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Secondary separation of coking coal middlings in spiral separators

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Paweł FRIEBE [1*], Piotr MATUSIAK [1], Daniel KOWOL [1]

Author's affiliations and addresses:

[1] KOMAG Institute of Mining Technology
Pszczyńska 37
44-100 Gliwice, Poland

*** Correspondence:**

e-mail: pfriebe@komag.eu

Abstract:

The results of recovery by secondary separation tests of coking coal middlings are presented. The gravitational separation method, based on the differences in densities among the feed grains in the stream of flowing water, was used in the tests. Coking coal middlings, obtained in the three-product separation process in the coal fines jig of the processing plant of the coking coal mine in the Silesian Voivodeship, were tested. The following spiral separators were used during the separation process: Reichert LD-4 and Krebs 2.85. Based the test results, the most advantageous feed density was determined for each separator. Using the above-mentioned feed density, the concentrate of the lowest ash content and the highest waste output was obtained. The process was repeated for the optimal density to check how the grain classes of the feed separate in the secondary separation products containing coking coal interlayers.

Keywords: coking coal, spiral separators, coal interlayers

1. Introduction

Due to the high content of impurities, raw hard coal is processed mechanically to increase the content of the useful component. Mineral processing includes classification, grinding, mixing with reagents (flotation), separation, dewatering or averaging [1].

The process of gravitational separation of raw hard coal enables its separation into a concentrate - a product with an increased content of a useful component, middlings and waste - a product with a reduced or trace content of a useful component [2]. In the case of interlayers in raw hard coal, the grains that are concretions of the useful component and waste rock, will be found in middlings. In most cases, the content of the useful component in middlings is insufficient for its industrial use.

The middlings, in the case of presence of interlayers, may be subjected to a grinding process to separate the useful component and waste rock. Then the ground material is directed to the secondary separation, to produce secondary concentrate, secondary middlings (in the case of threeproduct secondary separation) and secondary wastes. The secondary separation may be repeated many times, what is, however, determined by the economic analysis.

In the case of separation in the air, the grains of different densities are separated in a pulsating, often rising, air stream. This separation is mainly used for raw materials that are easily separable - with low density and without water. Such method has some ad-vantages and disadvantages. The lower quality of the end product compared to separation in the water medium is a disadvantage; dry product and low process costs are advantages [3]. As the content of interlayers in the raw material increases, the degree of separation difficulty increases, what requires using a medium of higher density, such as water [4].

2. Literature review

There is a large group of devices for beneficiation of minerals in a stream of water. These are machines, differing mainly in the direction of liquid movement, the distribution of forces acting on the grains in water, design solutions, and the way of collecting the products or feeding the material [5]. The method, in which the separation takes place in spiral separators, is one of the methods of gravitational separation in a water medium. In this method, the grains of different density are separated in a water stream [6].

A process of beneficiating the raw mineral is proceeded by preparatory activities i.e.: screening, crushing or classification. Their objective is to prepare the raw mineral in the way enabling to gain the maximal amount (concentration) of useful grains. In the majority of cases, for obtaining the optimum effect of separation, raw useful minerals, having not complicated characteristics, can be prepared for this process only once. However, quite often a single preparation of the mineral for a separation is not sufficient due to obtaining only a part of useful grains in the beneficiation process. The other part of these grains, as intergrown pieces or in other words the interlayers, is separated together with the dirt and after an appropriate further preparation it is subject to the secondary separation.

The grains of the dirt and of the useful mineral differ due to physical, chemical, electric, magnetic etc. properties which cause that their separation with use of many methods is possible. The bigger these differences, the easier it is to conduct the separation process and the obtained results are better.

Spiral separators are devices used for separation of fine-grained materials of different density and size [7, 8]. Fine-grained raw material, usually of the dimensions not exceeding 3 mm, can be used for separation. The lower grains size limit for low-density materials is 0.1 mm, and for high-density materials is 0.05 mm [9, 10]. A hydrocyclone can be used to remove grains below the lower limit of grains [11].

