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SEMI-INDUSTRIAL TESTS OF A PROTOTYPE OF A NEW GRINDING EQUIPMENT – A LABYRINTH DISINTEGRATOR

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The article provides a brief description of a prototype of a new grinding equipment – a labyrinth disintegrator, manufactured according to our developments, as well as the results of semi-industrial tests on various materials with different hardness and brittleness. A scheme for grinding the material and a dynamic scheme for moving the material through the labyrinths are presented. The results of sieve analyze of selected materials are presented, and granulometric curves for the distribution of particles of materials are constructed.

Keywords: disintegrator, particle size distribution, grinding, sieve analysis, electrodes TsS-1 (Sormite-1)

1 INTRODUCTION

At the present stage of development of science, the technical level of the equipment used and auxiliary devices, fixtures, tools, etc. in various industries does not fully meet the requirements. In this regard, there is a need to reconstruct the existing equipment or create new equipment and tools that improve the quality and reduce the energy intensity of the technological process [1]-[3].

Material grinding processes are widely used in various industries. There are a large number of machines used for grinding solid and lumpy materials. The choice of a mill for industrial and research purposes should be carried out taking into account the specific properties of the material to be grind and the conditions of its use [4]-[7].

Materials of metallurgical and foundry refractories (bricks of various configurations) are ground in ball mills. These bricks are lining materials for blast furnaces, converter furnaces, electric arc furnaces and bottom refractories for induction and thermal heating furnaces.

We found that all mills operating with grinding media are the most common type of grinders [5], contaminate the final product and overheating [7], [8]. It has been established that in the waterfall mode of a ball mill, the balls falling on the balls cut out thin steel petals from them so that about 150–200 grams are collected in one ton of grinding of such chips.

They, getting into the body of refractory bricks, melting when the furnace is heated, lead to rupture, crack them, which ultimately leads to an emergency situation in furnaces [9].

The purpose of this article is to reflect the results of work about creation of a grinding labyrinth disintegrator as an alternative to existing ball (rod) mills, by conducting a comparative analysis, which follows from the features and disadvantages of ball mills.

Their main feature is their integration into a certain technological chain in mining and ore mass production using a wet method. Ball mills have many disadvantages: bulky and high metal consumption, the need for large areas for the installation of large lifting equipment for maintenance; large irretrievable losses of metal for the manufacture of the lining of the inner working surface of the barrel, grinding balls and rods; contamination of the pulp with metal sludge; strong noise generated by the movement of crushing bodies; low efficiency and grinding efficiency, since a lot of energy is expended on lifting a huge mass of crushing bodies, and their contact with the crushed material occurs over an insignificant surface.

A significant part of the energy is lost on lifting worn-out balls, on heating. Studies have found that grinding for useful work consumes only about 1% of the total energy expended.

Despite significant shortcomings, ball (rod) mills still operate in mining and enrichment plants, in the coal industry and in the production of construction materials. This is explained by the fact, as noted above, the integration of these mills into an established technological chain, which consists of different units that work together with ball mills, from which it is impossible to remove the ball mill.

We have experimentally established that all barrel-type mills with grinding balls operate in a cascade mode, and the waterfall mode is carried out not by centrifugal forces, as indicated in some sources, but exclusively with the help of the so-called elevators. In addition, with the wet method of grinding, balls falling from a certain height onto the viscous pulp located on the surface of the grinding load lose their kinetic energy and thereby the efficiency of grinding.

In the Pavlodar electrolysis plant, at the anode-production workshop, charge materials, such as coal tar pitch in solid form, petroleum coke and anode cinders, are also subject to grinding to a certain fraction. The conducted experiments showed that the labyrinth disintegrator not only grinds, but also mixes them with the technological consistency.

2 TEST OBJECT

The labyrinth disintegrator is designed for grinding various solid materials in various industries: metallurgy, construction, coal industry, etc. The solid material crushed in the labyrinth disintegrator can be used to produce highly dispersed metallurgical refractories, which are lining materials for blast furnaces, converter furnaces, electric arc furnaces and hearth refractories for induction and thermo-heating furnaces.

The disintegrator (Fig. 1) consists of a body, which is a metal structure of three plates interconnected by four columns, fastened with nuts.

A loading funnel is centrally attached to the upper plate from above, and a fixed labyrinth disk and a receiving hopper for collecting and dispensing ground materials are bolted to it from below.

