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Possibility of "Topionica" - Veles Pb-Zn slag valorization by gravity concentration procedure

Mogućnost valorizacije Pb-Zn šljake "Topionica"- Veles postupkom gravitacijske koncentracije

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Abstract

This paper presents the results of laboratory tests of the valorization possibility of Pb-Zn slag "Smelter" -Veles, by gravity concentration. It is an inhomogeneous raw material that has a significant content of non-ferrous metals, primarily Pb, Zn and Cu, as well as the presence of precious metal in the form of Ag. The contents of the mentioned non-ferrous metals vary from a few percent to over 10%. The content of silver also varies from a few grams per ton to as many as tens of grams per ton of technogenic raw materials. Mineralogical analysis of the products of the grinding experiment by size classes determined that the useful components from Pb-Zn slag "Veles" are free at grinding fineness of -0.1 + 0.00 mm. Thus, the prepared technogenic raw material was subjected to magnetic separation and gravitational concentration processes. In this paper, only gravitational concentration is treated. It was decided to perform the gravitational concentration of the individual size classes on the Wilfley 13 shaking table, with the selected table surface for small classes and sludges. The obtained results of gravitational concentration of different size classes show that there was a separation of individual components into separate products.. This operation of the lead separation into concentrate (ΔH fraction) and silver in lead concentrate (ΔH fraction) was relatively successful, while the separation of zinc and copper in concentrate (ΔH fraction) gave slightly worse results. The best results in terms of content of Pb, Zn, Cu and Ag in concentrate (ΔH fraction) were achieved for the largest class (-100 + 75 μm) where the content of Pb in this product is 8.44%, zinc 7.42%, copper 0.77% and silver 125 g/t. In all other concentrates (ΔH fractions) obtained from smaller size classes, lower contents of non-ferrous metals and silver in them were obtained.

Keywords: *slag, technogenic raw material, gravitational concentration, shaking table*

Izvod

U ovom radu prikazani su rezultati laboratorijskih ispitivanja mogućnosti valorizacije Pb-Zn šljake "Topionica"-Veles, postupkom gravitacijske koncentracije. U pitanju je nehomogena sirovina koja ima značajni sadržaj obojenih metala, prvenstveno Pb, Zn i Cu, kao i prisustvo plemenitih u vidu Ag. Sadržaji pomenutih obojenih metala variraju od nekoliko procenata pa i do preko 10%. Sadržaj srebra takođe varira od nekoliko grama po toni do čak nekoliko desetina grama po toni tehnogene sirovine. Mineraloškom analizom proizvoda opita mlevenja po klasama krupnoće utvrđeno je da su korisne komponente iz Pb-Zn šljake „Veles", slobodne pri finoći usitnjavanja -0,1+0,00mm. Ovako, pripremljena tehnogena sirovina podvrgnuta je postupcima magnetna separacija i gravitacijska koncentracija. U ovom radu obrađena je samo gravitacijska koncentracija. Odlučeno je da se gravitacijska koncentracija pojedinačnih klasa krupnoće obavi na klatnom stolu Wilfley 13, pri čemu je izabrana površina stola za sitne klase i muljeve. Dobijeni rezultati gravitacijske koncentracije različitih klasa krupnoće pokazuju da je došlo do separacije pojedinih komponenti u zasebne proizvode. Ova operacija odvajanja olova u koncentrat (ΔT frakcija) i srebra u koncentratu olova (ΔT frakcija) je bila relativno uspešna, dok je odvajanje cinka i bakra u koncentratu (ΔT frakcija)

dalo nešto lošije rezultate. Najbolji rezultati u pogledu sadržaja Pb, Zn, Cu i Ag u koncentratu (ΔT frakcija) su postignuti za najkrupniu klasu (-100+75 μm) gde je sadržaj Pb u ovom proizvodu 8,44%, cinka 7,42%, bakra 0,77% a srebra 125 g/t. U svim ostalim koncentratima (ΔT frakcijama) dobijenim iz sitnijih klasa krupnoće dobijeni su manji sadržaji i obojenih metala i srebra u njima.
Ključne reči: *šljaka, tehnogena sirovina, gravitacijska koncentracija, klatni sto*

