Analysis of Influence of Different Types of Separators on Fine Grain Coal Class Enrichment Process in Respect with Qualitative and Quantitative Analysis of Separation Products

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Abstract

The Article presents comparative analysis of enrichment process of coal slurry that was conducted with use of different types of spiral coil separators and with consideration of influence of separators construction differences on obtained separation products. The best quality was achieved with feed material density of β=300 g/cm³ for both spirals with ash content of λi= 12,86% for Reichert LD4 and 2,85 λi= 12,86% for Krebs spiral.

Keywords: slurry coal, coal beneficiation, spiral separators, statistical analysis

Introduction

Ira B. Humphrey Jr. is considered to be the co-creator of spiral separators where separation occurs in fluid stream (water). The main construction element of a spiral is a through coiled around vertical axis. Spiral coil separators are used mainly for enrichment of fine grained iron ores, non-ferrous metal ores, silver, gold and other (Atesok G., Yildirim I., Celik M.S., 1993, Blaschke W., Blaschke S., 1999, Iwanow W.O., Prokopiew S.A., 2000). It is also possible to utilize spirals for enrichment of fine grained hard coals (Richards, R.G., Hunter, J.L., Holland-Batt, A.B., 1985, Richards R.G., MacHunter D.M.,Gates P.J, Palmer M.K.,2000 Arnold B. J., Petrunak D., 2006). Furthermore, spiral separators are used for secondary enrichment of tailings and fine grained waste from enrichment processes that contain certain amount of extractable usable grains (Blaschke Z.2000, Szpyrka J., Lutyński M., 2012 Lutyński A., Lutyński M.,2015) The grain class range of raw material that can be fed to a spiral is between 0,05 to 3,0 mm. However, most often the grain sizes of feed material used in enrichment process with spiral coil separators ranges between 0,1 to 2,0 mm with 15 to 25% consisting of solid parts in relation to water used in the process. Considering the economics of enrichment process as well as the fact that it proceeds automatically, the decision was made to use these type of devices i.e. spiral coil separator Reichert LD4 and Krebs 2,85 for the enrichment of coal slurry and for the study how construction differences influence quantity and quality of end products. These separators are different in terms of several of their construction elements. Detailed comparison is presented in table 1

Methodology

Analysis was conducted on two types of spiral coil separators i.e. Reichert LD4 and Krebs 2,85 that have different construction. The study of spiral separators construction differences influence on slurry separation process was conducted on three coal slurry originating from different places in GZW. Before enrichment slurry feeds were classified into narrow grain size ranges, and then subjected to quantitative analysis. Results are presented in figure 1.

Based on the conducted analysis, weighted average ash contents for studied slurries were determined. They amounted to: α1= 39,64%, α2= 43,36%, α3= 26,13% respectively. Ash content of the studied slurry feeds indicates that they contain certain amount of coal grains available for reclamation, which in result will lead to creation of better quality commercial products. In order to check how a high amount of silt will affect final separation products, the slurry feeds were not desilted prior to sending to spiral separators. Enrichment process was conducted for two different feed density values, equal to β=350 g/dm³ and β=300 g/dm³. This density of feed material was selected as a result of sample tests conducted in order to choose proper separation parameters. Feed material from three of the analyzed slurries was sent to Reichert LD4 and Krebs, 2,85 spirals. Obtained products of separation were divided into narrow grain class ranges and their ash content and mass yield was determined as shown in figures 2–19.

Based on the products of separation presented in figures 2-19 it was observed that the best separation results (concentrates) were obtained for density of β=300 g/dm3 for both Reichert LD4 and Krebs 2.85. Weight-

Tab. 1. Structural differences of the tested separators, source: own study

Tab. 1. Różnice konstrukcyjne badanych wzbogacalników

Separator / Construction feature	Spiral separator Reichert LD4	Spiral separator Krebs 2,85
Number of coils	10	6
Number of enrichment products	3	3
Coil angle	15°	15°
Separator height	5,15 m	2,85m

