

Separability of Calcined Magnesite Fines in Magnetic Field

Slavomir HREDZAK¹⁾, Marek MATIK²⁾, Michal LOVAS³⁾,
Ingrid ZNAMENACKOVA⁴⁾, Katarina STEFUSOVA⁵⁾, Anton ZUBRIK⁶⁾

¹⁾ Dipl. Ing., PhD.; Institute of Geotechnics, Slovak Academy of Sciences, Watsonova 45, SK-04001 Kosice, Slovakia; email: hredzak@saske.sk

²⁾ RNDr., PhD.; Institute of Geotechnics, Slovak Academy of Sciences, Watsonova 45, SK-04001 Kosice, Slovakia; email: matik@saske.sk

³⁾ RNDr., PhD.; Institute of Geotechnics, Slovak Academy of Sciences, Watsonova 45, SK-04001 Kosice, Slovakia;

⁴⁾ Dipl. Ing., PhD.; Institute of Geotechnics, Slovak Academy of Sciences, Watsonova 45, SK-04001 Kosice, Slovakia; email: znamenackova@saske.sk

⁵⁾ Dipl. Ing., PhD.; Institute of Geotechnics, Slovak Academy of Sciences, Watsonova 45, SK-04001 Kosice, Slovakia; email: stefusova@saske.sk

⁶⁾ RNDr., PhD.; Institute of Geotechnics, Slovak Academy of Sciences, Watsonova 45, SK-04001 Kosice, Slovakia; email: zubant@saske.sk

Abstract

Magnesite belongs to the most significant minerals of Slovakia. According to various statistical reviews Slovakia is in 4th–6th place in the world and its share ranges 2.25–3.63 % of total world production (Reichl et al., 2015; Brown et al., 2015).

Magnesite occurs in the belt from Lucenec to Kosice (south of central–east Slovakia) in the form of Fe-variety called breunnerite (commonly 10–30%, but also 8–17% or 5–50% FeCO₃), i.e. ferroan magnesite (Mg_{0.9-0.7}Fe_{0.1-0.3})CO₃ usually containing about 9% FeO (Šalát and Ončáková, 1966). As to CaO/SiO₂ ratio (modulus C/S >2 or <2), the both technological magnesite types, namely limy and silica ones occur. For this reason the research on magnesite and magnesia upgrading is focused on calcium and silica reduction. It is also important to observe behaviour of iron in separation process.

So, the contribution deals with the magnetic separability determination of calcined magnesite ore fines from the Mútnik deposit (silica type). The content of fines –0.5mm can attain 25–30%. The behaviour of this material in high gradient magnetic field of separator was studied on the basis of magnetic fractions analysis and mass yields. The product of best quality with the content of 81.91% MgO at a mass yield of 82.77% and MgO recovery of 89.19% was won at the induction of 0.06T. An enhancement of magnetic field induction resulted in mass yield growing, recoveries increasing of all components into magnetic product and finally, in its gradual contamination by gangue components. So, a magnetic product with the MgO content of 79.98% at a mass yield of 91.07% and MgO recovery of 95.81% was prepared at the highest induction, i.e. 0.45T. Magnetic separability analysis with regards to feed quality into separation enables to preset the suitable induction of field to achieve the required quality of separation products.

Keywords: magnetic separability, calcined magnesite fines

Introduction

The magnetic separability determination was performed by preparation of magnetic fractions in a dependence on induction/intensity of magnetic field (in Cagaš, 1972; Hredzák et al., 2008; 2009; 2014b; Kilin et al., 2012). This technique is similar to float-sink analysis realised in heavy liquids where specific-gravity fractions are obtained. Thus, the chemical analysis and mass yields of fractions enables to assess a separability/dressability or washability of ores and coals and on the basis of such analyses it is possible to predict the separation products quality and their mass yields at given conditions of beneficiation (Kozák a Cagaš, 1965; Špaldon, 1986; Lukáč, 1993).

Recently, an increased attention is paid to upgrading of calcined magnesia in magnetic field owing to intensive works on an optimisation of magnesite ore calcination process. Consequently, several magnesia specimens of different quality obtained

at various conditions of burning were subjected to dry high gradient magnetic separation (DHGMS) (Hredzák et al., 2011; 2013; 2014a).