Introduction

Slag from "Topionica" -Veles (Northern Macedonia) owned by the company "KEPS MONT GROUP" Skopje, according to the previously performed physical-chemical and mineral characterization is a potentially valuable raw material [1, 2]. Tests performed in the Laboratories of ITNMS and IRM-Bor showed that it is an inhomogeneous raw material with significant contents of non-ferrous metals, primarily Pb, Zn, Cu, and precious metal Ag is present. Slag from "Topionica" - Veles has a very variable content of useful metals, ranging from a wide range of several % of non-ferrous metals to over 10%, and the silver content is very variable from a few g/t to several tens of grams per ton of technogenic raw material.
Mineralogical tests have shown that the composition of techogenic raw materials is very complex and consists of amorphous and mineral phases, ie the microscopic method showed the following composition: **amorphous phase, lead alloys, zinc alloys, vistite (FeO), sphalerite, galena, cerusite, elemental silver, elemental copper, elemental iron, magnetite, spinel, rutile, hematite, troilite (FeS)**. The most common amorphous phase (glass matrix) of spinel, silicate and mixed (spinel-silicate) composition is in the sample, while vistite, which occurs in the form of skeletal separations in the glass matrix, is significantly less represented. Based on SEM analysis (scanning electron microscopy), these are Fe-Mn-Zn spinels. Lead and zinc alloys are the most common. Based on SEM analysis, these alloys are predominantly with copper. The grains of these phases range up to 100 μm, and appear almost exclusively as embeddings or inclusions, and in the best case simple to complex fusions with a glass matrix of elemental iron and vistite, while those larger than 100 μm are mostly free or in the form of simple fusions. The largest dimensions of these phases go up to 300 μm. The results of the mineralogical analysis have shown that the raw material is very complex and that for its eventual valorization and preparation it is necessary to examine in detail and determine what can be valorized and how it can be done [3, 4]. As this type of raw material has not been technologically treated so far in the laboratory or in the plant, so there are no starting points from the aspect of mineral preparation, the recording of all parameters relevant to the process of preparation and processing of this specific technogenic raw materials began. In addition, each phase of the preparation process was followed by analyzes that were supposed to indicate the relevance of the preparation process for the separation of useful components into commercial products.

Experimental part

Gravitational concentration of Pb-Zn slag "Veles"

The examination of the gravitational concentration was imposed as a possible solution for the valorization of Pb-Zn slag "Veles", after the unsuccessful application of magnetic separation for that purpose. When considering the manner and conditions for performing the gravitational concentration of slag, several premises must be taken into account, the main of which is that slag is not an ore, ie it is not a mineral raw material and mostly does not consist of minerals. Slag mainly consists of a glassy (amorphous) phase and metal alloys, as well as a smaller content of a mixture of amorphous phase and minerals. A detailed mineralogical analysis of slag was presented in a previous Study [2].

Mineral composition of Pb-Zn slag with properties of individual components

Previously performed grinding experiments and mineralogical examination by size classes determined that slag components are released at a grinding fineness of -0.1+0.00mm [2]. This means that such a ground sample of technogenic raw material can be considered as a starting point for the gravitational concentration and valorization of Pb-Zn slag "Veles", because only below -0.1mm the useful components of slag are free. In addition, this review presents the physical properties of the components present in Pb-Zn slag "Veles" that are important for defining the possibility of gravitational concentration.

