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Coal recovery from a coal waste dump

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Abstract. The possibilities and efficiency of coal recovery from the waste material located at the Central Coal Waste Dump in Poland were presented in this paper. The waste material includes significant amount of fly ash. Research conducted into determination of energetic properties of such wastes showed that the average ash content was 75.75% and the average gross calorific value was 7.81 MJ/kg. Coal was gravitationally separated from the waste material in a pulsatory jig and in a spiral washer including size fractions: 30-5 and 8-0 mm (this was crushed to a size <3.2 mm), respectively. The application of the pulsatory jig (pulse classifier) allowed to obtain a high-quality energetic concentrate with the ash content lower than 12% and the gross calorific value higher than 26 MJ/kg (with average yield 7.8%). The spiral separator gave much worse results. The average gross calorific value for the concentrate was 11.6 MJ/kg, with the high ash content 56.5% and yield approximately 26%.

1 Introduction

The Central Coal Waste Dump Przezchlebie (CCWD) is located in the Upper Silesia region of Poland. It was built in '60 of previous century. Previously it was the location of former sand mine which was flooded in 1955. The CCWD served for following hard coal mines: Makoszowy, Pstrowski, Bielszowice, Krupiński, Zabrze, Bobrek and Gliwice. In addition CCDW was used as fly ash landfill for Rybnik power plant. Fly ash storage was stopped in 1990 and coal waste was ended in 1999.

The CCWD is the one of the largest sites of this type within the region. The area is approximately 150 ha. There is a lack of detailed description of storage process and amount of waste material which is left at the dump, although it is estimated. It is assumed that currently there is about 25 mln m^3 of waste material and probably 65% of total value can be classified as mining wastes and 35% as power plant wastes.

Waste material located in the CCWD is not neutral for the environment. Considering chemical composition of wastes, there is a possibility of eluviations of dissolved components and their transport to water. This process intensifies when degree of weathering process increases and pH of water infiltrating through the dump decreases. The content of: SiO_2, Al_2O_3, TiO_2, Fe_2O_3, CaO, MgO, K_2O+Na_2O in the material from the CCWD was as follows: 45.22%, 18.48%, 0.99%, 4.06%, 1.40%, 1.41%, 1.21%. The content of the eluted elements was: Ba = 576 mg/kg, Cr = 76 mg/kg, Zn = 167 mg/kg, Co = 49 mg/kg, Mn = 1573 mg/kg, Cu = 130 mg/kg and Ni = 85 mg/kg [1]. The mentioned

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above content is similar to typical values obtained for coal waste dumps within the Upper Silesia region [2, 3].

Some amount of coal and sulphur in coal wastes creates fire hazard which is caused by natural processes of coal and pyrite oxidation. It is connected with gas and heat emissions to the atmosphere [4, 5].

In 2009 local authority started to do activities for the development of the site. Now, there are several directions of further works: recovery of coal and aggregates, application of ashes to construction of dump solid and technical reclamation of the site. These activities can give rational economic profits and can decrease negative impact of the dump on the environment.

To find optimal solution, the waste material was put into the analysis and research. The one of the aims was to determine possibility of coal recycling from the dump. The research into this matter was conducted with two methods based on gravitational separation - spiral separators and pulsation jigs. After separation of the size fraction of > 30 mm as the waste material, the tests were carried out for two different sizes:

- 30 – 5 mm – separation at pulsatory jig,
- 8 – 0 mm – separation at spiral washer (after crushing the particles to the size of <3.2 mm).

2 Selected properties of waste material from the dump

2.1 Preparation of the samples

The samples of waste material from the CCWD were taken according to Polish standard PN-ISO 18283:2008 [6]. The samples were taken from three excavations. The depth of sampling was 3-6 meters (measured from the surface of the dump). Mass of each sample was approximately 20 kg.

Preparation of laboratory samples was based on mixing up of raw samples to prepare averaged and general samples. Then, they were quartered and lowered to obtain samples no. I, II and III adequately for each excavation. To achieve proper analytical grain class the samples were preliminary and secondary crushed. The samples were taken into sieve analysis. Then the samples were creamed in a mortar to obtain grain size lower than 0.2 mm. It allowed to separate analytical samples. In addition, the samples were dried (except samples used to moisture determination). Among other parameters, hygroscopic moisture, ash content, net calorific value etc. were determined.

According to Polish standard PN-EN 1097-7:2008 [7] the density of the samples was as follows: 2.29872, 2.28103 and 2.00579 g/cm^3. Thus average value was 2.19518 g/cm^3.

