

Possibilities of Siderite and Barite Concentrates Preparation from Tailings of Settling Pit Nearby Markušovce Village (Eastern Slovakia)

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Abstract

The contribution deals with recovery of useful minerals such as siderite and barite from tailings collected in settling pit nearby Markušovce village (East Slovakia). The material from the pit was subjected to gravity pre-concentration and magnetic separation under laboratory conditions with the aim to verify a possibility of siderite and barite concentrates preparation. A fraction of +0.2–1 mm forming a 40.56 wt% of total grain size scale of the material from the pit and containing 35.71% SiO₂, 22.55% Fe₂O₃, 7.12% Al₂O₃, 5.48% Ba, and 3.89% SO₄²⁻ was tested in upgrading process. Thus, 78.18% of SiO₂, and 60.41% of Al₂O₃ at loss 21.70% Fe₂O₃ and 2.09% of Ba were removed in gravity pre-concentration. The iron concentrate with the content of 44.33% Fe₂O₃ at Fe recovery of 77.29% in magnetic product was obtained. Barite pre-concentrate with the Ba content of 46.21% at Ba recovery of 91.95% in non-magnetic product was won.

Keywords: tailings, recovery, gravity pre-concentration, magnetic separation

Introduction

The contribution describes a laboratory test of useful minerals recovery from tailings of the Markušovce settling pit. These minerals were deposited in the pit as a result of low ore beneficiation efficiency in the past caused by e.g. inco-ordinated upgrading process, ore properties changes (mineral composition, intergrowth) at exploitation advance, actual unavailability of suitable dressing machines after such changes, error grains in the upgrading process, etc.

The settling pit lies between the Markušovce and Rudňany villages. Its construction and operation are connected with former and current mining activities on the Rudňany and Poráš-Zlatník polymetallic ore deposits. As to nomenclature the settling pit in older papers was named Rudňany after Rudňany deposit and the facility of Iron Ore Works. Newer publications usually use adjective Markušovce, because the settling pit is located in the cadastral districts of the Markušovce and Zavadka villages, and in the bottom part of the Markušovce valley (Jakabský et al., 2010). The area of the Markušovce settling pit occupies 35.1 hectares, the length attains 1,085 meters and the width ranges from 165 to 345 metres. The thickness of deposited materials varies in the dependence on initial ground levels and it may achieve maximally about 38 metres. The settling pit is bounded by the natural ground level of the valley and also by three earthen dams (Jakabský et al., 2010). Recently, the settling pit is in operation by the SABAR, Ltd. Markušovce. Altogether 9,800,000 tons of the tailings of so-called flotation sands at the density of 1.59 t.m⁻³ and a total volume of 6,200,000 m³ are deposited in the settling pit (Karoli et al., 2008).

It is needed to mention that history of the settling pit started with building-up of so-called “New Industrial Plant – NIP” for complex processing of polymetallic Fe–Cu–Sb–Hg and barite ores. The design capacity of NIP was of 1 Mt ore/year. The ore dressing plant and the sintering plant were put into operation in 1964, mercury plant in 1970. The ore dressing plant included comminution, high intensity magnetic separation and flotation. The feed of ore was upgraded as follows: magnetic separation (siderite concentrate, roughing 0.6T, scavenging 0.7T), non-magnetic product was subjected to flotation of sulphides, cell product from sulphide flotation to flotation of barite. The cell product from barite flotation was final refuse deposited in the settling pit. The fine-grained siderite concentrate was further processed in sintering plant for blast furnaces. So called “collective sulphide concentrate” was roasted in the mercury plant to obtain suitable feed for copper and antimony smelteries (modified after Fabry, 1992).

The dominant minerals of the ore veins were represented by siderite, barite, Hg-tetrahedrite (schwarzite), chalcopyrite, pyrite, quartz, ankerite, dolomite, feldspars, cinnabar, etc. Thus, the gangue minerals, lost valuables and accompanying rocks of ore veins such as sericitic phyllite, chlorite phyllite, graphitic schist and fuchsite quartzite mainly occur in the settling pit (Jakabský et al., 1991).