Pb-Zn slag "Veles" consists of the following grains:

- oxidized lead alloys with copper and iron (Pb, Cu, O, Fe)
- oxidized lead alloys with copper (Pb, Cu, O,)
- specific grain weight oxidized lead alloy with copper γ=8.73-9.21 g/cm^3
- oxidized zinc alloys with copper (Cu, Fe, Zn, O)
- specific grain weight of oxidized zinc alloys with copper γ=6.33-6.73 g/cm^3
- grains of the mineral vistite γ=5.7 g/cm^3
- elemental iron grains γ=7.87 g/cm^3
- grains of galena mineral (PbS) γ=7.2-7.6 g/cm^3
- sphalerite mineral grains (ZnS) γ=3.9 - 4.1 g/cm^3
- amorphous phase grains (spinels) per frenclinite / magnetite chemical composition γ=5.07-5.22 g/cm^3
- silicate grains (by chemical composition gelenite / akermanite / wollastonite) γ=3.00 g/cm^3

Experimental conditions for performing gravity concentration experiments

In order for the experimental procedure of gravitational concentration on the sample of Pb-Zn slag "Veles" to be successful, several important conditions and principles were considered and harmonized:

- First of all, all theoretical principles, bases and knowledge in the field of gravitational concentration were respected, and as the most important from the segment of gravitational concentration of fine-grained classes.
- All experiences from previous tests of gravitational concentration and pre-concentration performed in ITNMS, on different ores, and primarily on similar mineral raw materials, were collected and analyzed.
- All mineralogical properties of technogenic raw material are considered, above all its structural and textural properties, degree of adhesion and liberation, as well as other physical properties that are important for gravitational concentration.
- Based on the mineral composition and properties of individual components, the determination of concentration criteria on the basis of which experimental tests are performed has been harmonized.
- Determination of the total number of size classes as well as their range on which the gravitational concentration procedure can be performed.
- According to all the previously listed parameters, the selection of the optimal device for performing experimental tests of the gravitational concentration of Pb-Zn slag "Veles" was made.

Concentration criterion for performing experiments

Concentration criterion is a parameter that defines the possibility to successfully perform the procedure of gravitational concentration of raw materials in water [3, 4]. Successful performance of the gravitational concentration procedure, ie separation of two minerals / components into separate products can be performed if the concentration criterion is higher than 1.5 ($\zeta > 1.5$). As the content of metal alloys in the sample of Pb-Zn slag "Veles" is about 5-6% (ie the content of tailings minerals just over 90%), the separation process was reduced to obtaining two products ΔH and ΔL. That is, the separation of the entire raw material into two fractions, of which ΔH concentrate of non-ferrous metal alloys and ΔL fraction of tailings [5, 6].

1. Separation in the two-component system of oxidized grains of lead-copper alloys - grains of the amorphous phase (spinels) when the concentration criterion for gravitational separation of these two components in a thin layer of water is calculated by the formula:

$$\zeta_1 = \frac{\gamma_{legPb} \quad -\gamma_{H2O}}{\gamma_{spinel} \quad -\gamma_{H2O}} = \frac{7{,}9}{4{,}1} = 1{,}927 \; \approx 1{,}93 \qquad (1)$$

2. Separation in a two-component system of oxidized zinc alloys with copper grains - grains of amorphous phase (spinels) when the concentration criterion for gravitational separation of these two components in a thin layer of water is calculated by the formula:

$$\zeta_1 = \frac{\gamma_{legZn-Cu} \quad -\gamma_{H2O}}{\gamma_{spinel} \quad -\gamma_{H2O}} = \frac{5{,}6}{4{,}1} = 1{,}37 \; \approx 1{,}4 \qquad (2)$$

As the first concentration criterion (ζ_1 = 1.93) is higher and the second lower (ζ_2 = 1.4) than the theoretical value of the concentration criterion $\zeta > 1.5$ required for successful separation of two minerals / components, it is adopted to perform the experiment that the criterion the concentration will be 1.5. It is obvious that the separation in the grain system of oxidized zinc alloys with copper - grains of the amorphous phase (spinels) will be problematic. Although when determining the specific mass of the amorphous phase, the worst option was taken to have amorphous phase grains (spinels) chemically similar to Franklinite / magnetite with a specific mass γ = 5.07 - 5.22 g/cm^3, while in reality it is a far more complex component. with a certain content of Si, Ca, Mg, Al, which gives the entire amorphous phase a specific mass certainly less than $\gamma < 5.0$ g/cm^3. But for safety reasons, it was assumed that the amorphous phase has a higher specific mass (density).