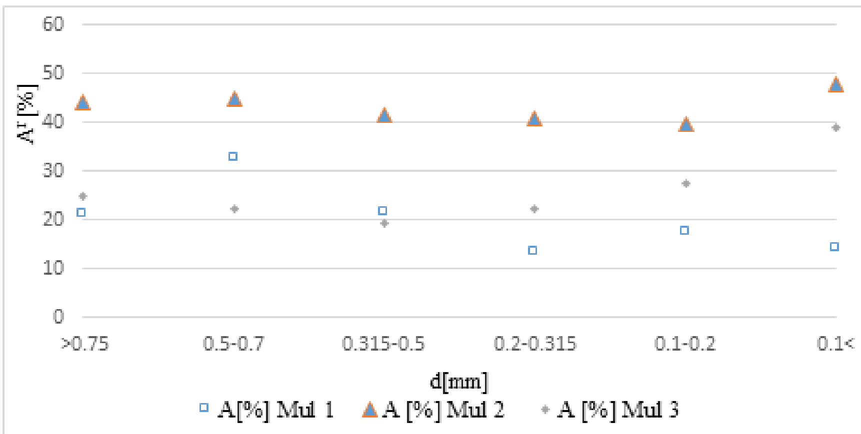

Fig. 1. Ash content in slurry feeds used for enrichment with consideration for specific grain sizes

Rys. 1. Zawartości popiołu w nadawach mułowych kierowanych do wzbogacania z uwzględnieniem poszczególnych klas ziarnowych

ed average ash content in concentrate of Slurry 1 obtained from Reichert LD 4 spiral was ʎi= 12,86% and ʎi= 15,00% from Krebs 2,85. In case of Slurry 2 the weighted average ash content in concentrate from Reichert LD 4 spiral amounted to ʎi= 39,83%, while from Krebs 2,85 it was ʎi= 42,03%. Such high ash content in Slurry 2 clearly indicates that this slurry is already almost completely devoid of usable grains, thus using this material for enrichment seems to serve no purpose. From Slurry 3 concentrate weighted average ash content from Reichert LD 4 spiral was ʎi= 19,95% and ʎi= 21,91% from Krebs 2,85 spiral. The difference in ash content in concentrates obtained from both spiral separators was around 7%. Lower ash content of concentrate from Reichert LD4 is probably the result of longer time the feed had to spent in the trough due to higher number of coils. The higher the number of coils and at the same time the longer the path that grains selected for separation have to travel allow grains of proper density to settle in the right place, which results in creation of so called density range that should form in spiral's trough.

In case of feed density of β=350 g/dm³ similar situation was observed like it was with feed density of β=300 g/dm³ i.e. better concentrate was obtained from Reichert LD4 separator that had weighted average ash content of ʎi= 15,64%, while concentrate from Krebs 2,85 spiral had weighted average ash content of ʎi= 23,88%. When it comes to obtained semi-products it seems reasonable to conduct secondary enrichment process, because qualitative and quantitative analysis that had been conducted proved that they contained some amount of usable grains. However, validity of conducting secondary enrichment of semi-products should be first subjected to economic analysis to secure a company from generating additional costs, which may not be covered by potentially low profits from sales of newly obtained products. Such situation may occur when a new product will have relatively low quantitative yield or when demand for secondary enriched product will be low.