Material and methods

The calcined magnesia fines (–0.5 mm) from Mútnik deposit were subjected to DHGMS using universal laboratory JONES-type electromagnetic separator in a cassette located between its poles. The cassette was lined by two grooved plates made of magnetically soft iron (Hredzák et al., 2013). In such way required induction and gradient of magnetic field were achieved.

The DHGMS was realised at five values of magnetic induction, namely 0.06; 0.11; 0.19; 0.30 and 0.45T. After separation at the lowest value of magnetic induction a non-magnetic product was consequently separated at higher induction value as it is schematically represented in Fig. 2. All obtained products were weighed and analysed.

Tab. 1. Magnetic fractions characteristics

Tab. 1. Charakterystyka frakcji magnetycznej

magnetic fraction [T]		yield γ [%]	$\kappa \cdot 10^{-6}$	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
	-0.06	82.77	66,489	81.91	3.22	4.87	0.26	2.78	4.69	0.56
0.06	-0.11	4.11	43,624	74.10	3.26	4.42	0.23	4.86	6.19	1.14
0.11	-0.19	1.35	17,552	55.55	5.62	4.38	0.19	8.40	11.91	3.73
0.19	-0.30	1.26	9,124	46.60	6.34	3.85	0.16	10.36	17.88	4.33
0.30	-0.45	1.58	4,653	41.36	9.10	3.29	0.15	12.97	18.11	5.83
+0.45		8.93	1,467	35.66	15.83	2.42	0.15	22.19	12.10	2.27
feed		100.00	57,384	76.02	4.51	4.59	0.24	4.93	5.89	0.91

Tab. 2. Recoveries of observed components into magnetic fractions ver. mass yield

Tab. 2. Uzysk składników we frakcji magnetycznej

magnetic fraction [T]		yield γ [%]	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
	-0.06	82.77	89.19	59.07	87.85	87.51	46.62	65.92	51.01
0.06	-0.11	4.11	4.01	2.97	3.97	3.96	4.05	4.32	5.13
0.11	-0.19	1.35	0.99	1.68	1.29	1.06	2.31	2.74	5.54
0.19	-0.30	1.26	0.77	1.77	1.05	0.83	2.64	3.81	5.97
0.30	-0.45	1.58	0.86	3.19	1.13	0.96	4.16	4.86	10.11
+0.45		8.93	4.19	31.32	4.71	5.68	40.22	18.34	22.24
feed		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 3. Calculation of parameters for magnesium (content as MgO)

Tab. 3. Obliczone zawartości magnezu (jako MgO)

magnetic fraction [T]	feed into separation			magnetic fractions			non-magnetic fractions				
	mass yield	content Mg	amount Mg	mass yield cumulative	Mg cumulative	content Mg	mass yield cumulative	Mg cumulative	content Mg		
	γ [%]	Mg [%]	Mg $\cdot\gamma$	$\Sigma \gamma \downarrow$	$\Sigma \text{Mg}\cdot\gamma \downarrow$	$\frac{\Sigma \text{Mg}\cdot\gamma \downarrow}{\Sigma \gamma \downarrow}$	$\Sigma \gamma \uparrow$	$\Sigma \text{Mg}\cdot\gamma \uparrow$	$\frac{\Sigma \text{Mg}\cdot\gamma \uparrow}{\Sigma \gamma \uparrow}$		
	a	b	c	d	e	f	g	h	i		
1	-0.06	82.77	81.91	6780.09	82.77	6780.09	81.91	100.00	7602.27	76.02	
2	0.06	-0.11	4.11	74.10	304.71	86.88	7084.80	81.54	17.23	822.18	47.71
3	0.11	-0.19	1.35	55.55	75.14	88.24	7159.94	81.15	13.12	517.47	39.44
4	0.19	-0.30	1.26	46.60	58.54	89.49	7218.48	80.66	11.77	442.33	37.59
5	0.30	-0.45	1.58	41.36	65.35	91.07	7283.84	79.98	10.51	383.79	36.52
6	+0.45		8.93	35.67	318.43	100.00	7602.27	76.02	8.93	318.43	35.66
feed		100.00	76.02	7602.27							