Size classes for performing gravity concentration experiments

As it was determined under a microscopic examination by size classes that below the size of - 0.10mm, in the sample of Pb-Zn slag "Veles" over 85% of the components are free, it was decided that the gravitational concentration procedure is performed on raw material crushed below 0.10mm. The size classes for the gravity concentration process are classified by the wet sieving process into the following 5 size classes:

-0.10 +0.075 mm; -0.075 +0.053 mm; -0.053 +0.037 mm; -0.037 + 0.025 mm; -0.025 +0.00 mm.

The granulometric composition of the ground Pb-Zn slag "Veles" sample was determined by measuring all the sieving oversize together with the undersize of the last sieve, the data were sorted and presented in the form of Table 1. Based on the data from the table, particle size distribution graph were drawn. Based on the graph, it was determined that the initial ground sample of Pb-Zn slag "Veles" for gravitational concentration has a d_{50} = 50.86 µm and d_{95} = 94.82 µm.

Table 1. Particle size distribution of Pb-Zn slag sample "Veles" for gravitational concentration

Size class, mm	M, %	↓∑ M, %	↑∑ M, %
- 0.100 + 0.075	22.45	22.45	100.00
- 0.075 + 0.053	25.11	47.56	77.55
- 0.053 + 0.037	17.79	65.35	52.44
- 0.037 + 0.025	15.77	81.12	34.65
- 0.025 + 0.000	18.88	100.00	18.88
Feed	100.00		

Conducting experiments method and gravitational concentration results

It was decided to perform the gravitational concentration of the individual size classes on the Wilfley 13 shaking table, with the selected table surface for small classes and sludges. Wilfley pendulum tables have proven to be very good devices for the gravitational concentration of small classes in a thin layer of water. From experience and based on theoretical principles, it was decided to perform the gravitational concentration procedure so that the definitive products (ΔH and ΔL) are obtained after double purification. The written scheme of sample preparation and the way of performing the experiment is given in Figure 1.