In the first half of 90s of 20th century the “Program of metal-mines reduction” was proclaimed by Czechoslovak government mainly due to unfavourable metals price on the world market, low metal content in ores of Czechoslovak deposits, and ecological movements. In this time all mining

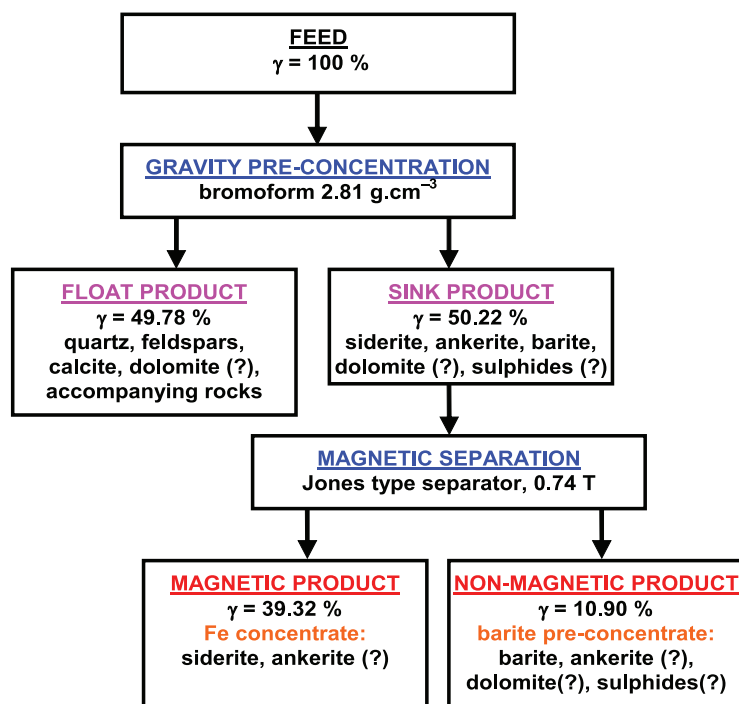


Fig. 1. Flow-sheet of performed upgrading
Rys. 1. Schemat przeprowadzonych badań laboratoryjnych

facilities were state-owned companies and realisation of the Program resulted in closing almost all metal-ore mines. As to Rudňany facility, mercury plant was closed in 1993, siderite exploitation was shut down in 1994.

Recently, residual proven and developed reserves of barite are mined and processed by the SABAR, Ltd. Markušovce. In 2014 annual mining output was of 21 kt at barite concentrate production of 15 kt (Shi, 2017). In 2016 the output of 23 kt is reported by Reichl et al. (2018). These published data correspond to personal information from the representatives of the company. For comparison Jakabský et al. (1991) reported production of 60 kt barite concentrate in 1990.

Considerations on tailings upgrading route

On the basis of above mentioned a question of the settling pit material upgrading way is still open. Generally, there are two basic contradictory concepts there. On the one hand there is intensive endeavour to attain maximal recovery of barite by direct feed of material to flotation (barite - froth product), followed by magnetic separation of cell product to obtain siderite concentrate. On the other hand there are considerations on pre-concentration of useful minerals to reduce necessary maximal capacity flotation line (and also magnetic separation capacity) with the aim to total upgrading cost minimization, but at an awareness of some barite losses in previous operations.

Thus, the various concepts can be considered after material excavation from the settling pit:

- flotation of sulphides (sulphides removal into froth, Cu-concentrate) → flotation of barite (cell product from sulphide flotation, barite recovery in froth) → magnetic separation of cell product from barite flotation to obtain siderite concentrate → non-magnetic product – sands for building industry,

- magnetic separation (Fe concentrate) → sulphide flotation of non-magnetic product (Cu-concentrate in froth product) → barite flotation of cell product from sulphide flotation (barite concentrate in froth) → cell product of barite flotation – sand for building industry (modified after Jakabský et al., 2010),
- gravity pre-concentration (quartz and waste rock removal in light product, sand for building industry) → magnetic separation of heavy product (Fe-concentrate) → barite flotation of non-magnetic product (barite concentrate in froth product or reverse flotation) → final flotation refuse – sulphides and residuum of other minerals.

Moreover, after above mentioned it must be taken into consideration, that sulphides are harmful admixture in all applicable/saleable products.

Materials and methods

The laboratory test of upgrading process was performed according to flow-sheet illustrated in Fig. 1. The grain size fraction of +0.2–1 mm was subjected to testing. This fraction has the highest mass yield and as to grain size it is suitable for the both heavy media separation and dry magnetic separation (also according to another flow-sheet, e.g. magnetic separation would be also the first step).