2.2 Determination of energetic features

Average free moisture content (W_{ex}), hygroscopic moisture content (W_h) and ash content (A^a) in the analytical samples were determined by the method given in Polish standards PN-80/G-04511 [8], PN-80/G-04512 [9]. Net calorific value and gross calorific value Q_j^a were determined according to Polish standard PN-ISO 1928:2002 [10]. Self-ignition of the samples as a result of oxygen supply was not detected during the tests conducted in calorimeter bomb. Therefore, benzoic acid was added to the samples as an activator. The acid was included during determination of gross calorific value. The total sulphur content S_t^a and organic coal C^a were determined with application of SC132 device (from LECO company) and by the Tiurin method. The results are given in Table 1.

Considering standards referred to aggregates, determined value of total sulphur content S_t^a in wastes (0.263-0.669%) does not disqualify tested material as an aggregate, although the content of organic coal is too high (above 1 %). Considering this result it is impossible to use the material as an aggregate according to requirements of the standard PN-S-06102:1997 [11]. When organic coal content is higher than 2% it is impossible to use the material for soil works purposes (according to PN-S-02205:1998 [12]) .

Table 1. Energetic features of waste material from CCWD.

Parameter	Sample I	Sample II	Sample III	Average
A^{a},%	77.49	79.05	70.70	75.75
C^{a} ,%	12.07	10.08	12.91	11.69
S_t^{a},%	0.263	0.669	0.395	0.442
W_{ex},%	2.1	2.6	3.8	2.8
W_{h},%	1.67	2.08	3.08	2.28
Q_j^{a}, MJ/kg	6.99	7.75	8.69	7.81
Benzoic acid content, %	13.8	14.3	11.7	13.3

Research into energetic parameters of the samples gave following values: coal content C = 10,08-12.91%, ash content A^{a} = 70.7 – 79.05%, gross calorific value Q_j^{a} = 6.99 – 8.69 MJ/kg. Obtained parameters (the range of ash content and coal substance content which was proved by significant gross calorific value) indicated that examinations were advisable and it is possible to recover coal from the waste material. Considering the experience of different companies involved in coal wastes processing it can be stated that there are economically proved methods of coal recovery from the dumps. The process can be profitable when coal content is higher than 8%.

Although coal recovery is justified not only because of economical purposes it also allows to reduce fire hazard at a dump and improve geochemical and geotechnical parameters of spin-off. It is very important in the case of application of this material for dump reclamation as well as outside the dump (e.g. for road constructions and other engineering applications). Although this direction of waste material application requires technological tests and selection of efficient recycling method.

3 Methodology of recovery process and results

Washing in heavy liquids is the one of the most efficient and economic method of separation of coal grains and deeds. This method is also applied by Haldex S.A., Zower S.A. during coal recovery from coal waste dumps [13, 14]. However, due to high content of fly ash in the waste material this method was rejected at the first stage of examinations. The grains of fly ash affected negatively on parameters of heavy liquid what reduced significantly the efficiency of the process.

3.1 Coal recovery in spiral washers

The research into possibility of coal grains recycling from CCWD was conducted at technical scale with application of spiral washer Reichert LD4. Wastes in raw state were not sufficient for direct tests because of too large size of the grains. Thus, they were crushed in a jaw crusher to obtain proper granulation of the material.

Coal wastes preparation process was preceded by the analysis of feed. Table 2 shows grain classes of the waste material d, their yield γ and ash content A^{a}.

Table 2. Grain classes and their output, total ash content.

Grain class *d*, **mm**	**Yield** γ, **%**	**The sum of yields** $\Sigma\gamma$, **%**	**Total ash content** A^a, **%**
>3.2	20.96	20.96	86.37
3.2-2.5	11.36	32.33	86.45
2.5-2.0	9.78	42.11	85.62
2.0-1.5	9.54	51.65	65.80
1.5-1.0	16.26	67.91	60.07
1.0-0.75	7.04	74.95	69.74
0.75-0.5	8.16	83.11	71.46
0.5-0.3	6.70	89.81	80.31
0.3 - 0.2	4.83	94.64	81.66
0.2-0.1	3.82	98.46	82.44
< 0.1	1.54	100.00	81.75

The granulometric analysis was conducted by separation of the material into many limited grain classes to obtain the optimum range of grain size which was the least burdened by the ballast (ash content). The highest mass fraction was detected for grains in classes >3.2 mm and 1.5-1.0 mm. A high level of ash content was detected in all measured classes. The significant silt content in the material could be noticed even macroscopically, as well as other mineral admixtures. In fact, they cause such high ash content.