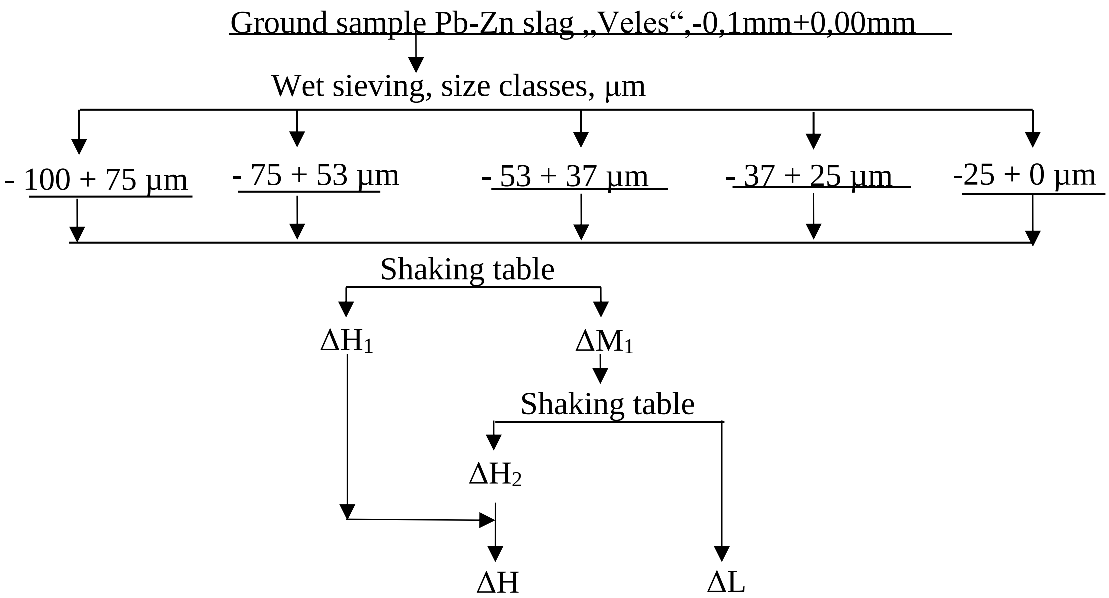

Figure 1. *Written scheme of preparation and separation of Pb-Zn slag sample "Veles", by gravity concentration procedure*

When performing the procedure of gravitational concentration on slag, it is very difficult to visually distinguish fractions by color (there is separation on the table, there are more strips but the difference in color is negligible), which is completely different in relation to ores.

All products obtained in the gravitational concentration process were dried, their masses were measured and samples were given for chemical analysis. After the obtained results of the chemical analysis, a mass balance was formed in which the contents and uses for all obtained products were presented. The mass balance in relation to the classes is shown in Table 2, and the mass balance in relation to the starting sample is shown in Table 3. In the mass balance in Table 2, each individual class is considered separately and each class represents 100% and from it on the shaking table products are given to the table, so we could see the contents and distribution of metals in each individual class. In the mass balance in Table 3, all classes and all products are considered in relation to the input, in addition, the total products of gravitational concentration on the shaking table table are given, with the content and distribution of metals in them.

Table 2. Gravitational concentration mass balance of Pb-Zn slag "Veles" for shaking table experiment in relation to the size classes

Size class, µm	Product	M, %	Pb,%	Zn,%	Cu,%	Ag,ppm	D_{Pb},%	D_{Zn},%	D_{Cu},%	D_{Ag},%
-100+75µm	ΔH	9.46	8.44	7.42	0.77	125.00	50.05	11.32	16.74	57.89
	ΔL	90.54	0.88	6.07	0.40	9.50	49.95	88.68	83.26	42.11
	Feed	100.00	1.59	6.20	0.43	20.42	100.00	100.00	100.00	100.00
-75+53µm	ΔH	20.44	4.10	7.29	0.52	51.50	52.84	23.20	25.51	58.98
	ΔL	79.56	0.94	6.20	0.39	9.20	47.16	76.80	74.49	41.02
	Feed	100.00	1.59	6.42	0.42	17.85	100.00	100.00	100.00	100.00
-53+37µm	ΔH	15.79	5.75	6.00	0.56	86.00	49.96	15.86	20.39	54.81
	ΔL	84.21	1.08	5.97	0.41	13.30	50.04	84.14	79.61	45.19
	Feed	100.00	1.82	5.97	0.43	24.78	100.00	100.00	100.00	100.00
-37+25µm	ΔH	14.97	4.90	6.00	0.55	82.50	38.81	15.31	17.70	46.07
	ΔL	85.03	1.36	5.84	0.45	17.00	61.19	84.69	82.30	53.93
	Feed	100.00	1.89	5.86	0.46	26.80	100.00	100.00	100.00	100.00
-25+0µm	ΔH	3.03	3.37	4.82	0.54	40.88	5.20	2.41	3.14	4.27
	ΔL	96.97	1.92	6.10	0.52	28.60	94.80	97.59	96.86	95.73
	Feed	100.00	1.96	6.06	0.52	28.97	100.00	100.00	100.00	100.00

Table 3. Gravitational concentration mass balance of Pb-Zn slag "Veles" for shaking table experiment in relation to the starting sample