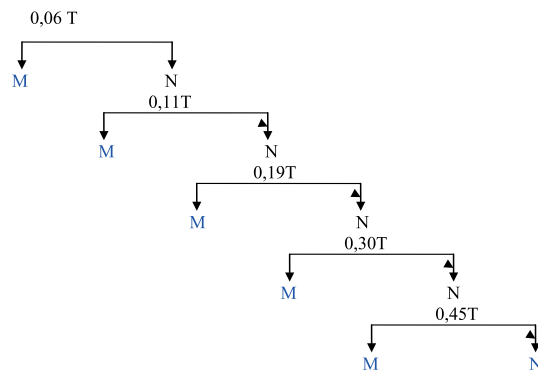


Fig. 1. Scheme of magnetic fractions preparation

Rys. 1. Schemat przygotowania frakcji magnetycznej

Tab. 4. Separation products quality at 0.06T

Tab. 4. Jakość produktów separacji, natężenie pola 0,06T

product	γ [%]	$\kappa 10^{-6}$	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	82.77	66,489	81.91	3.22	4.87	0.26	2.78	4.69	0.56
N	17.23	13,641	47.71	10.72	3.24	0.18	15.26	11.65	2.59
feed	100.00	57,384	76.02	4.51	4.59	0.24	4.93	5.89	0.91

Tab. 5. Recoveries into separation products at 0.06T

Tab. 5. Uzysk produktów przy 0,06 T

product	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	89.19	59.07	87.85	87.51	46.62	65.92	51.01
N	10.81	40.93	12.15	12.49	53.38	34.08	48.99
feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 6. Separation products quality at 0.11T

Tab. 6. Jakość produktów separacji, natężenie pola 0,11T

product	γ [%]	$\kappa 10^{-6}$	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	86.88	65,407	81.54	3.22	4.85	0.25	2.87	4.76	0.59
N	13.12	4,242	39.44	13.05	2.86	0.16	18.53	13.36	3.05
feed	100.00	57,384	76.02	4.51	4.59	0.24	4.93	5.89	0.91

Tab. 7. Recoveries into separation products at 0.11T

Tab. 7. Uzysk produktów przy 0,11 T

product	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	93.19	62.04	91.81	91.47	50.67	70.25	56.14
N	6.81	37.96	8.19	8.53	49.33	29.75	43.86
feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 8. Separation products quality at 0.19T

Tab. 8. Jakość produktów separacji, natężenie pola 0,19T

product	γ [%]	$\kappa 10^{-6}$	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	88.24	64,674	81.15	3.26	4.84	0.25	2.96	4.87	0.64
N	11.77	2,712	37.59	13.91	2.69	0.15	19.69	13.52	2.97
feed	100.00	57,384	76.02	4.51	4.59	0.24	4.93	5.89	0.91

Tab. 9. Recoveries into separation products at 0.19T

Tab. 9. Uzysk produktów przy 0,19 T

product	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	94.18	63.73	93.10	92.53	52.98	72.98	61.68
N	5.82	36.27	6.90	7.47	47.02	27.02	38.32
feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 10. Separation products quality at 0.30T

Tab. 10. Jakość produktów separacji, natężenie pola 0,30T

product	γ [%]	$\kappa 10^{-6}$	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	89.49	63,893	80.66	3.30	4.83	0.25	3.06	5.05	0.69
N	10.51	1,946	36.52	14.81	2.55	0.15	20.81	13.00	2.80
feed	100.00	57,384	76.02	4.51	4.59	0.24	4.93	5.89	0.91

Tab. 11. Recoveries into separation products at 0.30T

Tab. 11. Uzysk produktów przy 0,30 T

product	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	94.95	65.49	94.16	93.37	55.62	76.80	67.65
N	5.05	34.51	5.84	6.63	44.38	23.20	32.35
feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Tab. 12. Separation products quality at 0.45T

Tab. 12. Jakość produktów separacji, natężenie pola 0,45T

product	γ [%]	κ 10 ⁻⁶	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	91.07	62,865	79.98	3.40	4.80	0.25	3.23	5.28	0.78
N	8.93	1,467	35.66	15.83	2.42	0.15	22.19	12.10	2.27
feed	100.00	57,384	76.02	4.51	4.59	0.24	4.93	5.89	0.91