Apart from the subject of this article, KOMAG Institute of Mining Technology is also involved in other mining-related problems. The scope of KOMAG's activities also includes so-called urban mining, i.e. the recovery of valuable substances from urban waste. Currently, research is being conducted into the recovery of rare earth elements from WEE_NdFeB (waste of electronic equipment fitted with neodymium magnets) [12] or impregnated wood [13]. In addition, technical documentation is being developed for equipment used in urban mining such as shredders [14, 15].

3. Test objectives

Defining the most favourable feed density and determining the grain classes that are best suited for cocking coal recovery was the objective of tests described in this article. Intermediate product (middlings) containing interlayers from a pulse jig located in the selected coking coal processing plant, was the testing material. Two spiral separators were used in tests i.e. Reichert LD-4 and Krebs 2.85. Several separation tests were carried out at different densities to determine the most favourable feed density. Then, knowing the best density, the separation process was repeated. The grain size composition of the process products was analysed, along with the ash content in the grain classes. Based on the knowledge of the ash content in each grain class, the classes with the best grain separation efficiency were determined, i.e. those with a low ash content in the concentrate and a high ash content in the waste.

4. Grounds of separation processes in spiral separators

Spiral separators can be used for separation of fine-grained coal, iron ore, chromium, gold and sands containing heavy minerals [16, 17, 18]. They can also be used for the secondary separation of wastes from other processes [19, 20]. During a properly conducted process, the grains of the materials are separated according to their density.

The following two stages can be distinguished in the movement of any grain in the channel of the spiral separators [21]:

- the first stage, when the forces acting on the grain are out of balance, what results in a transient movement of the grain, both in the normal trough cross-sectional plane and along the trough; duration of this period depends on the physical properties of grains,
- the steady motion, when the forces acting on the grain are in balance; consequently, the grain moves at a constant speed along a helix path curvature.

Helical working through on which the feed flows - the suspension consisting of water and granular material – is the main working component of these devices [22]. The movement of the grains of the material consists of two following components [23]:

- the helical movement due to working through curvature and the pitch of the helix,
- the movement in the plane perpendicular to the trough surface, running through the centre of the trough curvature, as a result of which the depth of the suspension stream changes along the trough cross-section.

5. Methodology of recovery tests for determining the most favourable concentration, samples and used instruments

The tests were performed with use of middlings from a fine coal jig operating in a selected processing plant producing coking coal containing interlayers with the grain size of 30-0 mm. The weight of the taken sample was about 60 kg. Due to high water content, the tested material was initially dried, and then 25% of the material - 15 kg, were separated using the Jones divider. The obtained sample was analysed for its grain size distribution on a vibrating screen. In the result, 9 grain classes were obtained, which were tested to determine the ash content.

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The results are presented in Table 1. and Fig. 1. Based on the results, the grain size distribution curve was drawn together with the ash content in the given grain size classes.

Table 1. Grains size composition of raw material

Item	Grain class d [mm]	Output γ [%]	Ash content A [%]	Average ash content Aśr [%]
1.	>12	7.91	53.99	
2.	12-10	4.01	45.01	
3.	10-8	5.77	39.47	
4.	8-6	11.20	31.02	
5.	6-4	17.80	28.74	39.64
6.	4-3	8.65	29.22	
7.	3-2	12.33	31.10	
8.	2-1	14.58	40.20	
9.	<1	17.75	59.00	

