentrator, ore preparation, gravity-based beneficiation in centrifugal field, disintegration, a mill of impact-centrifugal action type.

Шпильовий К.Л., інженер

Шпильовий Л.В., к.т.н.

ТОВ «Азов-Мінералтехніка», Маріуполь

Білецький В.С., д.т.н., професор

Комарова О.І., викладач

Полтавський національний технічний університет імені Юрія Кондратюка

ТЕХНІКА ТА ТЕХНОЛОГІЯ ДЕЗІНТЕГРАЦІЇ Й ГРАВІТАЦІЙНОГО ЗБАГАЧЕННЯ РІДКІСНОМЕТАЛІЧНИХ РУД

На основі аналізу конструкцій відцентрових концентраторів обґрунтовано вибір апарата для збагачення рідкіснометалічних руд. Виконано дослідження процесу подрібнення пірохлорової руди в млинах різного типу та встановлено доцільність застосування млинів ударно-відцентрової дії для забезпечення селективності розкриття мінералів. Методом активного експерименту обґрунтовано раціональні технічні та технологічні параметри млина ударно-відцентрової дії. Проаналізовано вплив способів дезінтеграції на технологічні показники збагачення рідкіснометалевої руди Мазурівського родовища у відцентровому концентраторі Нельсона.

Ключові слова: відцентровий концентратор, рудопідготовка, гравітаційне збагачення у відцентровому полі, дезінтеграція, млин ударно-відцентрового типу.

Introduction. Development and improvement of technical devices for the enrichment of rare-metal ores is an important issue of mining machinery manufacturing. This is due to specific properties of processed raw materials - rare metals, which are more often poor and finely disseminated. Traditional gravity-based machines and methods of beneficiation of such ores do not provide sufficiently high recovery of metals into rough concentrates. Thus, long-term investigations of rare metals ores enrichment of Mazurovskoe deposit (the only in Ukraine) by various research organizations in order to develop effective technologies of enrichment did not reach positive results. Extracting the most valuable mineral – pyrochlore, – at the best case did not exceed 35÷40 % [1].

The general trend of involving the poor rare metal raw materials into processing and reducing the size of valuable components grains in it need to solve the problem of processing of finely disseminated ores and encouraging of dump products of enrichment, accumulated over a long period of processing plants operation.

Low in pyrochlores recovery values independently from methods of enrichment are due to dissemination of niobium ores, and related to it necessity of grinding them to a particle size 0,071 – 0,044 mm. Due to the high fragility of pyrochlore and its lower strength, in comparison with other minerals of the ore, it is taking place its regrinding and formation of oily spot on the surface of rock constituents, inclusions of pyrochlore on the high layer of albite, microcline, nepheline grains. Surface properties of these minerals are changed, contrast of their properties is reduced and, as a consequence, the efficiency of enrichment.

Improvement of ore preparation by investigation of the known methods of selective disintegration, selection and justification of equipment and technologies that provide the least regrinding of pyrochlore, and high indicators of its extraction in the conditions of gravitational enrichment, is a relevant task.

Analysis of recent research sources and publications. In terms of broad involving poor disseminated rare metal raw materials in to processing, the main direction of development of gravity-based means of separation has become the theoretical substantiation and development of technologies and devices for the enrichment of fine-grained and fine-dispersed materials.

The gravity-base method is used to enrich the ore of a sufficiently wide range of grain size from 500-600 mm (heavy-medium separation) to 0,005 mm (in centrifugal concentrators). This method is environmentally friendly and in many cases the least expensive. Principles of gravity-based separation is widely used both in the direct enrichment of various ores, and in ores preparation for products classification and dehydration.

There has been created a scientific base of gravity concentration [2 – 3]. The efforts of researchers and designers has always been focused on two main and interrelated issues: improving the accuracy of ore components separation and improving processing equipment productivity.

At first this problem was solved by reducing the thickness of the slurry flow in the devices of gravity concentration, and decrease in flow rate of the pulp. There have been proposed gateways of small filling with different kinds of trapping coatings, which were operated successfully. There appeared slurry concentration tables with shallow ariplane and without them (Hollman), multideck slurry concentrators with periodic flushing of concentrate (Moseley), tape slurry concentrators with continuous discharge (Crossbelt), were improved multideck cone separators (Reichert), were widely used screw-gateways [4]. However, while reducing the particle size of enriched material to ensure high quality performance it was always necessary to get significant diminished performance of separators. Attempts to apply high-frequency vibrations of pulp in the apparatus with a thick layer of concentrated particles during isolation and on vibrating chutes were unsuccessful.

Today the greatest prospects in creation of machines and technologies for the enrichment of fine-grained and finely disseminated ores, sands, and anthropogenic materials are associated with the use of centrifugal separators of various types [5], in particular, the pressure and free-flow. The former appeared in the middle of the last century and represented the hydrocyclones with the truncated conical portion, the so-called short-head hydrocyclones. They provided a relatively high degree of concentration of high density valuable components under a small output of concentrate. In devices of such type the movement of slurry flow is turbulent by nature, that definitely leads to intensive intermixing of the material, which is divided, and decreasing accuracy of the gravity separation.

At the end of the twentieth century there were developed the first designs of free-flow centrifugal gravity concentrators, that have given new opportunities in gravity-base concentration [6]. The successful and wide application of these devices in mining and concentrating plants confirmed the high perspective of further research and new design developments in this direction.

Centrifugal field in separators or concentrators is created by means of twisting of flow that freely moves in the apparatus, the wall of the bowl that rotates. A necessary condition for centrifugal enrichment of minerals in water environment is the availability of transport (flushing) flows in the direction that does not coincide with the force vector of the centrifugal field. In free-flow centrifugal gravity concentrators, feeding moves along the axis of rotation to the central part of apparatus bowl. Suspension is tightened to forced rotational movement, forming a three-dimensional spiral stream. The material is stratified throughout the trapping surfaces of rotating [7].