The testing stand included the feed bin and LD 4 washer (built of two beds having six reels and dewatering screen). The feed was delivered gravitationally from the bin with high-speed agitator and then it was mixed-up with the air from a compressor. The movement of the agitator and air stream caused that feed did not embedded in the bin and had constant density.

The preparation process was conducted with the following technological parameters:

- density of feed β= 300 g/dm^3,
- the time of feed mixing in the bin with the agitator (included additional aerodynamic stirrers for improvement of averaging of feed before washing) was 3 minutes,
- the amount of additional water delivery to the washer was 500 dm^3/h.

Table 3. Results of qualitative and quantitative analysis of separation products, n/m - not measured, n/a - not added.

Parameter, unit	**Concentrate**	**Middlings**	**Rejects**
S_t^a ,%	0.45	0.31	0.40
W_h, %	1.59	1.34	1.33
A^a ,%	56.5	74.8	83.1
Q^a , MJ/kg	11.58	3.42	n/m
Benzoic acid content, %	n/a	n/a	n/a

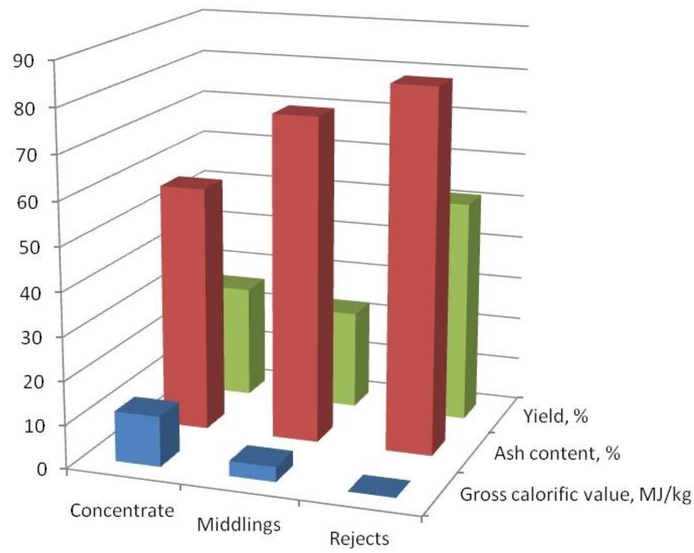

Figure 1. Parameters of products after spiral washers.

Table 4. Results of qualitative and quantitative analysis of separation products.

Particle size mm	Concentrate		Middlings		Rejects	
	Yield, γ_c,%	Ash content A_c^a , %	Yield, γ_m,%	Ash content A_m^a , %	Yield, γ_r,%	Ash content A_r^a , %
>3.2	35.17	66.80	15.58	85.95	12.14	86.37
3.2-2.5	19.37	60.56	8.84	84.69	5.88	86.45
2.5-2.0	11.71	56.37	11.23	81.94	6.41	85.62
2.0-1.5	8.89	45.10	11.61	77.16	8.11	85.80
1.5-1.0	9.61	27.14	20.35	61.50	18.83	84.07
1.0-0.75	2.43	18.14	8.46	57.60	10.25	81.74
0.75-0.5	3.27	21.49	7.55	47.14	13.64	81.46
0.5-0.3	2.98	15.96	5.67	44.81	11.46	80.31
0.3-0.2	1.95	35.80	4.34	56.79	8.18	81.66
0.2-0.1	3.03	63.82	4.56	72.57	3.88	82.44
<0.1	1.60	76.91	1.82	79.75	1.20	81.75
Sum	100.00	-	100.00	-	100.00	-
Average	-	53.92	-	69.74	-	83.42