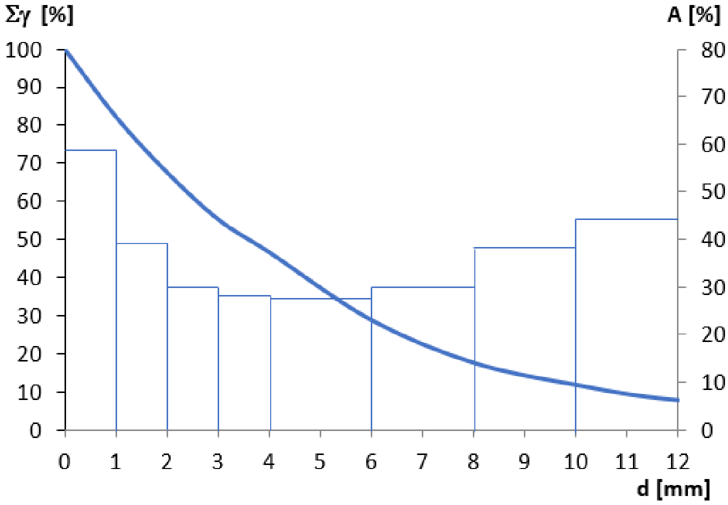

Fig. 1. Grain size curve with ash content in each grain class [own source]

After the tests, the previously separated 25% of the material were combined back with the rest of it. The material was then divided into two equal parts using the Jones divider.

The first part, weighing 28.6 kg, is hereinafter referred to as feed 1. This material was the feed for testing to determine the most favourable density. The feed 1 was crushed in a jaw crusher and then directed to the vibrating screen. The obtained product of crushing was screened on the vibrating screen of the mesh size 2 mm. The upper product of screening was sent to re-crushing on the jaw crusher. The bottom product from the vibrating screen and the crushing product were combined.

Next, the grain size distribution and the ash content of feed 1 were determined in each grain class. The results are presented in Table 2, Fig. 2 and used to plot the grain size composition curve together with the ash content in the given classes.

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After considering the results of the former analyses, the separated grain classes of feed 1 were combined again. The material was sent for separation in spiral separators to determine the most favourable density.

Table 2. Grains size composition of feed 1

Item	Grain class d [mm]	Output γ [%]	Ash content A [%]	Average ash content Aśr [%]
1.	>3	24.24	34.90	
2.	3-2	17.22	33.50	
3.	2-1	28.11	31.46	37.10
4.	1-0.5	16.90	44.19	
5.	<0.5	13.55	48.47	

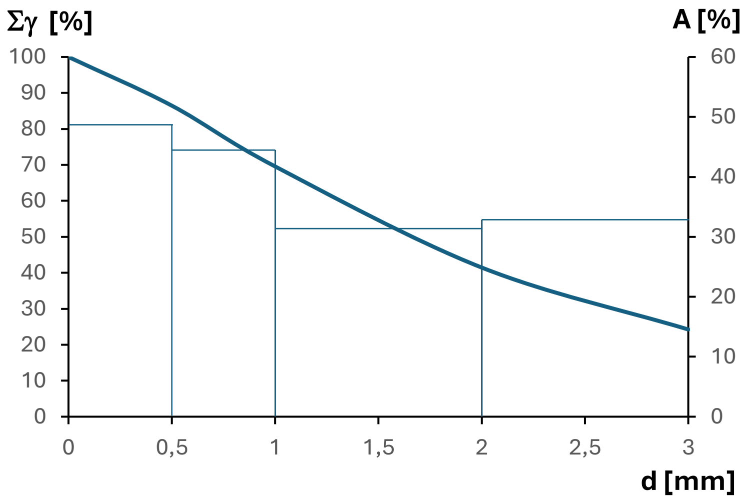

Fig. 2. Grain size curve of feed 1 after crushing at the given ash content in each grain class [own source]

The second part of the raw material weighing 28.6 kg is hereinafter referred to as feed 2. This material was sent for crushing in the laboratory jaw crusher. Then the material was analysed for grain composition using the laboratory vibrating screen. The obtained grain classes were tested for ash content, and the results are presented in Table 3 and in the diagram (Fig. 3).