The main advantages of centrifugal concentrators in comparison with other devices of gravity concentration are: large specific capacity, high degree of concentration; high recovery of small and fine particles of heavy minerals; the ability of operational management of concentration degree.

Numerous designs of free-flow centrifugal gravity concentrators have different technical and technological parameters. The choice of apparatus design which will provide high rates of separation of ore minerals of a specific type of ore, and justification of machine technical and technological parameters remain non formalized procedure.

Taking into account that pyrochlore ore, to which Mazurovskoe deposit ore belong to are easily overgrinded and centrifugal concentrators do not provide a high separation ore performance while working with material smaller than 0.02 mm, it is important to choose a mill for grinding.

For a long time the study of the selective grinding of pyrochlore ores did not attract appropriate attention. Ores disclosure is carried out by methods which are based on minerals grinding, which are not specifically aimed at the destruction of their planes of cleavage [8]. When the final aim of grinding is to form the possibly new material surface per unit of energy expended, this goal is not only inconsistent with, but contrary to the basic objectives of ore preparation for beneficiation, as it does not conform to the principle «not to split anything extra». This is one of the reasons that the preparation of the ore remains the most energy-intensive, cost and badly managed operation in ore processing technology [9]. With the increasing of specific surface area of the grinded material, it occurs the aggregation of particles, there arise considerable efforts of molecular interactions that begin to exceed the force of separation, that leads to the reduction of the beneficiation selectivity [10].

The ores selective disintegration in apparatus of different designs was studied in many works [11, 12]. Ores desintegration process in mills of impact-centrifugal type were studied in many works [13, 14]. In the work [15] for the first time there were identified. Some common factors of rare-metals ore grinding of several foreign deposits. Some conclusions have been done. They are: in these ways of the disintegration the bulk of

massive material is being destroyed by the planes of cleavage. Ores and mineral grains destruction character as a result of milling is largely determined by structural features. Even at the same compressive, tensile or shear loads, the stress state and deformation of the ore lumps and separate grains will be difficult. So, under the destruction of the calcite grains by separation in terms of cleavage area on the destruction surface there are formed ledges (steps) on which shear deformation are develop. Under the destruction of polycrystalline ore by stretching, displacement or compression there are always plane shear and detachment [11, 12, 15].

The selection of the general problem parts, which were not resolved before. In the work [16, 17] there were initiated the study of the process of disintegration of rare metals ore of Mazurovskoe deposit. This work is a continuation of previous studies that have not yet evaluated the choice of the rational design of centrifugal concentrator to enrich finely disseminated ores of Mazurovske deposits and to justify the technical and technological parameters, to select grinding mill type and study the influence of grinding ore methods on the technological indicators of enrichment in a centrifugal field.

Statement of the problem. The aim of this work is to justify the rational design of centrifugal concentrator and study the effect of disintegration methods on the ore beneficiation index in the separator of centrifugal type, to study the process of selective disintegration of Mazurovskoe niobium ore deposits in grinding apparatus of various types, to justify rational method of ore grinding and technical and technological parameters of the process.

Main material and results. When investigating there were used the basic types of Mazurovskoe ore deposit – *mariupolite*, mineral and chemical composition of which is given in the work [17]. Pyrochlore is the only the actual niobium mineral of Mazurovskoe deposit, in which the mineral grains are in small amount (0,15-0,17 %) and forms small breeding clusters of small grains in albite, seldom - in lepidomelane and aegrine [18]. Pyrochlore has the form of automorphic isometric small grains (0,005-0,030 mm, sometimes up to 0.05 mm) and crystals of octahedrites shape of reddish-brown or yellowish-brown color, with a greasy luster. Pyrochlore density is 4,2 g/cm³, the strength according to the Mohs scale – 2...3 [19].

Experimental study of ores grinding and determination of the optimal design of the disintegrator included the study of the kinetics of comminution and disclosure of rare-metals ore in the mills that implement various physical principles of grinding. There has been tested a bullet, rod milling, grinding in the mills of impact-centrifugal type.

The presence of fine pyrochlore ore minerals disseminations in Mazurovskoe deposit ores requires ore grinding to the size of 0,063÷0,044 mm for a more complete disclosure of aggregates. On the other hand, such fine grinding leads to the formation of large amounts of sludge (up to 27 % of the original ore), and it is lost at least 15-20 % of Nb₂O₅. Extraction of valuable components from the sludges is rather problematic. Therefore, the main criterion for the choice of the mill construction was a low level of valuable components losses from the sludge by crushing, and a high degree of disclosure on cleavage contacts of minerals.

In the study of different disintegrants, the primary assessment of ore grinding effectiveness, in accordance with the first criterion (reducing losses with sludge) was carried out by the comparison of the sieve composition of crushed products and distribution of component in size classes. These data are presented in Fig. 1, 2.

From these data it follows that for the main types of Mazurovskoe deposit ore – *mariupolite*, – for grinding methods in ball and rod mills one can see an increase of content of niobium pentoxide in grinded products in the interval of –0,09 +0,010 mm size (maximum in the interval of –0,02 +0,01 mm). For impact-centrifugal milling method, high content of pentoxide of niobium in the grinded product was observed in the range of –0,056 +0,044 mm (Fig.1).