A cylindrical bracket is installed on the middle plate, which is a housing for the rotor assembly of the mechanism. The rotor assembly consists of a vertical drive shaft, on which a movable disk with a hub is mounted on top, and a double-stranded belt pulley is mounted on the bottom. The shaft rotates supported by two radial and one thrust ball bearings.

To this plate from one end, from below, a special platform is attached, with the help of bolted connections, for a flange-type electric motor, which rotates the rotor assembly of the mechanism with the help of a belt drive.

The bottom plate serves as a support frame for four vertical columns and is mounted on a decorative tray that protects the bottom threaded connections from damage.

The disintegrator drive is a flange-mounted electric motor powered by an industrial network of □ 380 V, reliably grounded, with standard current-carrying devices [10].

A distinctive feature of the labyrinth disintegrator from similar grinding equipment [11]-[13] is the ability to adjust the gap between the upper fixed and lower rotating disks using replaceable washers of various thicknesses, which makes it possible to control the degree of grinding of the coarse fraction.

On the working surfaces of the labyrinth disks, 3.5 mm thick layers of high wear resistance and hardness are deposited with electrodes TsS-1 (Sormite-1).

The usage of this technology is due to the fact that the labyrinth discs are flat bodies with alternating thickness. Such products cannot be hardened, the surface layers of labyrinths in the traditional way in a hardening furnace due to the appearance of warpage and cracks during subsequent rapid cooling in the liquid. And, hardening with high-frequency currents requires a special inductor installation, the manufacture of which exceeds the cost of the disintegrator itself.

The use of a surfacing layer with high hardness and wear resistance not only protects the working surfaces of the labyrinth discs, but also, due to the increased surface roughness, materials are ground more intensively. As the surfacing layer wears out, they are renewed again, with sormite surfacing.

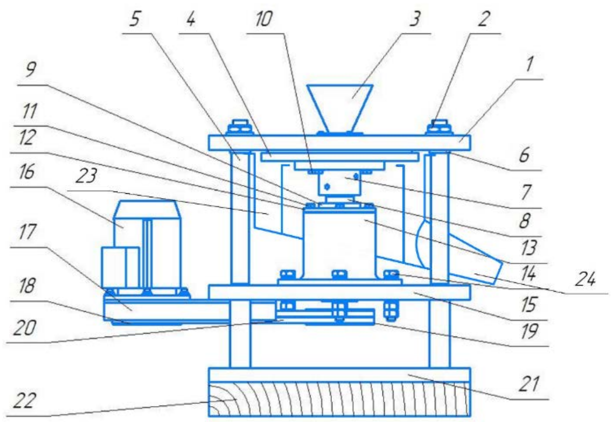

Fig. 1. Structural diagram of the labyrinth disintegrator. 1 – top plate; 2 – nut with washer; 3 – inlet pipe; 4 – movable disk with a central divider;5 – column; 6 – adjusting washer replaceable; 7 – conical bracket; 8 – drive shaft; 9 – cover; 10, 11 – fixing screw with washer; 12 – felt seal; 13 – bottom bracket cylindrical; 14 – fixing bolt with washer; 15 – medium plate; 16 – flanged electric motor; 17 – electric motor mounting plate with side stiffeners; 18 – motor pulley; 19 – rotor pulley; 20 – drive belt; 21 – bottom plate-frame; 22 – decorative pallet;
23 – an annular receiving hopper in a diametrical section made of tinplate; 24 – outlet pipe for the exit of ground materials

The grinding of the material occurs due to the centrifugal forces of the entrained initial particles through the labyrinths to the periphery of the disks (Fig. 2), because the ratio of gaps between disks to the periphery decrease according to a certain pattern.

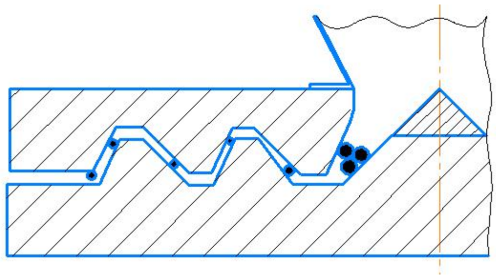

Fig.2. The scheme of grinding the material

The novelty of the design of the labyrinth disintegrator is confirmed by the patent of the Republic of Kazakhstan (patent application No. 124363, application registration number 2021/0651.1 dated 10/27/2021).