Table 3. Grains size composition of feed 2

Item	Grain class d	Output γ	Ash content A	Average ash content Aśr
	[mm]	[%]	[%]	[%]
1.	>3	10.05	35.88	
2.	3-2	17.05	33.00	
3.	2-1	24.03	33.53	43.66
4.	1-0.5	17.91	47.20	
5.	<0.5	12.49	51.98	

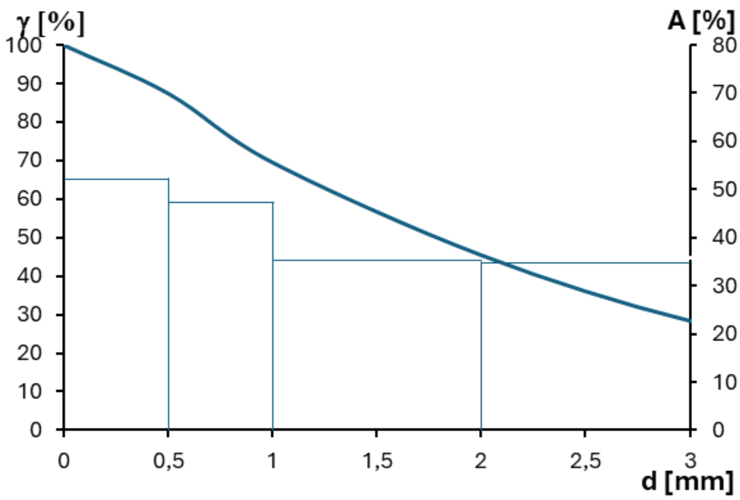

Fig. 3. Grain size curve of feed 2 after crushing at the ash content in each grain class [own source]

The Reichert LD-4 spiral separator was the first of the two devices used in the testing process. This device is designed for a separation of hard coal [6] and it had the following technical parameters [26]:

- spiral height: 2500 mm,
- spiral radius: 450 mm,
- coil width: 280 mm,
- coil inclination: 15°,
- number of coils: 6,
- width of the gaps between cutting tools successively 80 mm, 85 mm, 100 mm for lightweight, intermediate and heavy products,
- product collection: 3 outlets at the bottom of the separator and an additional heavy product collecting tray in the middle of the separator.

The device has two working troughs made of plastic, without any linings. The separator is equipped with a feeding tank and the feed is mixed by an agitator and compressed air. Mixing ensures a uniform dispersion of material particles in the feed and its constant density.

Krebs 2.85 separator was the second device used for testing and it had the following technical parameters [22]:

- spiral height: 1750 mm,

- spiral radius: 450 mm,
- coil width: 280 mm,
- coil inclination: 15°,
- number of coils: 2.85,
- width of the gaps between cutting tools 80 mm, 85 mm, 100 mm successively for lightweight, intermediate and heavy products,
- product collection: 3 outlets at the bottom.

This separator is equipped with two working troughs, 2.85 turns each. They are made of plastic without any linings. The feed is supplied from the same tank as in the Reichert LD-4 separator.

To determine of the most favourable concentration, feed 1 was used in the testing process. Concentrations of 300g/l, 350g/l and 400g/l were selected for separation in the Reichert LD-4 separator. After each separation test, excess water was poured out of the tanks, the separation products were collected and dried. Then, after drying, the separation products were weighed, representative samples were taken and the ash content was determined. Then, after sampling, the separation products were combined again and further tests for another concentration were conducted.

The concentrations of 300 g/l and 350 g/l were selected for separation in the Krebs 2.85 separator. Due a necessity of combining the separation products, the test for concentration of 400 g/l was abandoned, due to the partial loss of the finest grains fraction. After each separation test, excess water was poured out from the tanks and the separation products were collected and dried. Then, the separation products were weighed, representative samples were taken and the ash content was determined. Subsequently, the products were combined and the separation process was repeated at the next concentration.

6. Results of separation tests for determining the most favourable concentration

The results of the product analyses of separation tests in the Reichert LD-4 separator at the concentrations: 300 g/l, 350 g/l and 400 g/l are given in Table 4.