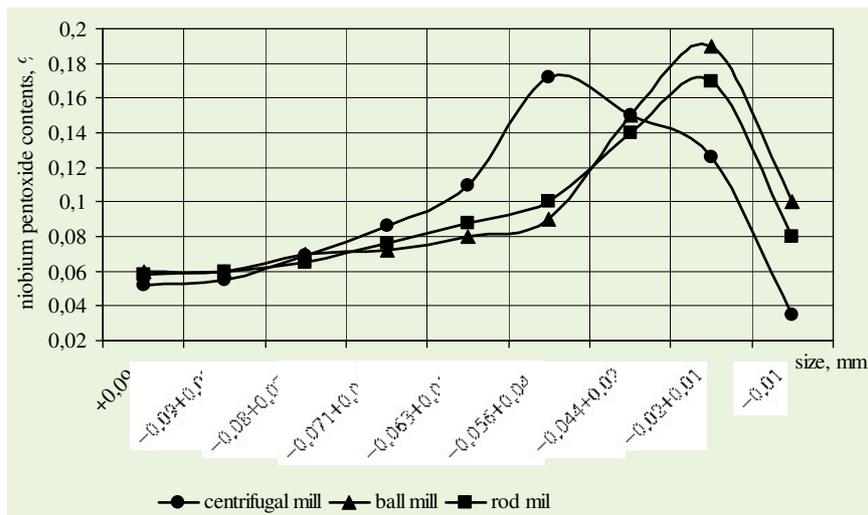


Figure 1 – Dependence of the content of niobium pentoxide from the particle size of crushed product and the method of disintegration

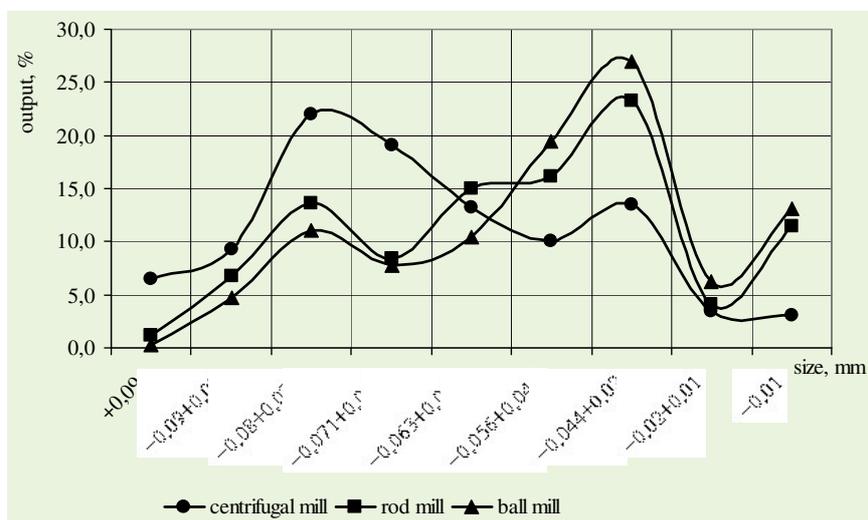


Figure 2 – Dependence of the classes emission from the particle size and the method of disintegration

The maximum output of the crushed material for grinding in a ball and rod, mills have the class from $-0,044$ to $+0,02$ mm (Fig. 2). For centrifugal grinding mill the maximum is in the class from $-0,08$ to $+0,071$ mm. This is probably due to the different strength of pyrochlore and host rocks.

The analysis of niobium pentoxide distribution on size classes showed that the removing of pentoxide of niobium in sludge ($-0,01$ mm) is the lowest when grinding in a centrifugal-impact action mill – not higher than 0,03 % (relative), the highest is up to 12 % of niobium pentoxide – when grinding in a ball mill.

The results of the gravitational analysis of the crushed material made by the method [20], showed that unlike with other methods of disintegration, the maximum value of niobium pentoxide extraction in a heavy fraction with a density above $2,8 \text{ g/cm}^3$ is in size of $0,071 \div 0,050$ mm when grinding in a mill of impact centrifugal action. In this type of disintegration niobium pentoxide losses are minimal.

Disclosure data of the investigated variety of ore – mariupolite – during disintegration in apparatus of different designs are given in Table 1 (assessment of disclosure was conducted on non-metallic component). As you can see, the degree of their disclosure after various

grinding methods varies widely. Evaluation of the results was performed using the indicator of ore preparation effectiveness of ore disclosure in accordance with the formula for its determination [15].

The calculated value of this index for each method of disintegration is given in Table 1. Based on this comparison, the most acceptable were centrifugal impact grinding, which greatly exceeds in the efficiency the grinding in the rod mill type. It is characteristic, that the value of the indicator of the effectiveness of ore pretreatment on disclosure of ore for this method of disintegration is close to unity, which indicates a preferential disclosure of ores for the planes of cleavage.

Comparing the evaluation results of the ores disclosure selectivity by various methods, we must say that for ores of Mazurovskoe deposits, grinding in a mill of centrifugal-impact type gives the best results. Thus there is a selective destruction of both ore and non-metallic (albite, microcline, nepheline) minerals. The degree of destruction is determined by the characteristics of ores and methods of disintegration. The data, confirming the existence of a selective destruction of ore, is shown in Fig. 1, 2 and in Table 1.

Table 1 – Evaluation results grinding of mariupolite

The methods of ores disintegration	Size (% class -0,1 mm)	Output of class, %				Contents Nb ₂ O ₅ , %				The degree of disclosure of non-ores material, %	Index of intracrystalline fracture (i)
		-0,044 mm		+0,044 mm		-0,044 mm		+0,044 mm			
		<2,8	>2,8	<2,8	>2,8	<2,8	>2,8	<2,8	>2,8		
Ball mill	96,3	43,84	0,96	51,77	3,43	0,070	2,95	0,040	0,59	77,4	0,38
Rod mill	94,8	37,68	1,22	56,87	4,23	0,068	3,01	0,038	0,82	71,2	0,48
Impact-centrifugal mill	93,5	18,30	1,60	74,16	5,94	0,027	0,92	0,023	4,70	93,7	0,87

In cours of mariupolite crushing, - there is a significant increase in the mass fraction of niobium pentoxide in thin classes. This increase can be used for fractionated enrichment of large and small classes after grinding. But such fractionation should provide high performance technology to extract of niobium pentoxide from thin classes. Based on the criterion of better disclosure of ores, as determined by the degree of expansion and the efficiency coefficient of pretreatment on disclosure of ores, the rational design of the mill for Mazurovskoe deposit ores is a centrifugal-impact type apparatus.