Statistical verification of coal slurry enrichment process

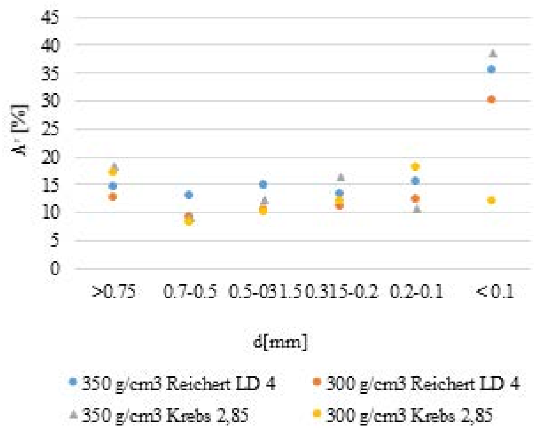

Fig. 2. Ash content of concentrate in selected grain classes of Slurry 1

Rys. 2. Zapopielenie koncentratu w poszczególnych klasach ziarnowych mułu 1

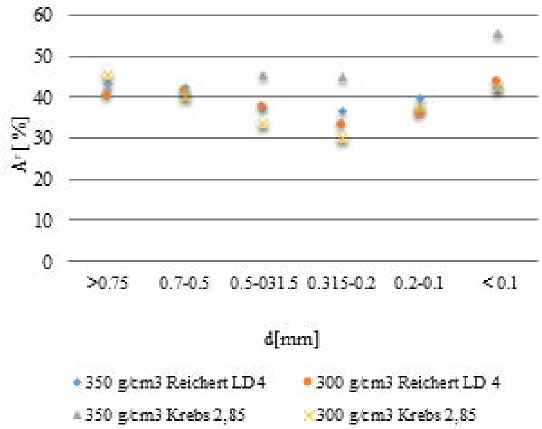

Fig. 3. Ash content of concentrate in selected grain classes of Slurry2

Rys. 3. Zapopielenie koncentratu w poszczególnych klasach ziarnowych mułu 2

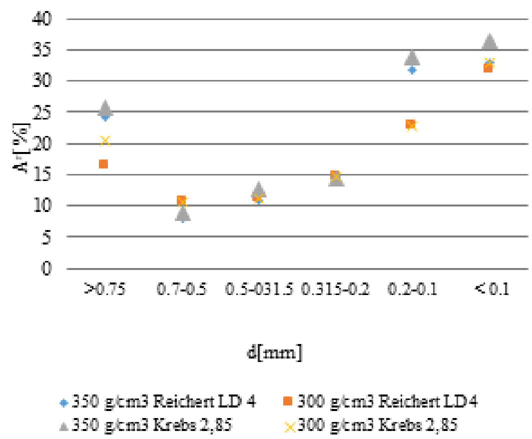

Fig. 4. Ash content of concentrate in selected grain classes of Slurry3

Rys. 4. Zapopielenie koncentratu w poszczególnych klasach ziarnowych mułu 3

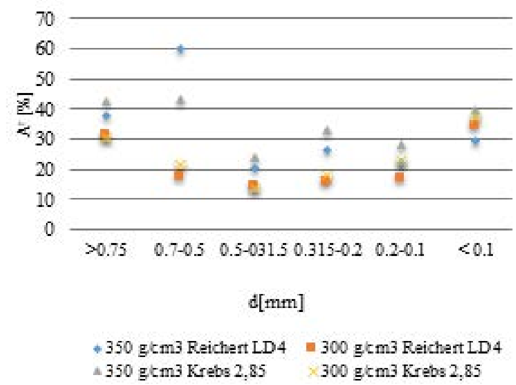

Fig. 5. Ash content of semi-product in selected grain classes of Slurry 1

Rys. 5. Zapopielenie półproduktu w poszczególnych klasach ziarnowych mułu 1

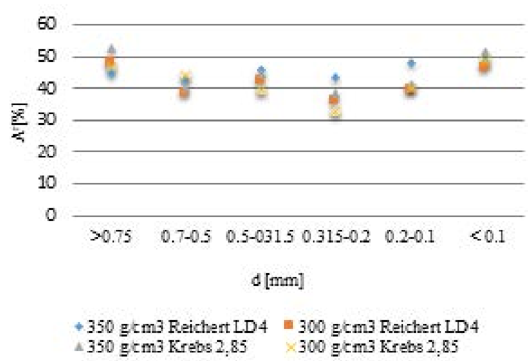

Fig. 6. Ash content of semi-product in selected grain classes of Slurry 2

Rys. 6. Zapopielenie półproduktu w poszczególnych klasach ziarnowych mułu 2

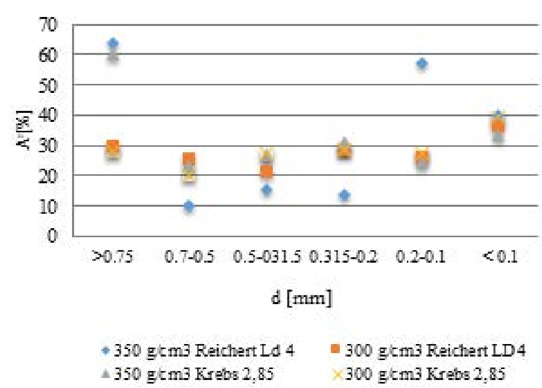

Fig. 7. Ash content of semi-product in selected grain classes of Slurry 3

Rys. 7. Zapopielenie półproduktu w poszczególnych klasach ziarnowych mułu 3

Tab. 2. Average value and variance calculated for products with density of β=350 g/cm3

Tab. 2. Wartość średnia i wariancja obliczona dla produktów o zagęszczeniu β=350 g/cm3

	Reichert LD4						Krebs 2,85					
	Concentrate		Semi-product		Waste		Concentrate		Semi-product		Waste	
	x	s	x	s	x	s	x	s	x	s	x	s
Slurry 1	15,65	75,72	35,95	214,32	56,43	80,34	17,63	117,44	37,98	60,48	52,28	165,04
Slurry 2	42,17	8,08	44,56	4,98	48,01	4,98	44,37	37,55	46,80	35,87	46,91	113,11
Slurry 3	23,89	115,32	30,86	221,10	59,76	28,35	24,85	135,83	32,38	190,79	56,51	19,55

Average values and variance were determined based on obtained products of separation for both Reichart LD4 and Krebs 2,85. Hypothesis was assumed that both independent populations have normal distribution with equal variance. Populations were designated based on products obtained from each separator. Can it be then assumed that obtained products from different separators are the same?