Table 4. Results of separation in the Reichert LD-4 spiral separator at concentrations: 300 g/l, 350 g/l and 400 g/l

Item	Separation product	Concentration 300 g/l		Concentration 350 g/l		Concentration 400 g/l	
		Output γ	Ash content A	Output γ	Ash content A	Output γ	Ash content A
		[%]	[%]	[%]	[%]	[%]	[%]
1.	Concentrate	24.82	18.88	26.27	19.73	34.19	21.36
2.	Middlings	32.73	28.17	37.80	32.04	43.95	35.90
3.	Waste	42.45	52.11	35.93	53.55	21.85	56.57
4.	Average ash content Aśr [%]	36.03		36.53		35.44	
5.		Separation time: 1' 13" 65"'		Separation time: 1' 04" 68"'		Separation time: 55" 83"'	

The results of the product analyses of separation tests in the Krebs 2.85 separator at the concentrations: 300 g/l, 350 g/l are presented in Table 5.

Table 5. Results of separation process in the Krebs 2.85 separator at concentrations: 300 g/l or 350 g/l

Item	Separation product	Concentration 300 g/l		Concentration 350 g/l	
		Output γ [%]	Ash content A [%]	Output γ [%]	Ash content A [%]
1.	Concentrate	30.11	20.10	26.64	19.52
2.	Middlings	40.87	30.27	36.26	27.52
3.	Waste	28.92	52.03	37.10	56.57
4.	Average ash content Aśr [%]	33.50		36.17	
5.		Separation time: 1' 20" 80'"		Separation time: 1' 11" 66'"	

7. Discussion of separation results at selected concentrations

Raw coking coal interlayers contain 39.64% of ash. The lowest ash content belongs to the 6-4 mm class and amounts to 28.74%, with output 17.80%. The highest ash content was found in the <1 mm class - it amounted to 58.98%, with the output in the class 17.75%. Also, grains >12 mm showed a high ash content of 53.99%, with an output of 7.91%.

The feed 1, used for a determination of the optimum concentration contained 37.10% of ash. The lowest ash content was found in the grain class 2-1 mm, amounting to 31.46%, with the output class of 28.11%. The largest grains >3 mm, representing 24.24% of the total given feed, contained 34.90% of ash. The smallest grains <0.5 mm showed the highest ash content, amounting to 48.47%, with the output of 13.53%.

In the Reichert LD-4 separator, the tests were conducted at concentrations of 300 g/l, 350 g/l, and 400 g/l. In the result of the separation tests, each time the separation products differed in their output and ash content.

Three products were obtained for the feed concentration of 300 g/l. The largest amount of material went to waste, 42.45% containing 52.11% of ash, the smallest amount of material went to the concentrate, 24.82 with the ash content of 18.88%. In turn, the out-put of the middlings was 32.73% and the ash content was 28.17%. The ash content in the feed, calculated from the balance equation, was 36.03%. The time from opening the feed tank to the flow of feed from the tank was 1 minute and 13.65 seconds.

At the concentration of 350 g/l, most of the material was transferred to the middlings i.e. 37.80% with the ash content of 32.04%. The smallest amount of material was transferred to the concentrate, i.e. 26.27% with the ash content of 19.73%. The waste output amounted to 35.93% with the ash content of 53.55%. The ash content in the feed was 36.53%. The feed flow time from the feed tank was 1 minute and 4.68 seconds.

The feed of the concentration 400 g/l was divided into three products. The highest output was observed for the middlings and it amounted to 43.95% with the ash content of 35.90%. The output of the concentrate was 34.19% and it contained 21.36% of ash. The lowest waste output was 21.85% with the ash content of 56.57%. The average weighted ash content in the feed was 35.44%. The feed flow time from the tank was 55.83 seconds.

For separation in the Krebs 2.85 separator, the feed concentrations of 300 g/l, 350 g/l and 400 g/l were assumed. During the tests, the separation test at the concentration of 400 g/l was abandoned

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because the material with each subsequent test had less and less fine grains. Fine grains were washed out when water was poured from containers for the separation products.