To justify the optimal technological parameters of ore selective crushing, investigations were carried out in ДЦ-0,36 centrifugal mill of centrifugal impact type. The mill was equipped with a dynamic centrifugal separator and dust cleaning system.

The dependence of the content of class -0,044 mm (C , %) in the crushed product on the peripheral speed of the rotor of centrifugal mill (V), the load on the mill in the original ore (Q) and size of original ore (d) were studied using active experiment. For planing of the experiment there was used rotatable central compositional plan of second order [21]. The main levels, the intervals of variation of factors and the study area boundary given in Table 2, have been selected on the basis of apriori information and the results of preliminary experiments.

Processing of results of experiments and analysis of regression models was performed using the module «Design of experiments» of statistical software Statgraphics Plus 5.1 [23].

Adequate model ($R^2 = 99,5 \%$) taking into account the importance of factors given in normalized (coded) form received as the regression equation:

$$C = 50,409 + 9,71388X_1 - 8,01511X_2 - 4,98155X_3 - 1,97968X_1^2 - 0,99625X_1X_2 - 0,89375X_1X_3 + 0,848765X_3^2 \quad (1)$$

Table 2 – The main levels, the intervals of variation of factors and investigation field boundaries

Parameters	Marking	Code	Unit	Main levels				
				+1,682	+1	0	-1	-1,682
Angular velocity (peripheral speed) of centrifugal mills rotor	V	X_1	m/sec	86,88	80	70	60	53,18
Size of output ore	d	X_2	mm	18,7	16	12	8	5,3
Consumption of output ore	Q	X_3	kg/h	2841	2500	2000	1500	1159

The values of the regression coefficients in equation (1) determine the strength of influence of the relevant factors or their combinations on the magnitude response function, and the sign before the coefficient, - the nature of this influence. As you can see, the content of the class $-0,044$ mm in the original product are mostly affected by peripheral speed of the rotor of the centrifugal mill and the particle size of the original ore. But we must take into account that the factors X_1 and X_3 enter the equation in the form of quadratic terms, that leads to an underestimation of their influence on the response function when evaluating the magnitude of the regression coefficients.

Analysis of the regression model, implemented using the statistical software «Statgraphics Plus 5.1», showed that the increase of peripheral speed of the centrifugal mill accelerator leads to a notable increase in the content of the class $-0,044$ mm in the original grinding product. The growth of the content of this class is slowing down slightly when you change the peripheral speed of the accelerator from 80 to 85-87 km/h. Speed 85-87 m/sec. can be considered optimal for the model of centrifugal-impact action mill.

The increase of original ore size, feeding to the grinding, leads to a decrease of the content of the class $-0,044$ mm. The highest content of this class occurs when grinding small ore particles size 6-4 mm.

Finally, the increased load on the centrifugal mill in the original ore, also leads to a decrease in the content of the class $-0,044$ mm in the finished product. Optimal one according to this criterion of load should take 1100-1200 kg/h.

As it is known, the separation efficiency of a mixture of minerals in a centrifugal field depends on the mobility of the mineral bed in the bowl of the concentrator. Therefore, when designing devices of this type, the main efforts are aimed at finding effective ways of breaking the minerals in the zones of concentration of heavy fractions in the separator. Today there are several ways of loosening of mineral bed designs of centrifugal concentrators are differed [24]:

- due to the reversal translational harmonic vibrations of housing - drum, which rotates;

- with the help of special scrapers;
- with the help of a water jets applied to the surface of the pulp, which rotates;
- with the help of trapping cone vibrations;
- by changing the radius of the trapping cone surface;
- by supplying pressurizing water from the external side of trapping cone through the holes in it.

Let`s analyze the basic structural differences of these separators (Fig. 3). In separators of the first type of the separation of minerals occurs in a thin layer of slurry, which is fed onto the inner surface of sebokeng rotating drum (Fig. 3a). For loosening of adhering particles the drum makes along the axis the reciprocating harmonic vibrations with frequency and amplitude, which provide loosening (rosperity) of grains of the bed in which heavy particles of minerals are trapped.