As to gravity pre-concentration the bromoform 97% stabilised with ethanol, with a density of 2.81 g.cm⁻³ (Alfa Aesar) was applied as a heavy media.

The Dry High Gradient Magnetic Separation (DHGMS) has been carried out using universal laboratory magnetic separator JONES in a cassette located between its poles. The cassette was lined by two grooved plates made of magnetically soft iron. The separation was performed at 0.74 T.

Tab. 1. Dependence of chemical composition on grain size – major elements [%]
 Tab. 1. Zależność składu chemicznego od wielkości ziarna – główne pierwiastki [%]

grain size [mm]	γ [%]	κ	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba
+1.000	3.22	795	33.90	9.54	2.23	1.38	1.23	27.45	0.83	1.27	2.32	3.48	5.41
0.200–1.000	40.56	613	35.71	7.12	1.62	0.94	0.94	22.55	0.58	1.29	1.50	3.89	5.48
0.100–0.200	35.95	1671	27.96	7.52	1.86	1.29	1.24	26.05	0.80	1.40	1.67	4.55	7.18
0.071–0.100	3.50	4290	20.28	4.12	0.93	1.58	1.09	31.47	0.48	0.63	1.18	1.56	6.24
0.063–0.071	7.09	3448	20.95	4.46	1.20	1.59	1.02	31.68	0.49	0.78	1.17	1.77	5.66
0.040–0.630	5.36	4393	22.76	4.60	1.09	1.61	1.08	32.51	0.55	0.68	1.21	1.77	6.47
–0.040	4.33	3339	26.59	6.46	1.70	1.63	1.31	30.89	0.81	1.14	1.41	3.36	7.61
Feed	100.00	1649	30.19	6.88	1.65	1.21	1.09	25.82	0.66	1.23	1.53	3.74	6.27

Tab. 2. Dependence of chemical composition on grain size – minor elements [ppm]
 Tab. 2. Zależność składu chemicznego od wielkości ziarna – pierwiastki towarzyszące [ppm]

grain size [mm]	γ [%]	κ	V ₂ O ₅	Cr ₂ O ₃	Zr	Ni	Co	Zn	Cd	Pb	Sr	Cu	Sb	As	Hg
+1.000	3.22	795	452	80	63	78	42	42	42	17	818	475	263	66	68
0.200–1.000	40.56	613	489	60	61	60	27	36	37	10	836	592	122	44	39
0.100–0.200	35.95	1671	563	410	45	70	43	34	48	16	1071	493	141	81	39
0.071–0.100	3.50	4290	151	100	66	70	33	49	43	23	780	602	181	138	51
0.063–0.071	7.09	3448	226	440	74	75	33	54	37	20	723	545	157	103	38
0.040–0.630	5.36	4393	253	280	95	82	36	49	43	21	858	655	214	208	68
–0.040	4.33	3339	370	300	141	93	58	59	58	28	1138	917	331	251	131
Feed	100.00	1649	466	240	62	68	36	39	43	15	927	567	152	83	46

Tab. 3. Distribution of chemical components into grain size classes - major elements [%]
 Tab. 3. Rozkład zawartości składników chemicznych w klasach ziarnowych – główne pierwiastki [%]

grain size [mm]	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba
+1.000	3.61	4.46	4.35	3.66	3.62	3.42	4.01	3.32	4.87	2.98	2.77
0.200–1.000	47.98	41.95	39.89	31.40	34.92	35.43	35.34	42.53	39.68	42.15	35.43
0.100–0.200	33.30	39.27	40.60	38.19	40.83	36.27	43.20	40.91	39.16	43.68	41.15
0.071–0.100	2.35	2.09	1.97	4.55	3.49	4.26	2.52	1.79	2.69	1.45	3.48
0.063–0.071	4.92	4.59	5.16	9.28	6.62	8.70	5.22	4.49	5.41	3.34	6.39
0.040–0.630	4.04	3.58	3.54	7.10	5.30	6.74	4.43	2.96	4.23	2.53	5.52
–0.040	3.81	4.06	4.47	5.82	5.21	5.18	5.29	3.99	3.97	3.86	5.25
Feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 4. Distribution of chemical components into grain size classes - minor elements [%]
 Tab. 4. Rozkład zawartości składników chemicznych w klasach ziarnowych – pierwiastki towarzyszące [%]