3 CONDITIONS AND TEST METHODOLOGY

The purpose of the study is to compile the technical characteristics of the labyrinth disintegrator when grinding materials, with different gaps between the disks. From the design of the disintegrator, we know the following data:

- gaps between discs Δ=10, 8, 6, 4, 2 mm;
- the initial supplied fraction by size depending on the gaps between the discs (Δ10=35–30 mm, Δ8=25–20 mm, Δ6=15–12 mm, Δ4=10–6 mm, Δ2=5–3 mm);
- installed power, 3 kW;
- rotational speed of the lower movable disk n=1500 rpm.

It is necessary to determine the hourly output q (kg/h) depending on the type of material and the gap between the discs, as well as the size of the corresponding grinding fraction.

Research was carried out in the laboratory of the department "Metallurgy" NJSC Toraigyrov University.

Six types of material were selected for the study: copper-molybdenum ore of the Aktogay deposit, limestone used as a flux in the smelting of ferrous metals in electric arc furnaces, and broken chromium-magnesite bricks used in lining the brickwork of furnaces. All these materials are characterized by increased hardness and abrasiveness. Therefore, three more lumpy materials were taken: coal tar pitch, petroleum coke, anode cinder, which are charge materials in the production of anode blocks for aluminum electrolysis production.

Unlike the first three materials, the latter are carbonaceous non-abrasive materials.

Crushed lumpy materials were previously crushed on a laboratory jaw crusher and sieved on a vibrating screen with 35 mm cells, for a gap Δ=10 mm; 25 mm for gap Δ=8 mm; 15 mm for clearance Δ=6 mm; 10 mm for gap Δ=4 mm; 5 mm for gap Δ=2 mm.

Each material was selected with a mass of 2500 grams so that for each type, grinding was carried out 5 times, 500 grams each. The grinding results were sifted through a standard set of sieves of the Usman Mechanical Plant for 5 minutes.

The results of sieving for this type of material and for the size of the gap were averaged and the indicators were recorded in the form of tables.

Samples weighing 500 grams are taken in order to determine the rate of material supply to the receiving funnel, which affects the performance result.

This approach allows you to choose the type of dispenser in the future.

Table 1. Sieve analysis of the studied materials

Sievenumber	The average grinding value of materials by sieves at Δ=10 mm											
	Coppermolybdenumore		limestone		Crushed parts of chrome magnesite bricks		Coaltarpitch		Petroleum coke		anodecinder	
	g	%	g	%	g	%	g	%	g	%	g	%
2,5	286	57,2	190	38	220	44	290	58	290	58	230	46
1,6	155	31	170	34	190	38	150	30	190	38	205	43
1,0	46	9,2	90	18	75	15	35	7,0	16	3,2	43	8,6

Sievenumber	The average grinding value of materials by sieves at Δ=10 mm											
	Coppermolybdenumore		limestone		Crushed parts of chrome magnesite bricks		Coaltarpitch		Petroleum coke		anodecinder	
	g	%	g	%	g	%	g	%	g	%	g	%
0,63	9	1,8	30	6,0	10	2,0	17,5	3,6	-	-	6	1,2
0,40	3	0,6	15	3,0	-	-	-	-	-	-	-	-
0,315	-	-	3	0,6	-	-	-	-	-	-	-	-
0,20	-	-	-	-	-	-	-	-	-	-	-	-
0,16	-	-	-	-	-	-	-	-	-	-	-	-
0,10	-	-	-	-	-	-	-	-	-	-	-	-
0,063	-	-	-	-	-	-	-	-	-	-	-	-
0,050	-	-	-	-	-	-	-	-	-	-	-	-
Pallet	-	-	-	-	-	-	-	-	-	-	-	-
Total	499	99,8	498	99,6	495	99	492	98,6	496	99,2	484	98,8