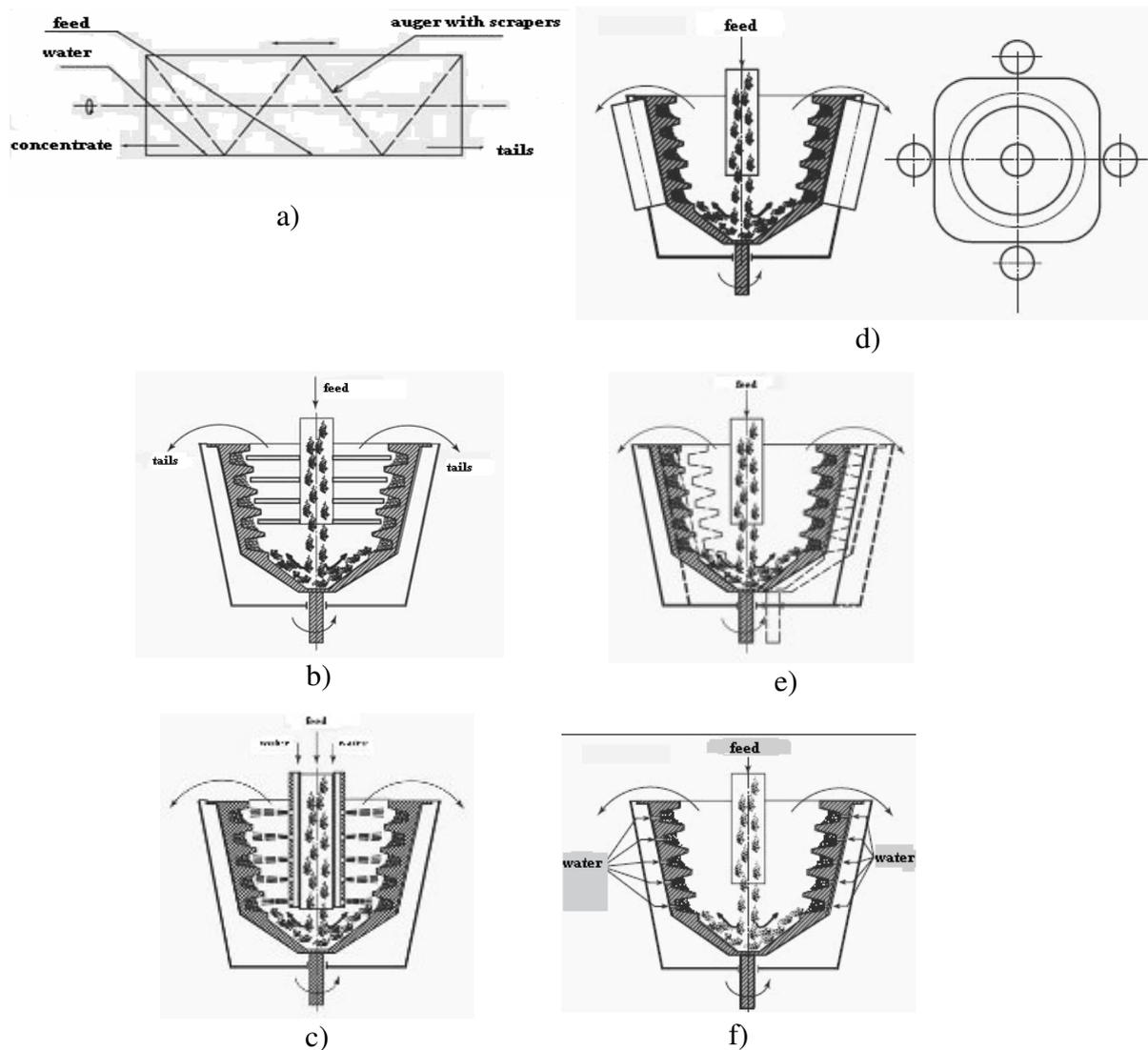


Figure 3 – Design features of mineral bed loosening [11]:

- a – due to the reciprocal harmonic of the drum shell;
- b – using knives;
- c – using jets of water that are fed to the pulp surface which rotates;
- d – due to the change of the radius of the surface of the bowl (floating bed);
- e – using the vibration of the bowl;
- f – by supplying water under pressure from the external side of the bowl through the holes in it.

Discharge of the concentrate is carried out using scrapers attached to the edges of the screw, which rotates with the frequency slightly lower the frequency of the drum rotation. This ensures the movement of the concentrate in the direction opposite to the direction of the pulp flow. The concentrate is additionally washed with fresh water. The enrichment in a thin layer of the pulp provides the highest separation index of small size particles of 5-6 microns. However, the productivity of such machines is small due to the fact that the pulp layer has a thickness of only 1-2 mm. For example, MGS industrial separators with drum diameter of about one meter have a capacity of 1,5-3,0 t/h [24].

Most of the existing separators of other types have a conical working bodies – cup, installed vertically or horizontally. The process of separating in them is involved in such a way. Pulp by itself, enters the lower part of the bowl that rotates. Under the action of centrifugal force, mineral particles are discarded to the walls of the cup and, rising up, fill annular recesses (riffle) in it. It is formed a bed of mineral particles. Slurry passing over the surface of the bed, loosens the layer of material to a small depth where sequestration of heavy grains take place. Light particles are displaced by the heavy ones and fall in the tails. Heavy particles are concentrated in riffles, until the filling of merifluor space and compaction of the bed. If not to loosen the bed, it will quickly be thicken, and in 10-15 minutes separation of heavy particles almost stop.

Rosperity of concentration of heavy fractions zone contributes to the penetration of the heavy minerals in the depth of bed so that lengthens the process of effective enrichment up to several hours. A way to hang the linen greatly affects the efficiency of the separation process in a centrifugal concentrator.

Centrifugal concentrator with a loosening of bed by scrapers (Fig. 3b) appeared on the market of mineral processing equipment in the early 1980-es in Australia [25]. While processing output material in such separator the amount of useful material in the concentrate to output ore is increased in 100-600 times. The removal of minerals with density of 8000 kg/m^3 and a particle size of $-2,0+0,2 \text{ mm}$ – up to 80 %. A serious drawback in the design of the separator, and primarily in the method of bed loosening, is that even small performance gains ($10\div 15 \text{ g}$), imposed on the pupl flow, compress the material in that part of riffles where scraper is missed, to such an extent that it is necessary to cut down while unloading concentrate. Howerer this part of valuable components is lost.

The design of the concentrator with bed loosened by water jets (Fig. 3c), which is supplied to the inner surface of the bowl is rotating, similar to the previous one, where instead of the scrapers along the radius through the holes of the hollow shaft they receive jets of water which loosen up the surface of the bed [26]. Many models of this centerator are offered abroad, but the difficulty of adjusting the mode of separation, a significant impact on the process of loosening vibrations of the granulometric composition of pulp feeding, pressing interriffles space, difficulty rinsing of concentrate is not allowed to create a competitive machine.