Tab. 13. Recoveries into separation products at 0.45T

Tab. 13. Uzysk produktów przy 0,45 T

product	MgO	LOI	Fe ₂ O ₃	MnO	CaO	SiO ₂	Al ₂ O ₃
M	95.81	68.68	95.29	94.32	59.78	81.66	77.76
N	4.19	31.32	4.71	5.68	40.22	18.34	22.24
feed	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The product quality was determined as follows. Loss on ignition (LOI) at 1000°C and SiO₂ content were assayed gravimetrically. Other elements such as Mg, Fe, Mn, Ca and Al have been determined by atomic absorption spectroscopy using the device VARIAN with accessories: Fast Sequential AAS AA240FS, Zeeman AAS AA240Z with Programmable Sample Dispenser PSD120, Graphite Tube Atomizer GTA120 and Vapor Generation Accessory VGA-77.

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

Results: the quality of magnetic fractions and recalculation to two-product separation

The results of the magnetic fractions analyses are introduced in Tables 1 and 2. Thus, according to a mass yield values it was shown that majority of grains is magnetic-sensitive. As to MgO content the best quality (magnetic) product was achieved at 0.06T. Naturally, the worst quality (non-magnetic) product was obtained at 0.45T with the lowest MgO content and the highest contents of CaO and SiO₂ as well as the highest value of LOI (Table 1).

It is needed to advert to the values in the first line of Table 2. On the one hand the recoveries of MgO, Fe₂O₃ and MnO are little higher than mass yield and on the other side the recoveries of CaO, SiO₂, Al₂O₃ and LOI are significantly lower. Thus, MgO, Fe₂O₃

and MnO are predominantly bonded in magnetic minerals conversely CaO, SiO₂, Al₂O₃ and LOI in non-magnetic phases.

On the basis of values in Table 1, the recalculation of parameters for two-product separation of every component, namely MgO, LOI, Fe₂O₃, SiO₂, CaO, Al₂O₃, MnO including magnetic susceptibility was carried out. The example of recalculation is introduced in Table 3 for MgO. The following relations are valid for the values in columns and lines in this Table: i) $c = a \cdot b$. ii) $a1 = d1$, then $d2 = d1 + a2$, $d3 = d2 + a3$, etc. iii) $c1 = e1$, then $e2 = e1 + c2$, $e3 = e2 + c3$, etc., iv) $f = e/d$

Similarly, the calculations for non-magnetic fractions were performed. On the basis of calculated values the separability, magnetic and non-magnetic fractions curves have been constructed enabling continuous data reading (Fig.2).

Finally, the parameters of two-product separation are presented in Tables 4–13.

Conclusion

The contribution demonstrated the determination of magnetic separability of calcined magnesia fines. Thus, behaviour of this material in magnetic field is possible to predict in such way. The determination is very important because the content of fines in calcined magnesia can attain of 30.7–38.2% under 1 mm and/or 25.17–30.19% under 0.5mm.

The results of analyses showed that: (i) the cleanest magnetic product with the highest Mg content (81.91%) can be achieved at the lowest magnetic induction, but also at the lowest mass