Statistical study was conducted based on random sample. Following results were achieved for both samples and presented in table 2 and 3.

Following hypotheses were formulated to find answers to the question asked:

H_0: $m_1 – m_2 = 0$

H_1: $m_1 – m_2 \neq 0$

Where m_1 and m_2 are average values for population, while for products obtained from separators average values are designated as x_1, x_2. Empirical statistics, which will verify the assumed hypothesis is supported by the formula [Aczel, 2010]:

$$t_{emp} = \frac{x_1 - x_2}{s_r} \quad [1]$$

where:

s_r – standard error of a difference

If $|t_{emp}| < |t\alpha|$ then with statistical significance of 5% there is no basis to reject null hypothesis, which states that average values are equal. Then the conclusion can be drawn that obtained products do not vary between one another in terms of ash content, separator selection or that enrichment method has any significance. In a situation when null hypothesis is rejected then it means that obtained products vary in ash content depending on type of separator that had been used for separation process. It highly important in regards to economics of enrichment process and for adjusting obtained products to the regulations related to environmental protection.

Critical statistic that settles if the assumed hypothesis should be accepted or not was read from t-Student tables for significance level of 0,05 and 10 degrees of freedom and amounted to 2,2281. The results with accordance to the formula were presented in tables 4–7.

As a result of conducted statistical test to check the difference of qualitative parameters of products obtained from Reichert LD4 and Krebs 2,85 separators it is clear that in most cases assumed null hypothesis should be rejected in favor of alternative hypothesis. It means that there are significant differences of ash content in obtained products in relation to selected type of separator. However, in four cases null hypothesis should be accepted. These cases are: semi-product Slurry 1 and Slurry 3 for density of β=350 g/cm^3 and semi-product Slurry 2 and Slurry 3 for density of β=300 g/cm^3.

The cause of this result can be associated with human error during enrichment process and high content of clay minerals in analyzed material. Thus to evaluate this assumption the evaluation of quotient of two variances was conducted: s_1^2 / s_2^2. Variance was designated for each product obtained from Reichert LD4 and Krebs 2,85 separator respectively. The results of calculations are presented in table 2 and 3.

Verification of null hypothesis about equality of average value requires fulfilling the assumption that the studied characteristics (populations) have normal distribution with equal variance. Testing of this assumption is based on Fisher-Snedecor distribution.

Presumption about equality of variance was formulated:

H_0: $\sigma_1^2 = \sigma_2^2$

H_1: $\sigma_1^2 > \sigma_2^2$

(selection of one-sided alternative hypothesis is a result of statistical tables construction)

Test formula is as follows (Aczel, 2010):

$$F_{emp} = \frac{s_1^2}{s_2^2}$$

the value of quotient of samples variance should be an improper fraction, i.e. no smaller than one, thus higher variance must be moved to a denominator – this means that sample 1 is the sample with higher variance.