Another construction of centrifugal concentrator with the bed loosening by changing the surface radius of the catching bowl (Fig. 3d) appeared in the 90-es of XX c. almost simultaneously in several countries. A special feature of its design is wrought catching vertical bowl made from polyurethane. A bowl, obtienen from three or four sides by the rollers, takes in its upper part the form of a triangle or square with smoothed angles. Settling in the interriffles space of the bowl, the particles, moving, periodically approach and receed from the axis of the bowl rotation. The bed is loosened mechanically with level of loosening depending on the frequency of the bowl rotation. On the heavy minerals concentrated in bowl riffles, there are overlaid variables on the rate of acceleration, and changes of the shape of the bowl surface provide the hanging of particles, that creates favorable conditions for separation. The main disadvantage of these separators is the lack of strength of the cup in rough use, which can withstand large alternating loads and connected with it energy intensity drive due to the need of the compressive rollers moving in the bowl [28].

Centrifugal concentrators with a bed loosening by using vibrations (Fig. 3d) of trapping cone (bowl) in which the regulation of concentrate solidification process is carried out by the blow vibration creating a circular planetary oscillations of the axis of the bowl rotation with a frequency of 150 Hz and an amplitude of 1-3 mm, were not used widely in industry on core operations through low productivity [27].

In the apparatus with the bed loosening due to water pressure (3e), which is supplied from the external side of the catch bowl through the holes in the bowl container to prevent the pressing of concentrate in riffles from the outside of the bowl towards the settling of mineral particles, water is supplied under pressure. Water jets create a common pressure gradient in riffle directed toward the centrifugal field, loosen concentrated layer of minerals, creating favorable conditions for the enrichment process. The ability to control the pressure of water supplied to the cup, allows to adjust the degree of bed loosening in concentrate riffles, which in turn creates optimal conditions for the concentration of minerals of different density and size. The degree of concentration in the separator of this type is up to 3000. The disadvantages of this device include low extraction of particle size of less than 0,02 mm (40-60 %) and the need for individual, experimental selection of water pressure for each type of mineral raw. At the same time, these concentrates are most widely used in industry, as in practice of enriching the necessity of crushing ore to a particle size less than 0,02 mm for the disclosure of minerals rarely occurs, and selection of the required water pressure for a particular type of mineral raw materials is not difficult [29].

Analysis of structures for free-flow concentrators, results of comparative tests of equipment of various types [30], allows to recommend centrifugal separator of the latter type for the beneficiation of rare-metal ores of Mazurovskoe deposit.

In Fig. 4 it is shown a scheme of a centrifugal concentrator construction, which explains the principle of the apparatus operation. Separation of minerals in this concentrator occurs in the following way. Pulp along the supply tube 6 is fed into the bowl 3 and sinks to the bottom. Under the action of centrifugal forces particles of the solid phase are displaced on the inner walls of the bowl to the top and consistently fill the riffles 2. Towards the particles motion from the holes 4 in riffle water jets are supplied from water jacket of the cup 5.

The water flow in the separator cup provides the advantage that the feed, concentrate and tails are less thickened, which prevents the silting-up of discharge lines.

The combination of gravitational acceleration high force (from 60g to 200g) and the original process of cultivation bed loosening by water provide such design with the higher degree of extraction of heavy mineral grains. With that it is achieved the maximum degree of reduction, full automation and concentrate saving (which is important, because of the high cost of rare metals concentrates). The capacity factor of such equipment reaches 98 %.

The design of the concentrator of periodic action, which implements this method of bed loosening is shown in Fig. 5. In the enclosure of the apparatus, there is a closed removable cover from the top 5 there is a shaft unit 8, mounted in two bearing supports. On the rotor there is mounted the bowl (cone) 6 with a water jacket. On the inner surface of polyurethane bowls special annular grooves – riffles are made, which accumulate the heavy fraction of material, which is separated. Water from the water jacket is fed into the middle of the bowl under slight pressure through the openings system in the bore walls. At the bottom of the bowl there is a special plug-in cone 7, which prevents rapid wearing process of the bowl bottom. On the alternating cone, it is fixed baffle plate 1, which serves for distribution of supply pulp. Concentrate supply by the pulp is carried out through the supply pipe 2, which passes through the removable lid. Through a multiport node 11 and the sealing sleeve 9 it is used the supply of water into the bowl of the concentrator. Erosion of compacted sludge is carried out through a chute 12. Beneficiation tails are discharged from the apparatus via a plug-in nozzle 4, a removable lid 5 and slot. Rotation of the concentrator bowl is provided from the electric drive through a belt drive and pulley on the rotor shaft 8.

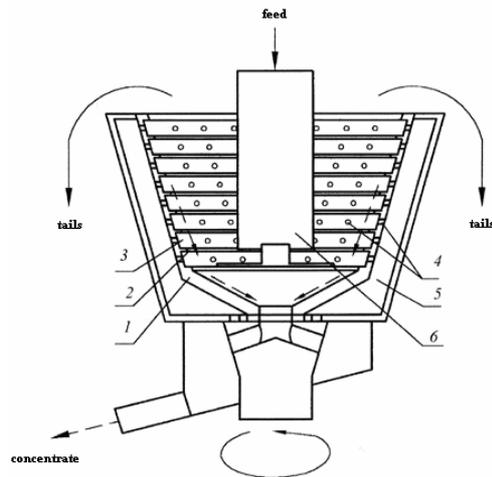


Figure 4 – diagram of the concentrators:

1 – concentrate removal chute; 2 – the annular grooves (riffles); 3 – concentrator bowl;
4 – holes for water flow; 5 – water jacket; 6 – supply pipe