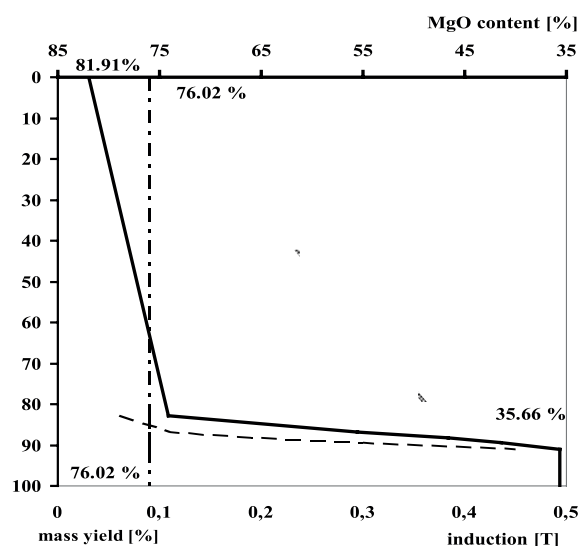


Fig. 2. Separability curves for MgO
Rys. 2. Krzywa wzbogacalności MgO

yield and Mg-recovery, (ii) a limitation of Mg losses in non-magnetic product is possible only on the expense of Mg content reduction (gradually to 79.98%) in magnetic product at higher values of induction during separation, where the magnetic product is gradually impure by gangue minerals at growing mass yield, (iii) significant reduction of gangue components such as CaO, SiO₂ and Al₂O₃ in magnetic product is attainable.

Chemical analyses and recoveries similar trends of magnesium, iron and manganese point to mutual bond or better said all these elements occur in

the lattice of magnesite. For this reason iron and manganese removal is not possible to achieve using physical technique of upgrading.

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Literatura – References

- BROWN, T.J.; WRIGHTON, C.E.; RAYCRAFT, E.R.; SHAW, R.A.; DEADY, E.A.; RIPPINGALE, J.; BIDE, N.; IDOINE, N. 2015. *World Mineral Production 2009–13*. Nottingham: British Geological Survey, NERC.
- CAGAŠ, Z. 1972. "Magnetic Separability of Minerals, Its Determination and Assessment. In Proceedings of the Xth Nationwide Mineral Processing Conference." *Dept. of Min. Proc.*: 51–59.
- HREDZÁK, S.; LOVÁS, M.; JAKABSKÝ, Š.; GEŠPEROVÁ, D.; BRIANČIN, J.; BALOG, M. 2008. *Analysis of Feed into Scavenging Stage of Magnetic Separation. Research report for SIDERIT, Ltd.* Nižná Slaná. Košice: Institute of Geotechnics SAS.
- HREDZÁK, S.; LOVÁS, M.; JAKABSKÝ, Š.; BRIANČIN, J.; BALOG, M.; GEŠPEROVÁ, D.; FEČKO, P.; MUCHA, N.; JANÁKOVÁ, I. 2009. "Magnetic Separation and XRD Study of Magnetite-bearing Feldspar Sands from the Philippines." *Proceedings of the Int. Conference on „Mineral Resources of Slovakia and their Utilization“*, Hotel Repiska, Demänovská Dolina SR, October 8–9, 2009, Slovak Mining Society (ed. Beránek M., Pastor J.), Banská Bystrica: 143–151.

5. HREDZÁK, S.; OLIJÁR, A.; MATIK, M.; SPIŠÁK, J.; BRIANČIN, J.; ŠTEFUŠOVÁ, K. 2011. *Magnetic Upgrading of Calcined Magnesia Fines*. In *Proceedings of the 15th Conference on Environment and Mineral Processing Part II* (eds. Peter Fečko and Vladimír Čablík). Ostrava: VŠB – Technical university of Ostrava, Faculty of Mining and Geology, Institute of Environmental Engineering, June 8–10th.
6. HREDZÁK, S.; LOVÁS, M.; ZNAMENÁČKOVÁ, I.; MATIK, M.; ZUBRIK, A.; BRIANČIN, J.; ŠTEFUŠOVÁ, K. 2013. "Contribution to Possibilities of Dry Low-Intensity High-Gradient Magnetic Separation of Calcined Magnesite." *Proc. Int. Conf. on „New Mineral Policy - Advanced Technologies in Mining, Geology and the Environment“*, Hotel Repiska, Demänovská Dolina, October 10–11, 2013 Slovak Mining Society (ed. Beránek M.), Banská Bystrica.
7. HREDZÁK, S.; PJURA, L.; LOVAS, M.; ZNAMENACKOVA, I.; MATIK, M.; ZUBRIK, A.; STEFUSOVA K. 2014a. "High Gradient Magnetic Separation of Calcined Magnesite." *Proceedings of the 14th International Multidisciplinary Scientific GeoConference SGEM 2014, Albena, Bulgaria, June 17–26, 2014. Geoconference on Science and Technologies in Geology, Exploration and Mining*, Exploration and Mining, Mineral Processing, STEF92 Technology Ltd., Sofia, Bulgaria, 1(3): 875–882.
8. HREDZÁK, S.; LOVÁS, M.; ZNAMENÁČKOVÁ, I.; MATIK, M.; ZUBRIK, A.; ŠTEFUŠOVÁ, K. 2014b. "Magnetic Analysis of Magnesite Ore Fines." *Proc. Int. Conf. on „New Mineral Policy - Advanced Technologies in Mining, Geology and the Environment“*, Hotel Repiska, Demänovská Dolina, November 13-14, 2014 Slovak Mining Society (ed. Beránek, M.), Banská Bystrica: 150–157.
9. KILIN, V.I.; YAKUBAILIK, E.K; KOSTENENKO, L.P.; GANZHENKO, I.M. 2012. "Dressability of Abagas hematite-magnetite ores." *Journal of Mining Science* 48: 363–368.
10. KOZÁK J. AND CAGAŠ, Z. 1965. *Assessment of Dressability and Methods of Mineral Processing*. Technical book, Prague: SNTL/SVTL.
11. LUKÁČ, J. 1993. *Physical Techniques of Beneficiation Process*. Košice: University textbook ES BF TU.
12. REICHL, C.; SCHATZ, M.; ZSAK, G. 2015. *World - Mining - Data, Minerals Production*. Federal Ministry of Science, Research and Economy 30.
13. ŠALÁT, J. AND ONČÁKOVÁ, N. 1966. *Mineralogy II*. 1st edition, VŠT Košice: SVTL Bratislava.
14. ŠPALDON, F. 1986. *Mineral Processing. National textbook*. Bratislava/Prague: ALFA/SNTL.