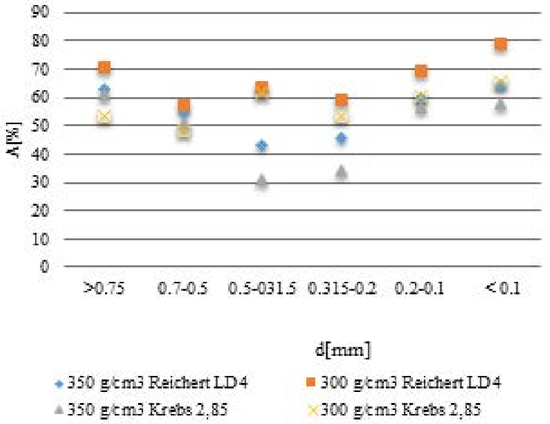

Fig. 8 Ash content of waste in selected grain classes of Slurry 1

Rys.8. Zapopielenie odpadu w poszczególnych klasach ziarnowych mułu 1

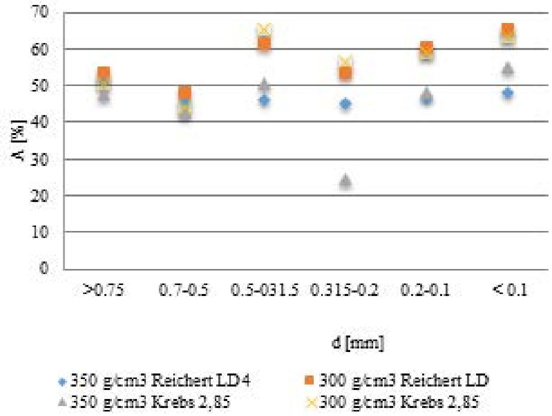

Fig.9 Ash content of waste in selected grain classes of Slurry 2

Rys.9 Zapopielenie odpadu w poszczególnych klasach ziarnowych mułu 2

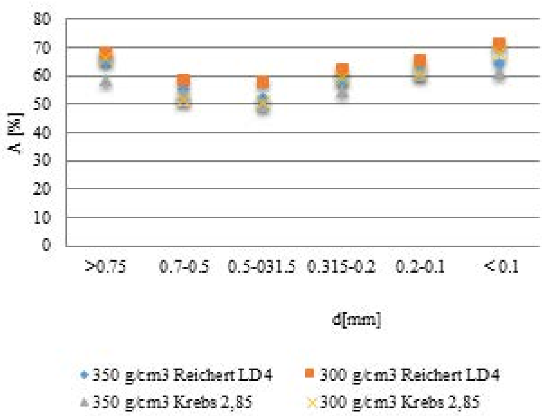

Fig.10 Ash content of waste in selected grain classes of Slurry 3

Rys.10 Zapopielenie odpadu w poszczególnych klasach ziarnowych mułu 3

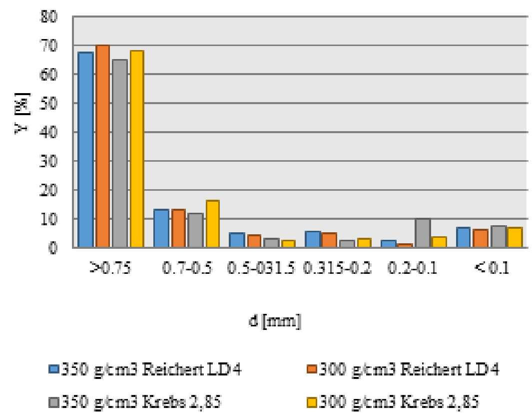

Fig.11 Concentrate yield in selected grain classes of Slurry1

Rys.11 Wychód koncentratu w poszczególnych klasach ziarnowych mułu 1

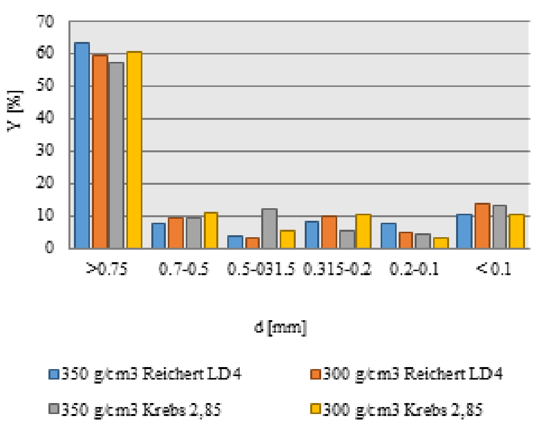

Fig.12 Concentrate yield in selected grain classes of Slurry2

Rys.12 Wychód koncentratu w poszczególnych klasach ziarnowych mułu 2

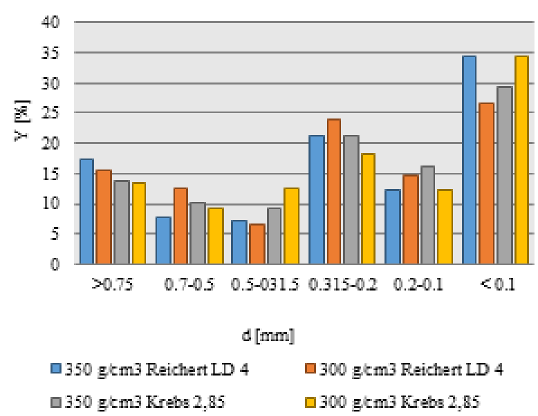

Fig.13 Concentrate yield in selected grain classes of Slurry 3

Rys.13 Wychód koncentratu w poszczególnych klasach ziarnowych mułu 3

Tab. 3. Average value and variance calculated for products with density of β=300 g/cm³