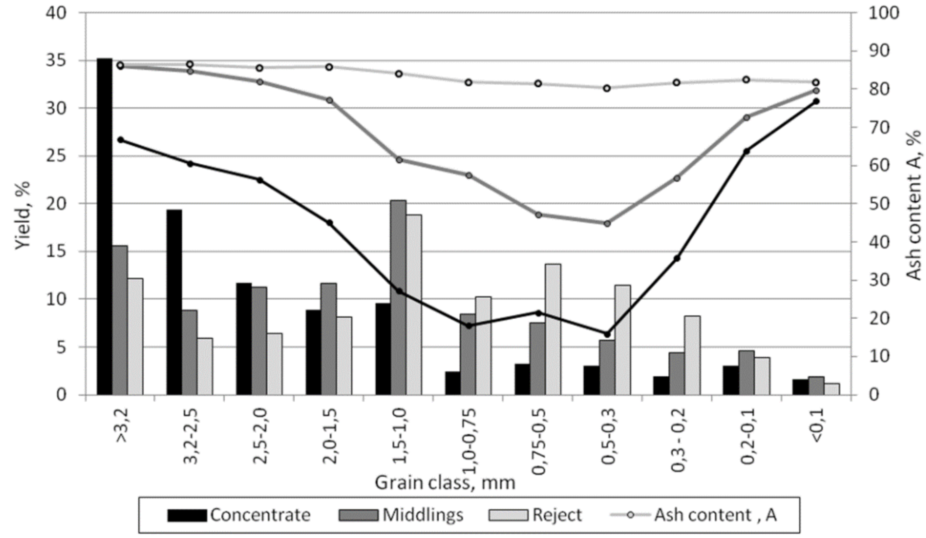

Figure 2. Qualitative and quantitative analysis of separation products.

Three products were obtained as the results of washing process: concentrate, middlings and rejects. Their yields were γ_c = 26.0%, γ_m = 22.67% and γ_r = 51.33%. The products were taken into the qualitative and quantitative analysis. The results of the analysis of obtained products are presented in Table 3 and Figure 1. The results including grain class classification of these products are presented in Table 4 and Figure 2.

The analysis of density separation gave following observations. Middlings do not have value in use as well as rejects (with high ash content in tested classes). It indicates on a lack of coal grains in the products. It should be mentioned that the feed and obtained products of separation (tested in particular grain classes) are given as average values. They were obtained from several series of tests. In the case of concentrate, the material can be divided into three main groups of grains. Size fractions 3.2-1.5 mm has relatively high ash content what can be caused by former washing processes when grains of clean coal are separated from feed and this class was storied at the dump as rejects. The second grain class is 0.2 – 0 mm. Considering this class it can be noticed that there is dependence between increase of ash content in the material and decrease of grain size. The average ash content in these fractions was α_{avg} = 58.70% (the lowest grains of stone with silt admixture mostly made this class).

The size fraction of 1.5 – 0.3 mm was the most valuable. The average ash content was α_{avg} = 23.12 %, and mass fraction was γ = 18.28 %. This size fraction had some energetic potential, which can be used, e.g. as an admixture to fine coal being used in power plants.

3.2 Coal recovery in a pulse classifier

The research into the recovery of coal grains in the size fraction 30-5 (0) mm was undertaken "in-situ" by industrial tests. Komag pulsatory classifier K-102 (a pulsatory jig) was in use. The functioning of the jig is based on a typical gravitational washing of the minerals performed by stratification of feed at an open grid plate (sieve deck) in pulsated water medium [15]. Stratification is conducted according to grain fractions and density of the components of feed. As the result of washing process three products were achieved: concentrate, rejects and spin-off (as a result of loss of fine grains through the sieve deck), however, spin-off was not under the tests during this research.

Inter-screen product from two-deck open grid classifier with a mesh size 30 mm (the upper deck) and 5 mm (the lower deck) created feed which was then transported to washing. Loading of the pulsatory jig during the tests was ~ 80 Mg/h. Due to density content, the determination of ash content and gross calorific value in obtained fractions was started, in the laboratory analysis, just after de-slurrying of the sample (the removal of grains <0.5 mm). Feed which was transported to washing had high ash content 77.91% and low gross calorific value 4.44 MJ/kg. The fraction with density >1.8 g/cm^3 was the main part of feed (90.53%).

The results of undertaken research showed that in washed post-coal wastes the content of grains of flammable substance can be significant. In this case the yield of concentrate was 7.66%. The average ash content was 19.96% and gross calorific value was 26.16 MJ/kg. The rejects from washing (with the yield 92.34%) had trace coal grains content (<1.5 g/cm^3) 0.15%, high ash content 83.61% and very low gross calorific value 2.45 MJ/kg [16,17].

The results of physicochemical analysis of feed and of the products of washing are presented in Table 5 and Figure 3.

Table 5. Results of physicochemical analysis of feed and the products of washing – size fraction 30-5 (0.5) mm.