grain size [mm]	V ₂ O ₅	Cr ₂ O ₃	Zr	Ni	Co	Zn	Cd	Pb	Sr	Cu	Sb	As	Hg
+1.000	3.12	1.09	3.28	3.68	3.79	3.47	3.17	3.67	2.85	2.69	5.57	2.55	4.77
0.200–1.000	42.55	10.27	40.11	35.69	30.70	37.53	35.27	27.20	36.69	42.34	32.58	21.45	34.53
0.100–0.200	43.42	62.20	26.23	36.91	43.33	31.42	40.55	38.58	41.66	31.26	33.37	35.00	30.61
0.071–0.100	1.13	1.48	3.74	3.59	3.23	4.40	3.53	5.39	2.95	3.71	4.17	5.80	3.89
0.063–0.071	3.44	13.16	8.50	7.80	6.56	9.84	6.16	9.51	5.54	6.81	7.33	8.77	5.88
0.040–0.630	2.91	6.33	8.25	6.44	5.41	6.75	5.41	7.54	4.97	6.19	7.55	13.39	7.95
–0.040	3.43	5.48	9.89	5.90	6.99	6.60	5.90	8.10	5.33	7.00	9.44	13.03	12.36
Feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 5. Composition of float and sink products
Tab. 5. Skład produktów analizy densymetrycznej

product	γ [%]	κ	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba	Sr
Float	49.78	78	56.07	8.64	0.88	0.31	0.55	9.83	0.42	0.57	1.90	0.22	0.23	53
Sink	50.22	1143	15.52	5.61	2.35	1.56	1.33	35.16	0.73	2.00	1.11	7.55	10.68	1613
Feed	100.00	613	35.71	7.12	1.62	0.94	0.94	22.55	0.58	1.29	1.50	3.89	5.48	836

Tab. 6. Recovery of chemical components into float and sink products
Tab. 6. Zawartości składników w produktach wzbogacania grawitacyjnego

product	γ [%]	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba	Sr
F	49.78	78.17	60.42	27.07	16.46	29.07	21.70	36.32	22.03	62.92	2.83	2.09	3.15
S	50.22	21.83	39.58	72.93	83.54	70.93	78.30	63.68	77.97	37.08	97.17	97.91	96.85
Feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 7. Composition of magnetic and non/magnetic products
Tab. 7. Skład produktów magnetycznych i niemagnetycznych

product	γ [%]	κ	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba	Sr
M	78.30	1449	17.13	6.36	2.63	1.990	1.61	44.33	0.45	0.58	1.22	0.60	0.83	134
N	21.70	39	9.69	2.92	1.33	0.001	0.31	2.08	1.74	7.14	0.71	32.59	46.21	6946
Sink	100.00	1143	15.52	5.61	2.35	1.560	1.33	35.16	0.73	2.00	1.11	7.57	10.68	1613

Tab. 8. Recovery of chemical components into magnetic and non/magnetic products
Tab. 8. Uzyski składników w produkcie magnetycznym i niemagnetycznym

product	γ [%]	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba	Sr
M	78.30	86.44	88.71	87.70	99.99	94.93	98.72	48.26	22.66	86.11	6.22	6.08	6.51
N	21.70	13.56	11.29	12.30	0.01	5.07	1.28	51.74	77.34	13.89	93.78	93.92	93.49
Sink	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 9. Total balance: quality of separation products
Tab. 9. Bilans całkowity: jakość produktów wzbogacania

product	γ [%]	κ	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba	Sr
Float	49.78	78	56.07	8.64	0.88	0.31	0.55	9.83	0.42	0.57	1.90	0.22	0.23	53
M	39.32	1449	17.13	6.36	2.63	1.99	1.61	44.33	0.45	0.58	1.22	0.60	0.83	134
N	10.90	39	9.69	2.92	1.33	0.001	0.31	2.08	1.74	7.14	0.71	32.59	46.21	6946
Feed	100.00	613	35.70	7.12	1.62	0.94	0.94	22.55	0.58	1.29	1.50	3.89	5.48	836

The products from gravity pre-concentration: Float and Sink were filtered and decanted by methanol and water to remove rest of bromoform, and dried. All separation products were weighed to determine a mass yields “ γ ”, and assayed using XRF. The volume magnetic susceptibility was also measured to observe iron mineral distribution.