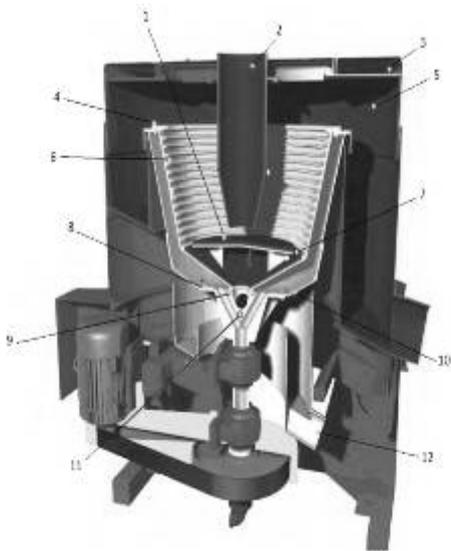


Figure 5 – KNELSON KC-XD concentrator with periodic loading out of the concentrate:

1 – reflective plate;
2 – supply pipe;
3 – changeable wearing skirt;
4 – changeable nozzles for discharge of sludge;
5 – removable cover;
6 – resistant polyurethane bowl;
7 – changeable wearing cone;
8 – rotor with removable shaft;
9 – seal sleeve;
10 – drain plug sediment;
11 – multiport junction;
12 – concentrate washing out chute

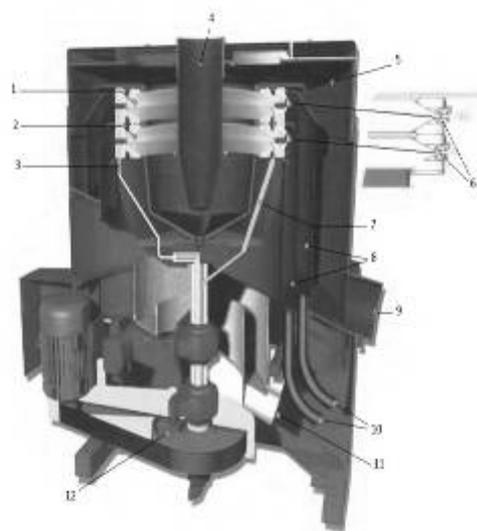


Figure 6 – KNELSON CVD-32-2 concentrator with continuous loading out of the concentrate:

1 – the second concentration ring;
2 – the first concentration ring;
3 – air supply;
4 – supply pipe;
5 – collection of tails;
6 – valves;
7 – water jacket;
8 – concentrate collections;
9 – tailings loading out chute;
10 – concentrate loading out nozzles;
11 – drain pipe;
12 – electric drive

The concentrator operation is carried out in the following way. Enrichment cycle begins with water supply from the water jacket through the holes system in the walls of the bowl (in riffles) in the middle of the bowl under a slight pressure. Then along the supply pipe in the bowl pulp is fed. Upon reaching the flow allocator at the bottom of the concentration bowl, pulp is directed upwards under the action of centrifugal force. The solid phase of the pulp fills the annular grooves (riffles) from the top to bottom. Upon accumulation of solid phase in the bowl there is formed a concentrational bed. Particles with high specific gravity are concentrated in riffles of the bowl, while lighter particles of gangue material are forced out of the bowl into the tailings chute.

After the completion of the established cycle of enrichment it occurs flush of accumulated concentrate in the concentrator chute through the original multi-port node. This operation is carried out automatically and takes maximum 2-3 minutes. While washing out staff access to concentrate is excluded which ensures their safety.

During machine operation all the particles in the concentrator bowl are under the influence of centrifugal force, the magnitude of which is regulated depending on the particular application conditions. The choice of the optimal rotor speed is based on several technological factors, such as the results of laboratory testing, specific gravity of heavy mineral grains and rocks, granulometric composition and content of useful mineral in the ore.

The concentrators with continuous discharge of the concentrate (Fig. 6) differ structurally from the series XD. They are specially designed for the case when it's necessary to have high output of the concentrate, which cannot be achieved in concentrators with periodic loading out. In these concentrators water is used for loosening the bed that serves in the middle of the bowl through the system of holes in the bowl walls, and high centrifugal accelerations. Pulp feed supply and loading out of the concentrate takes place simultaneously.

The work of the concentrator is taking place in the following way. First, in the middle of the bowl from a water jacket water is supplied through a system of holes in riffles. Then the supply pulp is fed through the supply pulp into the bowl.

Having reached the bottom of the bowl, the pulp under the centrifugal force effect is pushed up on the cup walls to a concentration of grooves (riffles). The pulp solid phase fills riffles, forming a bed. Water supplying into the bowl, provides more effective catching of the grains of the heavy fraction in riffles. The valves are actuated by compressed air, so the operator can regulate the concentrate output, if it's necessary, - apart from each ring. The concentrate is sent into the concentrates chute, and the tails are dropped through the upper part of the bowl into the tailings chute.

Under the pilot conditions the experimental «Azov-Mineraltehnika» wash house there were carried out investigations on the influence of methods of desintegration on the ore beneficiation index in the separator of centrifugal type. The original output ore was divided into two parts of approximately of 120 tons, one of which was grinded in the traditional ball mill of the MPs 1200*1200 type, the other - in a centrifugal mill of DC-0,36 throwing type. Both grinding devices worked in closed circuit with a separator of a transmission type. Milling was carried out to a particle size of 0,10 mm.

Ready-crushed material after each of the grinding devices again were divided into two parties, one of which was used directly for the preparation of pulp and served in a STS-400 centrifugal concentrator – the equivalent of the KNELSON CVD concentrator. The other party was subjected to magnetic separation at drum magnetic separators of СБ-25-100/0,25 and СБ-25-100/0,6 type for providing of optimum content of intermediate density minerals in the ore; then also it was served for the pulp preparation.

There were compared the results of minerals separation in a centrifugal field with different methods of grinding, and with different contents of minerals of intermediate density.

We investigated the nature of the pyrochlore grains disclosure with chosen grinding methods, the nature of pyrochlore grain distribution in size, and content of pentoxide of niobium in various size fractions, and the impact of weakened effect of the centrifugal mill on the process of consequent recovery of pyrochlore in gravity-based ore beneficiation in a centrifugal concentrator.