Tab. 3. Wartość średnia i wariancja obliczona dla produktów o zagęszczeniu β=300 g/cm³

	Reichert LD4						Krebs 2,85					
	Concentrate		Semi-product		Waste		Concentrate		Semi-product		Waste	
	x	s	x	s	x	s	x	s	x	s	x	s
Slurry 1	12,86	62,34	23,93	74,48	68,95	66,77	15,00	15,42	26,52	72,29	62,53	50,63
Slurry 2	39,83	37,55	44,39	33,23	56,69	6,45	42,03	32,11	44,83	35,87	54,79	63,32
Slurry 3	19,95	64,76	28,96	25,10	65,21	27,85	21,91	72,19	29,26	36,80	60,46	53,72

Tab. 4. Auxiliary calculations for designation of t-Student statistics for products with density of β=350 g/cm³

Tab. 4. Obliczenia pomocnicze do wyznaczenia statystyki t-Studenta dla produktów o zagęszczeniu β=350 g/cm³

	Concentrate		Semi-product		Waste	
	$\bar{x}_{(1)} - \bar{x}_{(2)}$	s	$\bar{x}_{(1)} - \bar{x}_{(2)}$	s	$\bar{x}_{(1)} - \bar{x}_{(2)}$	s
Slurry 1	1,99	0,79	2,03	1,34	4,15	0,82
Slurry 2	2,19	0,26	2,24	0,20	1,10	0,20
Slurry 3	0,96	0,98	1,52	1,36	3,25	0,49

Source: own study

Tab. 5. Auxiliary calculations for designation of t-Student statistics for products with density β=300 g/cm³

Tab. 5. Obliczenia pomocnicze do wyznaczenia statystyki t-Studenta dla produktów o zagęszczeniu β=300 g/cm³

	Concentrate		Semi-product		Waste	
	$\bar{x}_{(1)} - \bar{x}_{(2)}$	s	$\bar{x}_{(1)} - \bar{x}_{(2)}$	s	$\bar{x}_{(1)} - \bar{x}_{(2)}$	s
Slurry 1	2,13	0,72	2,58	0,79	6,42	0,75
Slurry 2	3,20	0,56	0,44	0,53	1,90	0,23
Slurry 3	2,96	0,73	0,29	0,46	4,76	0,48

Source: own study

Tab. 6. t-Student statistics for products with density of β=350 g/cm³

Tab. 6. Statystyki t-Studenta dla produktów o zagęszczeniu β=350 g/cm³

	Concentrate	Semi-product	Waste
Slurry 1	2,50	1,52	5,07
Slurry 2	8,46	10,99	5,41
Slurry 3	2,98	1,12	6,69

Source: own study

Critical value Fα is read from Fisher-Snedecor tables and if < Fα then there is no basis to reject null hypothesis. Otherwise alternative hypothesis is assumed. Critical statistic was read for statistical significance of 0,05 and degrees of freedom equal to $n_1 = 5$ and $n_2 = 5$. Results of these calculation are presented in tables 6 and 7.

The result of conducted statistical test proved that the majority of compared products have equal variance. This means that these products are similar to each other in regards to quality as a result of the enrichment process performed. However, in case of semi-products Slurry 1 and Slurry 3 with density of β=350 g/dm³ and semi-products Slurry 2 and Slurry 3 with density of β=300 g/dm³ null hypothesis should be rejected, which means that there are significant differences in conducted enrichment. The cause of this can be, as mentioned before, human error during enrichment process as well as high clay mineral content that results in worse enrichment results.