Size class, µm	Product	M, %	Pb,%	Zn,%	Cu,%	Ag,ppm	D_{Pb},%	D_{Zn},%	D_{Cu},%	D_{Ag},%
-100+75µm	ΔH	2.12	8.44	7.42	0.77	125.00	10.24	2.56	3.62	11.44
	ΔL	20.33	0.88	6.07	0.40	9.50	10.23	20.11	18.03	8.34
	in relation to feed	22.45	1.59	6.20	0.43	20.41	20.47	22.67	21.65	19.78
-75+53µm	ΔH	5.13	4.10	7.29	0.52	51.50	12.04	6.09	5.91	11.40
	ΔL	19.98	0.94	6.20	0.39	9.20	10.74	20.19	17.28	7.93
	in relation to feed	25.11	1.59	6.42	0.42	17.85	22.78	26.28	23.19	19.33
-53+37µm	ΔH	2.81	5.75	6.00	0.56	86.00	9.24	2.75	3.49	10.43
	ΔL	14.98	1.08	5.97	0.41	13.30	9.25	14.57	13.62	8.60
	in relation to feed	17.79	1.82	5.97	0.43	24.78	18.49	17.32	17.11	19.03
-37+25µm	ΔH	2.36	4.90	6.00	0.55	82.50	6.62	2.31	2.88	8.40
	ΔL	13.41	1.36	5.84	0.45	17.00	10.43	12.76	13.38	9.84
	in relation to feed	15.77	1.89	5.86	0.46	26.80	17.05	15.07	16.26	18.24
-25+0µm	ΔH	0.57	3.37	4.82	0.54	40.88	1.10	0.45	0.68	1.01
	ΔL+ Sludge	18.31	1.92	6.10	0.52	28.60	20.11	18.21	21.11	22.61
	in relation to feed	18.88	1.96	6.06	0.52	28.97	21.21	18.66	21.79	23.62
	∑ΔH	**12.99**	**5.28**	**6.69**	**0.58**	**76.12**	**39.22**	**14.16**	**16.58**	**42.68**
	∑ΔL+sludge	**87.01**	**1.22**	**6.05**	**0.43**	**15.26**	**60.78**	**85.84**	**83.42**	**57.32**
Feed		**100.00**	**1.75**	**6.13**	**0.45**	**23.17**	**100.00**	**100.00**	**100.00**	**100.00**

Commentary on the obtained results of the Pb-Zn slag "Veles" gravitational concentration

The fact that these are the first tests of the possibility of concentration and valorization of Pb-Zn slag "Veles", mineralogical properties of the sample (presence of amorphous and crystalline phases), structural texture characteristics and degree of components adhesion and liberation, and that useful components in the sample are mainly in the form of an alloy, they determined the method of performing the gravitational concentration procedure. The success of gravitational concentrations cannot be assessed on the basis of tests performed, because the investor (Keps Mont) did not submit the requirements, standards or quality that a product obtained with a concentration of Pb-Zn slag should achieve in order to be commercial. The slag sample for the gravitational concentration process was previously ground to the optimal size of -100 + 0μm, required to release useful components. According to chemical analysis, there is a high content of zinc in the sample, about 7%, about 2% lead and about 0.5% copper. However, total zinc and copper are not in the useful component of metal alloys, but are found in significant amounts in tailings. Lead, on the other hand, is mostly in its copper alloys. The high degree of comminution of the sample to a fineness of -100 + 0μm, caused the participation of the finest class -25 + 0 μm in the comminuted sample to be almost 19% (18.88%, Tables 2 and 3). The fact that non-ferrous metals are very soft and that they easily pass into the smallest classes when crushed, should be constantly taken into account.

From the obtained results shown in Tables 2 and 3, it can be seen that there was a separation of individual components into separate products. This fact shows that the adopted gravitational concentration parameters were well selected and applied during the experimental tests.

Regarding some products from Tables 2 and 3, it can be seen that the results related to the separation of lead in concentrate (ΔH fraction) and silver in lead concentrate (ΔH fraction) are relatively good. Regarding the separation of zinc and copper in the concentrate (ΔH fraction), the results are somewhat worse.