XRF spectrometer SPECTRO XEPOS model XEPO3 (Spectro Analytical Instruments, GmbH, Nemecko), at the element range of ¹¹Na – ⁹²U was used for assaying.

The volume magnetic susceptibility “ κ ” [10⁻⁶ SI units] was measured using the Kappabridge KLY-2, Geofyzika Brno at following conditions: the magnetic field intensity of 300 A.m⁻¹, the field homogeneity of 0.2 %, the operating frequency of 920 Hz, the range of $-1,999.10^{-6} \div +650,000.10^{-6}$ SI unit.

On the basis of mass yields and chemical analyses distribution / recovery of chemical component into grain size classes / separation product was calculated.

Results and discussion

The results of grain size analysis and quality of grain size classes are introduced in Tables 1–2.

The distribution of chemical components in grain size classes is reported in Tables 3–4.

The partial results of gravity pre-concentration and magnetic separation, respectively, are introduced in Tables 5–8. The quality of products and recoveries of observed chemical components within the frame of whole flow-sheet are described in Tables 9–10 (Feed = Float+Sink, Sink=M+N, Feed=Float+M+N).

The chemical analyses confirm known fact that main chemical components of the settling pit are SiO₂, Fe₂O₃, Al₂O₃, Ba and SO₄²⁻. For the ore upgrading control the company usually observes contents of SiO₂, FeTOTAL, BaSO₄, and Cu. The occurrence of sulphides indicate above all the content of Cu, further Sb, Zn, Hg, and Pb. Strontium in the product of sieving and separation has similar distribution as barium. So, it indicates an occurrence of celestine (SrSO₄)

Tab. 10. Total balance: distribution / recovery of chemical components into separation products

Tab. 10. Bilans całkowity: rozkład składników użytecznych w produktach wzbogacania

product	γ [%]	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba	Sr
Float	49.78	78.18	60.41	27.09	16.47	29.11	21.70	36.32	21.99	62.93	2.83	2.09	3.16
M	39.32	18.87	35.12	63.95	83.52	67.30	77.29	30.74	17.68	31.92	6.04	5.96	6.30
N	10.90	2.96	4.47	8.96	0.01	3.59	1.01	32.95	60.33	5.15	91.13	91.95	90.54
Feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 11. Comparison of settling pit material composition [1 – after Jakabský et al., 2010; 2 – after Petrák et al., 2011 and Tóth et al., 2012]

Tab. 11. Porównanie składu materiału zdeponowanego w osadniku [1 – wg Jakabský et al., 2010; 2 – wg Petráku i in., 2011 i Tóth i in., 2012]

author	[%]											[ppm]			
	SiO ₂	Al ₂ O ₃	MgO	MnO	CaO	Fe ₂ O ₃	TiO ₂	Na ₂ O	K ₂ O	SO ₄ ²⁻	Ba	Cu	Sb	As	Hg
This work	30.19	6.88	1.65	1.21	1.09	25.82	0.66	1.23	1.53	3.74	6.27	567	152	83	46
1	38.12	n.a.	n.a.	n.a.	n.a.	22.02	n.a.	n.a.	n.a.	n.a.	4,77	460	n.a.	n.a.	n.a.
2	30.70	5.30	2.80	1.30	1.90	28.60	0.40	n.a.	1.40	5.09	6.34	624	115	48	118

Tab. 12. Comparison of Fe and Ba concentrates, and SiO₂-bearing productTab. 12. Porównanie koncentratów Fe i Ba oraz produktu zawierającego SiO₂

Fe-concentrate - Fe ₂ O ₃				barite (pre-)concentrate - Ba				refuse / float – SiO ₂			
Jakabský, 2010		This work		Jakabský, 2010		This work		Jakabský, 2010		This work	
β [%]	ϵ [%]	β [%]	ϵ [%]	β [%]	ϵ [%]	β [%]	ϵ [%]	β [%]	ϵ [%]	β [%]	ϵ [%]
39.90	83.48	44.33	77.29	53.74	75.18	46.21	91.95	64.22	79.26	56.07	78.18
α [%]	ϵ [%]	α [%]	ϵ [%]	α [%]	ϵ [%]	α [%]	ϵ [%]	α [%]	ϵ [%]	α [%]	ϵ [%]
21.22	100.00	22.55	100.00	4.78	100.00	5.48	100.00	39.63	100.00	35.70	100.00
γ [%]		γ [%]		γ [%]		γ [%]		γ [%]		γ [%]	
44.40		39.32		6.69		10.90		48.91		49.10	

as isomorphous admixture in barite in the frame of barite–celestine series.