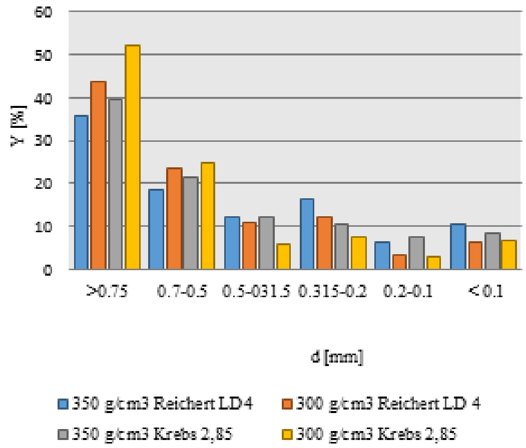

Fig.14 Concentrate semi-product in selected grain classes of Slurry1

Rys.14 Wychód półproduktu w poszczególnych klasach ziarnowych mułu 1

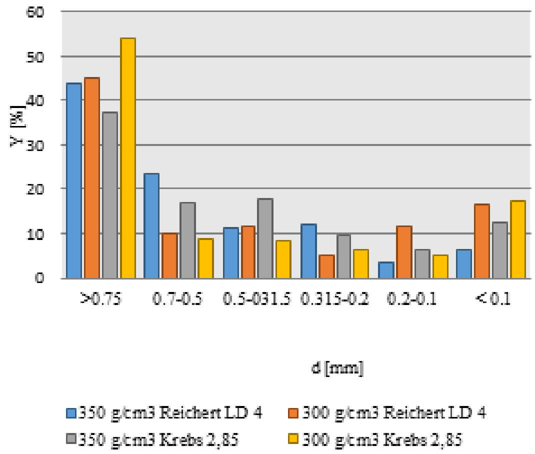

Fig.15 Concentrate semi-product in selected grain classes of Slurry2

Rys.15 Wychód półproduktu w poszczególnych klasach ziarnowych mułu 2

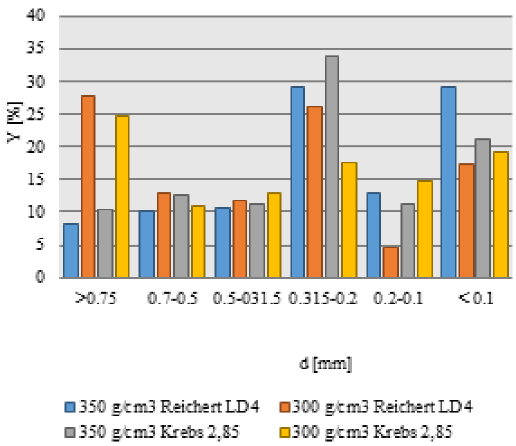

Fig.16 Concentrate semi-product in selected grain classes of Slurry3

Rys.16 Wychód półproduktu w poszczególnych klasach ziarnowych mułu 3

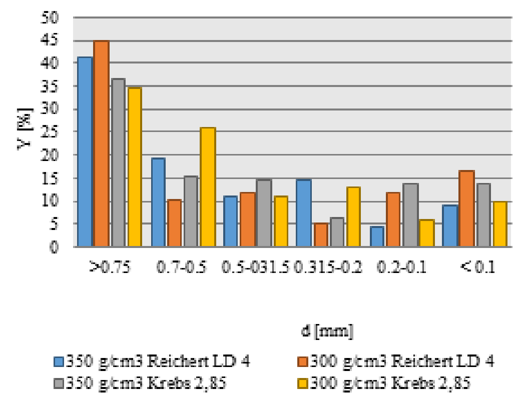

Fig.17 Concentrate waste in selected grain classes of Slurry1

Rys.17. Wychód odpadów w poszczególnych klasach ziarnowych mulu 1

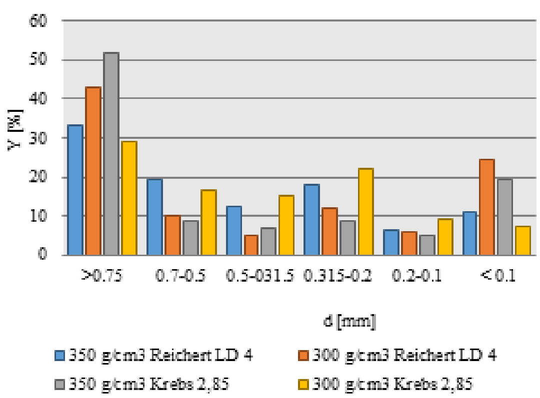

Fig.18 Concentrate waste in selected grain classes of Slurry2

Rys.18. Wychód odpadów w poszczególnych klasach ziarnowych mulu 2

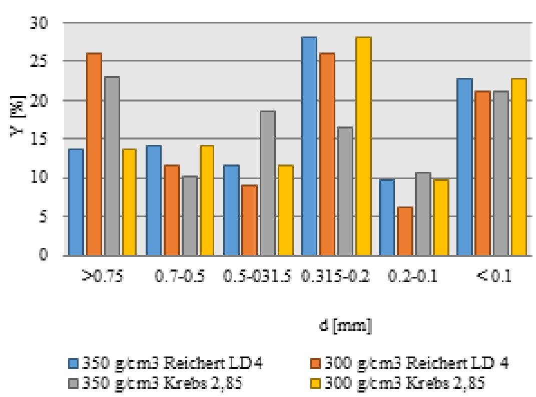

Fig.19 Concentrate waste in selected grain classes of Slurry3

Rys.19. Wychód odpadów w poszczególnych klasach ziarnowych mulu 3

Tab. 7. t-Student statistics for products with density of β=300 g/cm^3

Tab. 7. Statystyki t-Studenta dla produktów o zagęszczeniu β=300 g/cm^3

	Concentrate	Semi-product	Waste
Slurry 1	2,96	3,28	8,60
Slurry 2	5,72	0,83	8,21
Slurry 3	4,03	0,64	9,88

Source: own study

Tab. 8. F statistics for products with density of β=350 g/ dm^3

Tab. 8. Statystyka F dla produktów o gęstości β=350 g/ dm^3

	Concentrate	Semi-product	Waste
Slurry 1	1,5510	5,5435	2,0542
Slurry 2	4,6493	5,0061	2,7236
Slurry 3	1,1779	5,1589	1,4496

Source: own study

Tab. 9. F statistics for products with density of β=300 g/ dm^3

Tab. 9. Statystyka F dla produktów o gęstości β=300 g/ dm^3

	Concentrate	Semi-product	Waste
Slurry 1	4,0438	1,0304	1,3189
Slurry 2	1,1693	6,0795	3,8223
Slurry 3	1,1148	5,4663	1,9290

Source: own study

Conclusions

The conducted laboratory study of the enrichment of coal slurry based on selected types of spiral coil separators it leads to conclusion that using these devices gives the ability to obtain concentrates with low ash content. Additionally, it was noted that the construction differences between studied separators influence quantity and quality of obtained separation products. Final products from Reichert LD4 separator were characterized by better qualitative parameters than the ones from Krebs 2,85. Apparently it was an effect of higher number of coils and thus higher probability of feed grains traveling to their proper place in a stream of separated material on the surface of spiral's coil. Semi-products obtained during the enrichment process can be considered either commercial products or feed material for secondary enrichment, however, the decision about any actions taken in regards to the intermediate product should be based on prior economic analysis and thorough verification of market demand.