The best results regarding the content of Pb, Zn, Cu and silver Ag in the concentrate (ΔH fraction) were achieved in the treatment of the largest class (-100 + 75 μm) where the content of Pb in this product is 8.44%, zinc 7.42%, copper 0.77% and silver 125 g / t (Tables 2 and 3). In all other concentrates (ΔH fractions) obtained from smaller size classes, lower contents of non-ferrous metals and silver in them were obtained.

However, the best results in separation using gravity concentration were achieved for lead and silver, namely despite the relatively low lead content in the feed sample of 1.75%, obtained concentrates with Pb content of 3.37%, in the smallest class -25 +0.00 μm (Tables 2 and 3) up to 8.44%, in the class -100 + 75 μm (Tables 2 and 3). The silver content in concentrates ranges from 125 g/t for class -100 + 75 μm (Tables 2 and 3) and the lowest content of 51.5 g/t was achieved in concentrate for class -75 + 53 μm (Tables 2 and 3). The content of lead in the collective concentrate (combined of all ΔH fractions) is 5.28%, with a recovery of lead in it of 39.22% (Table 3), while the content of silver in the collective concentrate of gravitational concentration is 76.12 g/t, with a recovery of 42.68%. Similar results regarding the content and recovery of lead and silver in gravity concentrates obviously mean that silver follows lead, ie according to mineralogical analysis there is free silver and invisible silver in the lead structure [2]. Free silver, which is fine 2-5 μm, probably passed into the finest class (-25 + 0μm) during comminution and from there significantly passes into tailings at gravitational concentration [2]. When analyzing the silver content by size classes, the highest silver content is in the finest class (-25 + 0μm) 28.97 g/t (Tables 2 and 3). By gravitational concentration of the finest class, ΔL fraction was obtained with the highest silver content is 28.60 g/t (Table 3) compared to the same products obtained from other larger classes.

As for the concentration of copper and zinc in the heavy fraction (ΔH), separation was achieved here as well, however, the obtained results are worse than for lead and silver. Concentrates (ΔH fraction) were obtained for each size class, in which the zinc content is higher than in the ΔL fraction, except for the finest size class -25 + 0 μm (Table 3), where a lower zinc content in the concentrate was obtained. There were no such anomalies for copper, where the copper content for each class is always higher in the ΔH fraction than in the ΔL fraction (Table 3). This means that separation has been achieved. The content of zinc in the collective concentrate (combined of all ΔH fractions) is 6.69%, with a recovery of zinc in it of 14.16% (Table 3), while the content of copper in the collective concentrate is 0.58%, with a recovery of copper in it of 16.58% (Table 3). The poorer results achieved with zinc and copper can be attributed to the low concentration coefficient of 1.4 in the two-component system of oxidized grain alloys of zinc with copper - amorphous phase grains (spinels).

Conclusion

When reaching any conclusion on technological tests of the valorization possibility of the Pb-Zn slag "Topionica" -Veles sample, several important premises related to these preliminary technological tests must be pointed out:

- Pb-Zn slag "Topionica" -Veles, is not an ore but a technogenic raw material, and as such does not consist of minerals, but mainly of the amorphous glassy phase and useful components are lead, copper and zinc alloys.
- From the minerals present in the technogenic raw material, there are mostly artificial minerals that are rare in nature and that are formed in extreme conditions (in metrites, etc ...)
- These are the first comprehensive tests (first physical-chemical and mineralogical, and then technological tests) of Pb-Zn slag "Topionica" -Veles. These tests are new, there are no other practical or theoretical experiences (or were not available to us) related to the testing of this raw material.
- For these reasons, the procedures for preparation and valorization of useful components had to be adapted to this raw material. Therefore, during these researches, the most optimal procedures and methods of preparation for this type of raw material were examined. During the testing of this raw material, various parameters of its technological procedure of preparation and valorization were determined and defined.