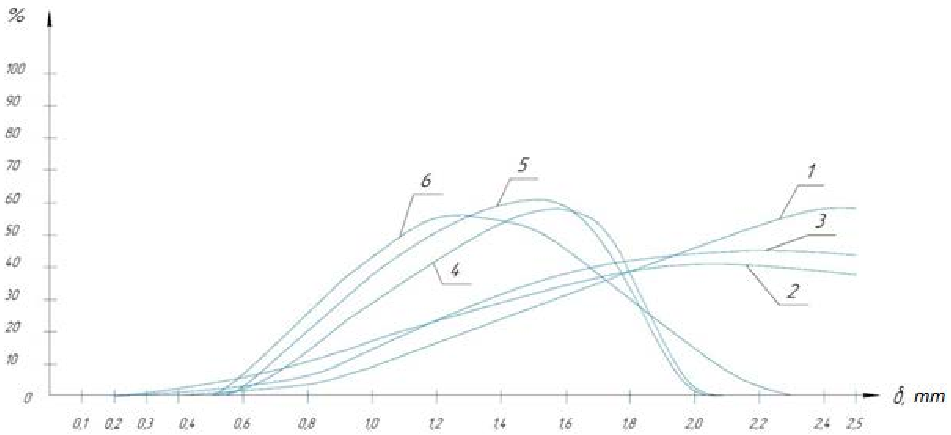

Fig. 3. Graph of the distribution for materials according to weights in sieve analysis withΔ=10 mm

Table 2. Sieve analysis of the studied materials

Sievenumber	The average grinding value of materials by sieves at Δ=10 mm											
	Coppermolybdenumore		limestone		Crushed parts of chrome magnesite bricks		coaltarpitch		Petroleum coke		anodecinder	
	g	%	g	%	g	%	g	%	g	%	g	%
2,5	-	-	-	-	-	-	-	-	-	-	-	-
1,6	250	50	225	45	150	30	-	-	-	-	-	-
1,0	175	35	200	40	260	52	90	18	60	12	130	25
0,63	65	13	60	12	75	15	230	46	215	43	230	45
0,40	5	1,0	10	2,0	11	2,2	100	20	140	28	85	17
0,315	-	-	-	-	-	-	58	11,6	60	12	40	8
0,20	-	-	-	-	-	-	20	4,0	20	4	6,0	1,2
0,16	-	-	-	-	-	-	-	-	-	-	-	-
0,10	-	-	-	-	-	-	-	-	-	-	-	-
0,063	-	-	-	-	-	-	-	-	-	-	-	-
0,050	-	-	-	-	-	-	-	-	-	-	-	-
Pallet	-	-	-	-	-	-	-	-	-	-	-	-
Total	495	99	495	99	496	99,2	498	99,6	495	99	491	98,2

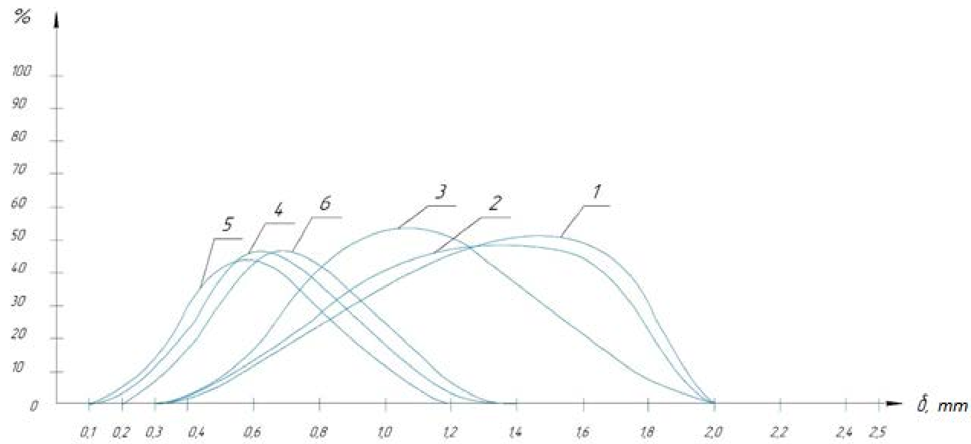

Fig. 4. Graph of the materials distribution according to weigh in sieve analysis withΔ=6 mm

Table 3. Sieve analysis of the studied materials

Sievenumber	The average grinding value of materials by sieves at Δ=10 mm											
	Coppermolybdenumore		Limestone		Crushed parts of chrome magnesite bricks		coaltarpitch		Petroleum coke		anodecinder	
	g	%	g	%	g	%	g	%	g	%	g	%
2,5	-	-	-	-	-	-	-	-	-	-	-	-
1,6	-	-	-	-	-	-	-	-	-	-	-	-
1,0	5	1	-	-	-	-	-	-	-	-	-	-
0,63	160	32	240	48	180	36	10	2	-	-	-	-
0,40	215	43	140	28	200	40	35	7	10	2	35	7
0,315	85	17	85	17	75	15	65	13	15	3	85	17
0,20	15	3	20	4	35	7	250	50	100	20	225	45
0,16	10	2	-	-	-	-	100	20	265	53	125	25
0,10	-	-	-	-	-	-	25	5	75	15	25	5
0,063	-	-	-	-	-	-	12,5	2,5	15	3	-	-
0,050	-	-	-	-	-	-	-	-	10	2	-	-
Pallet	-	-	-	-	-	-	-	-	-	-	-	-
Total	490	98	485	97	490	98	497,5	99,5	490	98	495	99