Separacja magnetyczna kalcynowanego magnezytu w polu magnetycznym

Magnezyt jest jednym z najbardziej znaczących minerałów na Słowacji. Według różnych przeglądów statystycznych, Słowacja jest uwzględniana między szóstym a szóstym miejscem na świecie w produkcji magnezytu, a jej udziały wahają się od 2,25–3,63% całkowitej produkcji światowej (Reichl in., 2015; Brown i in., 2015).

Magnezyt występuje w pasie od Lucenec do Koscic (południe centralno-wschodniej Słowacji) w formie odmiany metalu zwanej brunerytem (zazwyczaj 10–30%, lecz również 8–17% lub 5–50% FeCO₃) tj. ferromagnetyku (Mg_{0,9-0,7}Fe_{0,1-0,3})CO₃, zazwyczaj zawierającego około 9% FeO (Šalát i Ončáková, 1966). Co się tyczy proporcji CaO/SiO₂ (zmienna C/S > 2 lub < 2), to obecne są oba typy technologiczne magnezytu, mianowicie wapno i krzemionka. Z tego powodu badania nad ulepszeniem magnezytu i magnezji opierają się głównie na redukcji wapna i krzemionki. Obserwuje się także zachowanie żelaza w procesie separacji. Praca traktuje o określeniu efektywności separacji magnetycznej drobnych klas ziarnowych z prażonego magnezytu ze złoża Mútnik (typ krzemionki). Zawartość miazu w klasie -0,5mm może osiągać 25–30%. Badania przeprowadzono w separatorze o wysokim natężeniu pola magnetycznego. Produkt najwyższej jakości zawierał 81,91% MgO przy wydajności masowej 82,77%, uzysk MgO w wysokości 89,19% był otrzymany przy natężeniu pola magnetycznego na poziomie 0,06T. Zwiększenie indukcji pola magnetycznego spowodowało wzrost wydajności masowej, zwiększenie odzysku związków, niestety również stopniowy wzrost zanieczyszczenia składnikami skały płonnej. Zatem produkt magnetyczny zawierający MgO w ilości 79,98% przy wydajności masowej 91,07%, z uzyskiem MgO na poziomie 95,81% został uzyskany przy najwyższym natężeniu pola 0,45T. Analiza właściwości magnetycznych surowca przeznaczonego do separacji pozwala na wcześniejsze ustalenie odpowiedniej indukcji pola w celu otrzymania wymaganej jakości rozdzielanych produktów.

Słowa kluczowe: wzbogacalność magnetyczna, kalcynowany drobnouziarniony magnezyt