The test with the feed concentration of 300 g/l gave the following results: the highest product output was found in the middlings, amounting to 40.87%, the lowest output was obtained from waste 28.92% and the output of concentrate was 30.11%. The ash content was as follows: for concentrate 20.10%, for middlings 30.27% and for waste 52.03%.

Using the feed concentration of 350 g/l, the highest product output was obtained from waste 37.10% with an ash content of 56.57%. The lowest output was obtained for the concentrate, which was 26.64% and contained 19.52% of ash. The output for the middlings was 36.26%. The ash content of the middlings was 27.52%.

8. Conclusions concerning the impact of density changes on the products parameters

The tests enabled to analyse the secondary separation of middlings, containing coking coal interlayers, using the gravitational separation in water. Spiral separators: Reichert LD-4 and Krebs 2.85 were used in tests. By changing the feed density, a different separation of feed grains was reported. The products of different output and ash content were obtained. The lower average ash content in the products, obtained during the process, might depend on the way the products were collected. Each time the excess water was poured from the product tanks, a slight loss of the finest grains and those with the highest ash content might happen.

Increasing the feed density gradually every 50 g/l, from 300 g/l to 400 g/l and directing it to the Reichert LD-4 spiral separator, the following changes were observed:

- an increase of the concentrate output from 24.82%, through 26.27% to 34.19%,
- an increase of the ash content of the concentrate from 18.88%, through 19.73% to 21.36%,
- an increase of the output of middlings from 32.73%, through 37.80% to 43.95%,
- an increase of the ash content in middlings from 28.17%, through 32.04% to 35.90%,
- a reduction of waste output from 42.45%, through 35.93% to 21.85%,
- an increase of the ash content in the waste from 52.11%, through 53.55% to 56.57%.

Knowing the above relationship, the following conclusion can be formulated: the optimum concentration of the feed for separation in the Reichert LD-4 separator is 300 g/l. At this density, the concentrate with the lowest ash content and the highest amount of waste was obtained.

In the case of the Krebs 2.85 separator, by increasing the concentration from 300 g/l to 350 g/l, the following changes were observed:

- a decrease in concentrate output from 30.11% to 26.64%,
- decrease in ash content from 20.10% to 19.52%,
- a decrease in middlings output 40.87% to 36.26%,
- a decrease in ash content in the middlings from 30.27% to 27.52%,
- an increase in waste output from 28.92% to 37.10%,
- an increase in waste ash content from 52.03% to 56.56%.

Knowing the above relationship, the following conclusion can be formulated: the optimum feed density for separation in the Krebs 2.85 separator is 350 g/l. At this density, the concentrate with the lowest ash content and the highest amount of waste was obtained.

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9. Methodology and results of recovery tests for determining the most advantageously separating grain classes

In this part of testing, feed 2 was used. First, an attempt was made to separate the material in the Reichert LD-4 spiral separator. The previously determined, best density was used - 300 g/l. Then, the separation products were analysed in terms of the grain composition using the laboratory vibrating screen. The separation products were analysed regarding the ash content and the results are presented in Table 6. After analysing the separation products, they were combined to obtain the feed for the next separation test in another spiral separator.

Table 6. The analysis results of the grain size distribution and ash content for each grain class of separation products obtained in the Reichert LD-4 separator

Item	Separation product	Concentrate		Middlings		Waste	
		Output γ	Ash content A	Output γ	Ash content A	Output γ	Ash content A
		[%]	[%]	[%]	[%]	[%]	[%]
1.	>4	18.48	27.68	29.03	42.32	6.60	44.21
2.	4-3	16.30	27.03	9.12	40.73	4.57	46.30
3.	3-2	21.74	26.16	22.97	39.14	7.11	49.29
4.	2-1	27.17	16.30	21.07	36.11	23.86	53.71
5.	1-0.5	7.61	12.19	12.79	25.39	33.50	60.74
6.	<0.5	8.70	22.47	5.02	23.76	24.37	62.39
7.	Total	30.65	22.52	32.81	37.04	36.54	56.90
8.	Average ash content Aśr [%]	39.11					
9.	Separation time: 1' 11" 80"'						

Subsequently, the test was conducted in the Krebs 2.85 spiral separator. The previously determined most favourable concentration - 350 g/l was used. Then, the grain size distribution and ash content of the separation products were analysed. The results are presented in Table 7.