In addition to all the limitations presented in terms of physico-chemical and mineral properties of raw materials, as well as restrictions in terms of quantity and representativeness of the initial sample, within the technological research, the following procedures were examined:

Mineralogical analysis of the grinding experiments products by size classes [2] determined that the useful components from Pb-Zn slag "Veles" are free at fineness of crushing -0.1 + 0.0 mm. Thus, the prepared (ground) technogenic raw material is subjected to the process of gravitational concentration. Two products were obtained by gravity concentration, concentrate of non-ferrous alloys ΔH fractions and tailings ΔL fractions.

The concentration criterion for gravitational separation in a two-component system was determined:

1. grains of oxidized lead alloys with copper - amorphous phase grains (spinels) $\zeta1 = 1.93$,
2. grains of oxidized zinc alloys with copper - grains of amorphous phase (spinels) $\zeta2 = 1.37$.

The wet sieving process yielded five size classes for the gravitational concentration process: -0.100+0.075 mm; -0.075 +0.053 mm; -0.053 +0.037 mm; -0.037 + 0.025 mm; -0.025 +0.000 mm (item 3.5.2).

Gravitational concentration of individual size classes was performed on a Wilfley 13 shaking table. According to chemical analysis, the initial slag sample has the following content of non-ferrous metals: zinc about 7%, about 2% lead and about 0.5% copper [1]. A big problem for gravitational concentration was the finest class of size -25 + 0 μm, whose mass fraction in relation to the feed is significant 18.88%, and since non-ferrous metals are very soft, when ground they easily passed into the smallest class, which should be constantly taken into account. On the other hand, the range of sizes in the smallest class is huge, so that the adopted criterion of concentration does not valid to it, so then it has the largest losses in the ΔL fraction (Table 3).

The obtained results of gravitational concentration (Tables 2 and 3) show that there was a separation of individual components into separate products by size classes. This process of separation of lead

and silver into concentrate (ΔH fraction) was relatively successful, while the separation of zinc and copper in concentrate (ΔH fraction) gave slightly worse results. The best results in terms of content of Pb, Zn, Cu and silver Ag in concentrate (ΔH fraction) were achieved for the largest class (-100 + 75 μm) where the content of Pb in this product is 8.44%, zinc 7.42%, copper 0.77% and silver 125 g / t (Tables 2 and 3). In all other concentrates (ΔH fractions) obtained from smaller size classes, lower contents of non-ferrous metals and silver were obtained. The content of lead in the collective concentrate (combined of all ΔH fractions) is 5.28%, with a recovery in it of 39.22%. Content of silver in the collective concentrate of gravitational concentration is 76.12g/t, with a recovery in it of 42, 68% (Table 3). The content of zinc in the collective concentrate (combined all ΔH fractions) is 6.69%, with a recovery in it of 14.16%. Copper content in the cellective concentrate of gravitational concentration is 0.58%, with a recovery in it of 16.58% (Table 3). The poorer results achieved with zinc and copper can be attributed to the low concentration coefficient of 1.4 in the two-component system of oxidized grain alloys of zinc with copper - amorphous phase grains (spinels).
Based on the performed tests, it can be stated that the separation of non-ferrous metals and silver in the ΔH fraction of Pb-Zn slag "Veles", with relatively low yield, was successfully performed by gravitational concentration.
Determining the possibility of valorization of Pb-Zn slag "Veles", requires more research on a larger sample with the additional parameters definition. It is also necessary, in addition to the physical-chemical and mineral characterization, to determine the Bond working index, ie energy consumption, consumption of metals (coatings and balls) during grinding. By determining the operating parameters and consumption norms, the elements that economically burden the technological separation process and valorization of Pb-Zn slag "Veles" are defined. Further technological tests are aimed at improving the newly acquired knowledge and experience gained from previous tests, as well as obtaining products with defined metal contents and achieving greater utilization of useful components.

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