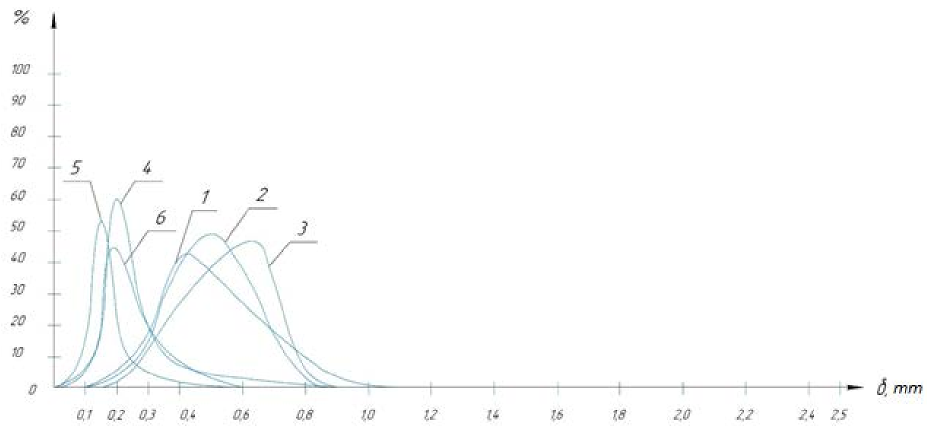

Fig. 5.Graph of the materials distribution according to weigh during sieve analysis withΔ=2 mm

When constructing graphs and tables, the materials were ground 5 times in turn in a disintegrator at appropriate gaps, then the results were averaged.

When compiling tables and graphs, we used approximation patterns and the laws of the Gaussian normal distribution, and based on them, the article showed the results for Δ=10, 6, 2 mm.

When constructing graphs, it was noticed that the distribution curves for each material, depending on the size of the gap Δ, steadily shift to the left and at the same time become, as it were, compact. From the chart atΔ=2 mm, with small assumptions, they could be combined into two generalized graphs (Fig. 6), since with a mental decrease in the gap between the grinding disks, the graphs in this form would merge.

Graphs for clarity are built on a double scale to clearly show the mode – 1, the median – 2 and the mathematical expectation m_s– 3 events.

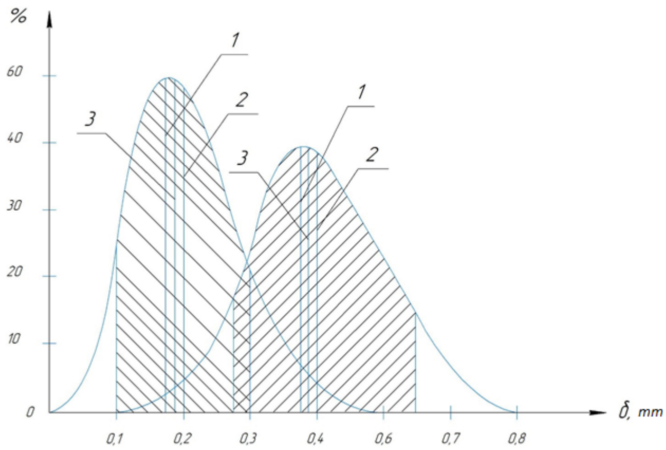

Fig.6. Graphs that determine the optimal area for grinding materials

The lines dropped from the peak of the Gaussian curves to the abscissa of the graphs are the mode; the lines lowered to the abscissa and dividing the areas under the Gaussian loop into two equal parts are the median; the lines between the median and the mode are, respectively, the mathematical expectation of the event. The numerical value of which for the left graph m_{sl}=0,18mm, and for the right – m_{sr}=0,38 mm. Values postponed fro mm_s at equal distances to the left and right, and the perpendiculars built from them to the abscissa, cut from the total area under the graph relative to the maximum area, are the optimal grinding value for this type of material. These areas are partially shaded in both graphs. Thus, for the left graph, the optimal grinding area is the fineness within σ_l=0,1–0,3 mm, and for the right graph – σ_r=0,28–0,65 mm. And values σ_{gen}=0,1-0,65 mm – are the maximum grinding values of all materials taken.