A comparison of settling pit material composition is performed in Table 11, where differently reported chemical components after various authors were recalculated to the same analytes. Under consideration that samples come from various places of the settling pit, moreover, the analyses were also performed by various analytical methods, the differences are not significant.

Finally, comparison of separation products parameters is introduced in Table 12, where:

- α [%] – a component content in the feed,
- β [%] – a component content in given product,
- ϵ [%] – a recovery of observed component into given product,
- γ [%] – a mass yield of given product.

Jakabský et al. (2010) realized upgrading process as follows:

- i) magnetic separation of siderite,
- ii) barite flotation of non-magnetic product.

In this case the feed into separation had lower grade, i.e. lower content of useful components/minerals and higher content of silica. Under application this flow-sheet a higher recovery of iron was attained (by 6.19%), but the recovery of Ba was lower by 16.77%. On the other hand barite concentrate reported by Jakabský et al. (2010) has higher grade by 7.5 %, but it was won by flotation. Barite (pre-)concentrate

prepared after flow-sheet in Fig. 1 represent “only” non-magnetic product after siderite separation.

Conclusion

The possibilities of tailings upgrading from the Markušovce settling pit using gravity and magnetic separation methods with the aim to prepare iron and barite (pre-) concentrates were studied.

An application of gravity pre-concentration enables to cut by half the feed for follow-up operation/s.

It means firstly an installation of smaller magnetic separators, i.e. half capacity in comparison with direct feeding of settling pit material into magnetic separation without gravity pre-concentration, and secondly also about 5-times lower capacity of flotation line. All these mentioned facts would be result in lower capital and running costs, respectively.

Moreover, laboratory test showed that losses of barite in light product of gravity pre-concentration and in magnetic product are low, i.e. 8.05 %. Thus, a flotation process would be applied for an enhancement of final product barite grade, naturally with some further losses of barite in a cell product of flotation.

Losses iron in light and/or non-magnetic products are disputable. It is well-known that accompanying rocks, mainly graphitic schist also contain iron, but bonded on (alumo-) silicates, which is unusable in iron metallurgy. So, the material balance calculated on the basis of total iron content as an analyte can distort the results of magnetic separation. The

assaying of siderite iron would be more suitable for magnetic separation process control and adjustment.

Finally, a hydrocyclone would be applied in a gravity pre-concentration under full scale operation after laboratory and pilot plant verification.

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Możliwości pozyskania koncentratów syderytu i barytu ze stawów osadowych zlokalizowanych koło miejscowości Markušovce (Wschodnia Słowacja)

Artykuł dotyczy możliwości odzysku minerałów użytecznych takich jak syderyt i baryt z odpadów zdeponowanych osadniku w pobliżu miejscowości Markušovce (Słowacja Wschodnia). Materiał z odwiertu poddano wstępnemu wzbogacaniu grawitacyjnemu i separacji magnetycznej w warunkach laboratoryjnych w celu weryfikacji możliwości uzyskania koncentratów syderytu i barytu. Klasa ziarnowa 0,2-1 mm ma wychód 40,56% wagowo i zawartość 35,71% SiO₂, 22,55% Fe₂O₃, 7,12% Al₂O₃, 5,48% Ba i 3,89% SO₄²⁻ była poddana wzbogacaniu. Uzyskano koncentrat o uzysku 78,18% SiO₂ i 60,41% Al₂O₃. We wstępnym wzbogacaniu grawitacyjnym usunięto 21,70% Fe₂O₃ i 2,09% Ba w stężeniu grawitacyjnym. Otrzymano koncentrat żelaza o zawartości 44,33% Fe₂O₃ przy uzysku Fe 77,29% w produkcji magnetycznym. Uzyskano koncentrat wstępny (produkt niemagnetyczny) barytu o zawartości Ba 46,21% i uzysku 91,95%.

Słowa kluczowe: odzysk, wstępna koncentracja grawitacyjna, separacja magnetyczna