The main method of determining the content of chemical elements in grinded and enriched products was x-ray analysis. The mineral composition of samples was controlled by optical method using a microscope, particle-size composition – sieve and sedimentation method.

The results of the analysis of ore grain-size classes are given in Table 3.

The ore crushed in the ball mill was divided into two technological samples weighing about 60 tonnes each, after that one sample was sent for beneficiation in a centrifugal concentrator, and the other one to magnetic separation. Magnetic separation was carried out in induction on the drum separator surface of 0,15 Tesla and 0,55 Tesla.

Table 3 – Grain-size classes distribution (Nb,Ta)₂O₅ in maripolite, grinded to 0,1 mm

Grain-size classes, mm	Grinding in a ball mill			Grinding in a mill of impact-centrifugal action		
	Output, %	Mass fraction (Nb,Ta) ₂ O ₅ , %	Distribution (Nb,Ta) ₂ O ₅ , %	Output, %	Mass fraction (Nb,Ta) ₂ O ₅ , %	Distribution (Nb,Ta) ₂ O ₅ , %
+0,074	6,4	0,060	3,84	16,3	0,052	8,48
-0,071+0,063	19,3	0,070	13,51	27,2	0,066	17,95
-0,063+0,050	29,5	0,080	23,60	20,1	0,095	19,00
-0,050+0,040	15,0	0,090	13,50	17,7	0,150	26,55
-0,040+0,020	10,5	0,101	11,36	8,9	0,170	15,13
-0,020+0,010	6,2	0,150	9,30	4,1	0,126	5,20
-0,01	13,1	0,190	24,89	5,7	0,135	7,69
Output material	100,0	0,100	100,00	100,0	0,100	100,00

The results of the ore minerals separation into heavy and light fractions without a preliminary partial recovery of minerals of intermediate density are given in table 4; with preliminary removal – in table 5.

Table 4 – Indicators of ore beneficiation in Nelsons concentrator without preliminary extraction of intermediate density minerals

Products of beneficiation	Grinding in a ball mill			Grinding in a mill of impact-centrifugal action		
	Output, %	Mass fraction (Nb,Ta) ₂ O ₅ , %	Distribution (Nb,Ta) ₂ O ₅ , %	Output, %	Mass fraction (Nb,Ta) ₂ O ₅ , %	Distribution (Nb,Ta) ₂ O ₅ , %
Heavy fraction	4,39	1,110	48,52	3,22	2,030	65,37
Light fraction	95,61	0,054	51,48	96,78	0,036	34,63
TOTAL:	100,0	0,1000	100,00	100,0	0,100	100,0

Table 5 – Indicators of ore beneficiation in Nelsons concentrator with the preliminary extraction of intermediate density minerals

Products of beneficiation	Grinding in a ball mill			Grinding in a mill of impact-centrifugal action		
	Output, %	Mass fraction (Nb,Ta) ₂ O ₅ , %	Distribution (Nb,Ta) ₂ O ₅ %	Output, %	Mass fraction (Nb,Ta) ₂ O ₅ %	Distribution (Nb,Ta) ₂ O ₅ %
Heavy fraction	3,79	1,36	55,54	2,52	3,22	77,25
Light fraction	96,21	0,049	44,46	97,48	0,028	22,75
TOTAL:	100,0	0,1000	100,00	100,0	0,100	100,0

Analysis of research results shows that the use of selective grinding in a mill of impact-centrifugal action type allows to get more complete disclosure of pyrochlore in coarser heavier grain-size classes. As a result, a centrifugal concentrator allows to increase in such grinding the mass fraction of niobium pentoxide in the rough concentrate to 2,03 % in extraction 65,37 %.

Partial recovery of intermediate density minerals prior to gravitational enrichment in a centrifugal field leads to a substantial increase in the degree of pyrochlore extraction, especially in the case of ore grinding in the mill of impact-centrifugal type. The mass fraction of niobium pentoxide in this case is 3,22 % in extraction of 77,25 %.

Prepared in this way ore is enriched in a centrifugal gravity-based separator with high recovery – 35 % (relative) higher then pyrochlores extractions from the ore, prepared in a ball mill. At this the content of niobium pentoxide in draft concentrate (2,03 %) is almost twice higher its value in grinding ore in a ball mill (1,11 %).

Preliminary removal of intermediate density minerals from the ore leads to a further increase in the degree of pyrochlores extraction in centrifugal grinding - by 39.1 % (relative), in comparison with the grinding in the ball mill.

Conclusions.

1. The mill of impact-centrifugal action is an efficient machine for grinding of rare metals ore of Mazurovskoe deposit from the point of view of minimization of niobium valuable component losses with slurries, and disclosure of minerals. At this there takes place selective destruction of both ore and non-metallic (albite, microcline, nepheline) minerals.

2. Disclosure of minerals in this mill is taking place in coarser class – 0,08÷0,071 mm. It promotes the growth of gravitational enrichment indicators. The minerals output of the «technological» (the most open) class at this significantly higher.

3. Optimal technical and technological parameters of the mill of impact-centrifugal action are: peripheral speed of the rotor – 85÷87 m/sec., the ore output productivity – 1100÷1200 kg/h., the initial ore particle size of 4÷6 mm.

4. Design of centrifugal concentrator with bed loosening by jets of water is optimal for the separation of pyrochlore ore minerals of Mazurovsky Deposit.

5. The ore, grinded in a mill of the impact-centrifugal action type, is beneficiated in the centrifugal gravitation separator with the recovery extractions higher (relative) on 35 % then pyrochlore extractions from the ore, prepared in a ball mill. At this the content of niobium pentoxide in rough concentrate (2,03 per cent) is almost twice higher its value in grinding ore in a ball mill (1,11 %).

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