To simplify the presentation of the essence of the experiments, we will refer all abrasive and hard materials to the right graph, summarizing the data, and all non-abrasive carbon-containing materials, we will refer to the left graph, also summarizing the data.

When grinding each sample of material weighing 500 grams = 0.5 kg, the time spent on grinding was recorded and graphs were builtτ=f(Δ), which are shown in the fig.7.

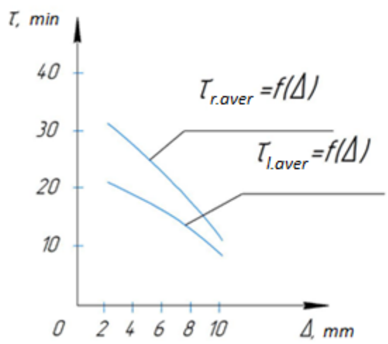

Fig. 7. Dependence of the grinding time τ on the gap time Δ

Using the graph data from Fig. 7, according to the formula

$$q\Delta = 60 / \tau_{aver} \cdot m \quad (1)$$

where τ_{aver}–grinding time, min;

m – weighing weight, kg

We determine the hourly productivity of the disintegrator with the appropriate gap and, based on the graphs (Fig. 3–5), we will draw up the technical characteristics of the disintegrator in the form of table 4.

Table 4. Technical characteristics of the labyrinth disintegrator

Name	Labyrinthdisintegrator				
Type	Disk-type				
Gaps between disks, mm	10	8	6	4	2
Initial fraction for all materials, mm	35–30	25–20	18–12	18–12	5–3
Grinding fraction, mm: - for abrasive materials - fornon-abrasivematerials	1,0–2,5 0,8–1,8	0,85–2,15 0,55–1,40	0,7–1,8 0,3–1,0	0,5–1,3 0,18–0,7	0,3–0,8 0,06–0,4
Grinding frequency: - for abrasive materials - for non-abrasive materials	18,6 25	15 23	12 22	8,9 18,2	7,3 17,4
Grinding capacity, kg/h: - for abrasive materials - fornon-abrasivematerials	150 231	100 150	79 111	66,5 100	57 83
Installedpower, kW	3				
Disc rotationfrequency, rpm	1500				
Overalldimensions, mm	760×160×820				
Weight, kg	728				

4 TEST RESULTS

During testing, the labyrinth disintegrator showed an average capacity of 200 kg/h on materials of various hardness and brittleness. Which for such a compact prototype device is acceptable.

The average values of the sieve analysis of the ground materials on the labyrinth disintegrator are given in table 1.

5 DISCUSSIONS

The design of the new labyrinth disintegrator is less energy-intensive compared to existing disintegrators, which is confirmed by the results gained by other authors [14,15], as well as the results of grinding in terms of granulometric properties depend on some factors, the influence of which is still being researched.

We have established the relationship between the size of the loaded material and the ground material; influence of gaps between disks on the final fineness of grinding; influence of material hardness and abrasiveness on sieving at a constant number of revolutions of a rotating disk, n=1500 rpm.

6 CONCLUSIONS

- It is established that the gaps between the grinding discs should be $\sigma \geq 2$ mm, in order to avoid collision of the sides of the discs with each other due to the occurrence of radial beats when grinding materials.
- It has been established that with a decrease in the gaps between the disks, the grinding spread decreases, which favors the production of more uniform powders in terms of granulometric composition.
- It has been established that the numerical values of the dispersion of the grinding fineness at different gaps decreases from 2,5–0,8 mm to 0,65–0,2 mm for hard abrasive materials and from 1,8–0.4 mm to 0,4–0,065 mm for non-abrasive carbon materials.
- It has been determined that the grinding time of materials increases as the gap between the discs decreases.
- It has been found that performance decreases as gaps decrease.
- It has been established that it is preferable for the proposed disintegrator to grind non-solid, non-abrasive materials, like the anode charge of aluminum electrolysis production.
- It is planned to change the number of revolutions of the movable disk in order to determine the influence of this parameter.

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