Density of fraction g/cm^3	Feed			Concentrate			Rejects		
	Yield, γ_f,%	**Ash content, A_f^a,%**	**Gross calorific value, Q_f^a,MJ/kg**	**Yield, γ_c,%**	**Ash content, A_c^a,%**	**Gross calorific value, Q_c^a,MJ/kg**	**Yield, γ_r,%**	**Ash content, A_r^a,%**	**Gross calorific value, Q_r^a,MJ/kg**
< 1.3	3.05	3.35	31.75	39.44	3.18	32.63	0.03	4.73	31.35
1.3-1.4	1.13	11.35	28.79	14.20	10.72	29.80	0.04	12.79	27.95
1.4-1.5	1.07	22.50	24.48	13.05	21.88	25.25	0.08	22.73	24.25
1.5-1.6	0.89	31.52	21.63	9.85	31.39	21.89	0.15	32.25	21.56
1.6-1.7	1.73	38.60	18.87	11.33	38.18	19.08	0.93	39.75	18.61
1.7-1.8	1.60	47.35	15.35	4.53	44.99	16.45	1.36	49.05	15.15
1.8-2.0	3.69	55.36	12.31	4.50	54.58	12.65	3.62	55.72	12.42
> 2.0	86.84	84.86	1.92	3.10	77.79	4.28	93.79	85.81	1.65
Sum	100.0	-	-	100.0	-	-	100.0	-	-
Average	-	77.91	4.44	-	19.96	26.16	-	83.61	2.45
Total yield. γ, %	100.0			7.66			92.34		

The parameters describing separation process and its efficiency were determined on the base of the results of the analysis. The parameters were: density of separation (d_{50}), probable dissipation (E_p) and imperfection (I).

The results of washing of mine wastes showed that pulsatory jig worked with a high efficiency of separation: imperfection coefficient was I = 0.124, probable dissipation was E_p=0.081 g/cm^3, and density of separation was d_{50}=1.651 g/cm^3.

Additional laboratory tests of the concentrate samples were carried out during exploitation of the pulsatory jig. It turned out that the product has very advantageous qualitative parameters [18]. The results showed in Table 6 are given under working conditions.

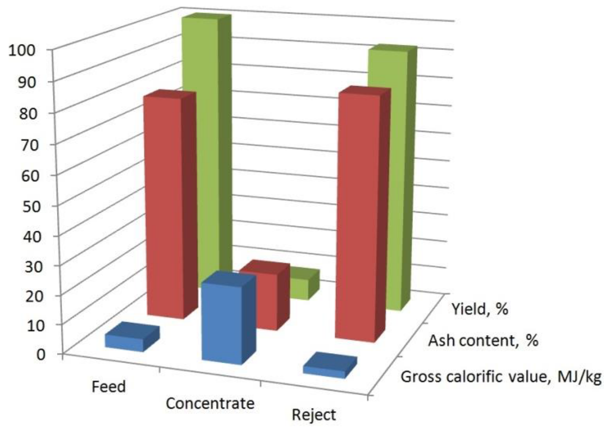

Figure 3. Parameters of feed and products of washing - industrial tests.

Table 6. Parameters of concentrate after jigging.

No. sample	Total moisture W_t, %	Ash content A_c^a, %	Gross calorific value, Q_c^a ,MJ/kg
1	8.1	12.0	26.14
2	7.8	11.3	26.79
3	8.3	11.7	26.65
4	9.2	10.8	26.46
average	8.35	11.45	26.51

4 Conclusions

The application of pulsatory jig for separation of wastes in 30-5 mm size fraction allowed to obtain a high-quality energetic concentrate with the ash content lower than 12% and gross calorific value higher than 26 MJ/kg. A spiral separator (applied in 8-0 mm size fraction) gave much worse results. The average gross calorific value for the concentrate was 11.6 MJ/kg, with the high ash content 56.5%. It was caused by the presence of fly ashes in the feed. Perhaps, removal of this component during wet screening could increase the energetic features of concentrate. To increase the parameters of concentrate as well as its yield the type of separator and/or the settings of the device should be optimized.

Efficiency of coal recovery from CCWD Przezchlebie was different and depended on applied device and enriched grain classes during washing tests. Properties of the material are significant reason of such a state (including presence of fly ashes and presence of coal in particular size fraction).

To sum up, the recovery of coal is necessary because it can cause not only financial profits but also can improve safety by reduction of fire hazard and negative impact on the environment. The material without coal could be applied for reclamation of the site or outside the dump as an aggregate. Furthermore, the reclaimed site can be an interesting place for further investments.

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