Actions that lead to improvement on qualitative parameters of raw slurries should be conducted with consideration of low emission and procedures leading to withdrawal of low quality coal fuels.

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General Information

The main aim of the V4 Waste Recycling XXI International Conference is to strengthen the intersectoral partnerships in environmental research and waste recycling, delivering knowledge transfer in science and technology.

The main topics of the V4 Waste Recycling XXI International Conference are devoted to the creation of circular economy and include:

- Recycling and utilisation of industrial wastes (metallurgical, power-engineering, mechanical engineering, chemical industrial, WEEE, end-of-life vehicles, plastics, demolishing waste, mining waste and tailings, etc.);
- Treatment and recycling of municipal solid waste and biowaste;
- Critical raw materials from secondary sources;
- Decontamination and remediation of contaminated areas;
- Waste water treatment and air quality control;
- Business activities in waste recycling;
- Legislation issues of recycling and waste utilization.

Conference language is English; all papers, presentations and communications are required in English. All accepted papers will be published in the ISBN-numbered Conference Proceedings and distributed among the participants. The selected papers will be advised for the publication in the Geosciences and Engineering Journal (HU ISSN 2063-6997), indexed by ProQuest.

Venue

The V4 WR XXI Conference will take place on the beautiful Campus of University of Miskolc, established in 1735.

Registration, fees and deadlines

All participants are kindly required to complete the registration form on the official website of the V4 Waste Recycling XXI International Conference until 31 August, 2018.

	Date	*Standard registration*	*Student registration*	*Accompanying person*
Early payment	31 July 2018	150 EUR	100 EUR	40 EUR
Regular payment	20 November 2018	200 EUR	140 EUR	50 EUR
On-site cash payment	22 November 2018	200 EUR	140 EUR	50 EUR

The registration fee covers the participation in the conference, conference proceedings, coffee breaks and refreshments, lunch and participation in the gala dinner on 22 November, 2018. Active B.Sc., M.Sc. and Ph.D. students are considered as students. For accompanying persons the registration fee includes participation in gala dinner and a guided sightseeing tour on 23 November, 2018.

Detailed registration and paper submission information and the conference website will be available soon!