Table 7. The results of the grain size analysis and ash content for each grain class of separation products in the Krebs 2.85 separator

Item	Separation product	Concentrate		Middlings		Waste	
		Output γ	Ash content A	Output γ	Ash content A	Output γ	Ash content A
		[%]	[%]	[%]	[%]	[%]	[%]
1.	>4	15.95	21.69	15.53	29.06	6.39	39.92
2.	4-3	15.23	22.73	8.96	33.59	4.68	41.51
3.	3-2	22.08	24.56	19.23	33.27	9.56	46.91
4.	2-1	22.22	16.87	29.67	28.12	28.56	49.72
5.	1-0.5	8.75	12.97	16.83	21.37	25.63	57.61
6.	<0.5	15.77	27.46	9.79	30.53	25.19	59.12
7.	Total	23.99	21.56	37.03	28.85	38.97	52.83
8.	Average ash content $A_{śr}$ [%]	36.45					
9.	Separation time: 1' 17" 24"'						

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10. Discussion of the results of the best separation efficiency grain classes

The analysis of tests results of the feed 2, after crushing, showed 43.66% of ash. The highest ash content was found in grain size class - <0.5 mm and it amounted to 51.98%, with the output of 12.49%. The lowest ash content was found in the grain size class 3-2 mm and it amounted to 33.00%, with the output of 17.05%.

The separation test was conducted at the most favourable density of 300 g/l in the Reichert LD-4 spiral separator. Three different products were obtained and their grain size distribution and ash content in the given grain classes were analysed.

In the first separation product, i.e. the concentrate, the ash content was 22.52% at the lowest output of 30.65%. The largest amount of grains, in relation to the product, was in the grain size classes 2-1 mm (27.17%) and 3-2 mm (21.74%) containing respectively 16.30% and 26.16% of ash. The concentrate contained the smallest amount of grains in classes <0.5 mm (8.70%) and 1-0.5 mm (7.61%), containing respectively 22.47% and 12.19% of ash. The grain classes 1-0.5 mm and 2-1 mm contained the smallest amount of ash, 12.19% and 16.30%, respectively. In turn, the largest amount of ash, 27.03% and 27.68%, was found in the grain classes 4-3 mm and > 4 mm.

In the second separation product, the middlings, the ash content was 37.04% with output 32.81%. The highest output of grain size class was found in classes > 4 mm (29.03%) and 3-2 mm (22.97%), containing respectively 42.32% and 39.14% of ash. The smallest amount of grains was in the grain size classes 4-3 mm (9.12%) and <0.5 mm (5.02%) and they contained 40.73% and 23.76% of ash. The highest ash content was found in classes > 4 mm and 4-3 mm, on the level of 42.32% and 40.73%, respectively. In turn, the lowest ash content was found in grain size classes <0.5 mm and 1-0.5 mm, containing 23.76% and 25.39%, respectively.

When testing the third separation product, the waste, the highest output, amounting to 36.54%, and ash content of 56.90% were reported. The majority of grain classes in the waste belongs to the classes with the highest ash content. These classes are <0.5 mm with an output of 24.37% and ash content of 62.39% and 1-0.5 mm with an output of 33.50% and ash content of 60.74%. Also, the lowest output of grain classes in the waste was in the class with the lowest ash content, i.e. classes 4-3 mm and > 4 mm. For the 4-3 mm class, the output of the grain class in the product was 3.47% and the ash content was 46.3%. For the class > 4 mm, the output and ash content was 6.6% and 44.21%.

Using the previously selected, most advantageous concentration of 350 g/l, the test was conducted in the Krebs 2.85 spiral separator. In the result of this process, three different products were obtained. They were analysed in terms of ash content, output, grain composition and ash content in grain size classes.

The lowest product output was the concentrate 23.99%, at the ash content level of 21.56%. Grain size classes 2-1 mm (22.22%) and 3-2 mm (22.08%) had the highest product output. On the other hand, classes 1-0.5 (8.75%) mm and 4-3 mm (15.23%) had the smallest output of concentrate. Grain classes 1-0.5 mm and 2-1 mm had the lowest ash content which amounted to 12.97% and 16.87%, respectively. The highest ash content was found in grain size classes <0.5 mm and 3-2 mm and amounted to 27.46% and 24.56%, respectively.

In the second separation product, the middlings, the ash content was 28.85% with an output of 37.03%. The highest content of the output of grain classes in the product was measured in classes 2-1 mm (29.67%) and 3-2 mm (19.23%). In turn, the lowest output of grain classes was determined for classes <0.5 mm (9.79%) and 4-3 mm (8.96%). The highest amount of ash was found in the grain classes 3-2 mm and 4-3 mm, i.e. 33.27% and 33.59%. The smallest amount of ash was found in grain classes 1-0.5 and 2-1 mm, i.e. 21.37% and 28.12%.

When testing the third product of separation, the waste, the highest output was measured for classes 1-0.5 mm (25.63%) and 2-1 mm (28.56%). The lowest output was found in classes 4-3 mm and >4 mm and it amounted to 4.68% and 6.39%, respectively. The highest ash content was determined for grain classes <0.5 mm and 1-0.5 mm, i.e. 59.12% and 57.61%, respectively. The lowest ash content was determined for classes 4-3 mm and >4 mm and it amounted to 41.51% and 39.92%.

11. Conclusions concerning the impact of density changes on the products parameters

The grain size composition tests, including a determination of ash content in grain classes, and their analyses enabled to find the grain classes of the feed that have the best separation efficiency. Using different spiral separators for the feed density of 300 g/l, a different grain distribution of the tested material was observed. Products that differed in ash content and output, were obtained.

Knowing the grain composition of the material separation products on both spiral separators, the conclusions concerning the following aspects were drawn:

- the output of grain classes in separation products:
    - grains > 2 mm give higher output in the middlings and concentrates,
    - grains 2-1 mm give similar output in separation products,
    - grains 1-0.5 mm give higher output in the middlings and waste,
    - grains < 0.5 mm give higher output in the waste and concentrate,
- the ash content in classes of grain separation products:
    - larger grains have lower ash content in the waste than smaller ones,
    - the lowest ash content in the concentrates was in grain classes 2-1 mm and 1-0.5 mm grain classes,
    - the highest ash content in the middlings was in the 4-3 mm grain class,
    - the lowest ash content in the middlings was in the 1-0.5 mm grain class,
    - the smallest difference in ash content between the separation products was in the > 4 mm class, for the Reichert LD-4 spiral separator it was 16.53% and for the Krebs 2.85 spiral separator it was 18.23%,
    - the largest difference in the ash content between the separation products was in the 1-0.5 mm class, for the Reichert LD-4 separator – 48.55% and for the Krebs 2.85 separator – 44.64%,
    - the 1-0.5 mm grain class was separated most favourably, because it had the lowest ash content in the concentrate and in the middlings and the highest one in the waste, among all the grain classes.

Analysing the results of separation products from the Reichert LD-4 and Krebs 2.85 spiral separators, it was found that the grain classes 4-3 mm and > 4 mm had the worst separation efficiency. In total, these classes achieved the highest ash content in the concentrate and in the middlings, and the lowest one in the waste.

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