

Coal from the waste disposal site of the Siersza mine (Trzebinia, Poland) and its properties as a possible alternative fuel

Beata Kosa^{1,a} and Alicja Kicińska¹

¹AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30 av., 30-059 Kraków, Poland

Abstract. The authors recovered bituminous coal from the dump of the closed down Siersza mine in Trzebinia, determined its properties and evaluated a possibility of applying it as an alternative fuel for the cement industry. The dump material was enriched in a laboratory using the gravity (jigs, shaking tables) and flotation methods of coal cleaning. The gross calorific value of the processing products, measured with a calorimetric bomb, ranges from 13.588 to 22.543 MJ·kg⁻¹. The contents of heavy metals, determined with XRF, are as follows: Fe 3.76–5.25 mg·kg⁻¹, Mn 0.037–0.132 mg·kg⁻¹, Ti 0.325–0.493 mg·kg⁻¹ and Zn 0.113–0.329 mg·kg⁻¹, while of Hg (determined with ASA) from 0.02689 to 0.21870 mg·kg⁻¹. The content of sulphur is 0.7349–1.0484 wt.% and of chlorine Cl 0.131–0.135 wt.%, the net calorific value of 13.446–22.538 MJ·kg⁻¹. The results indicate that the laboratory jiggling and flotation provide products that meet the parameters of the solid fuels selected by applicable to the needs of cement plants.

1 Introduction

Continuously growing amounts of waste enforce new ways of their neutralization and disposal. One of the methods of the economic management of coal-related waste is using them as alternative fuel in power stations, heat and power generating stations and cement plants [1-7]. However, such a use of processed waste requires an assurance that the material obtained complies with legal requirements. The plant utilizing an alternative fuel must not only know or recognize its properties but also consider whether the process of burning under current technological conditions will not break the environmental standards that set the emission limits of selected elements (compounds) into the environment.

The authors describe the tests that were conducted on samples of hard coal recovered from the dump of the closed down Siersza coal mine in Trzebinia. The aim of the study was to evaluate the possibility of using this material as a potential alternative fuel for cement plants.

2 Material and methods of study

The material tested in the study comes from the dump of the closed down Siersza coal mine in Trzebinia (S Poland). Its sampling grid was irregular due to the presence of stagnant water pools and the lack of clear-cut dump boundaries (Fig. 1). A total of 40

samples were collected with a weight of approx. 2 kg each.



Figure 1. Sampling site

Some of them were selected for petrographic and environmental investigations. The material was mixed, averaged, dried and subjected to mechanical pre-treatment: crushing and screening into two grain fractions, finer (<1 mm) and coarser (1–20 mm) ones.

^a Corresponding author: beata.kosa@wp.pl

The finer material was processed using two methods: the froth flotation and the gravity concentration on a shaking table, the latter preceded by hydrocyclone desilting. Three methods were used for the coarse material: the gravity concentration either in heavy media or in jigs and the flotation with the earlier crushing the material to the size <0.5 mm. Further analyses were conducted on the samples generated by the methods that provided most promising results of coal waste cleaning, i.e., a high coal recovery and a low ash content of the concentrates. Such conditions are fulfilled only by the group of 1–20 mm sized concentrates:

- (1) from the concentration table (Fig. 2), hereafter referred to as the sample CT,
- (2) from the jig separator, hereafter referred to as the sample P, and
- (3) from the flotation (Fig. 3), hereafter referred to as the sample F.

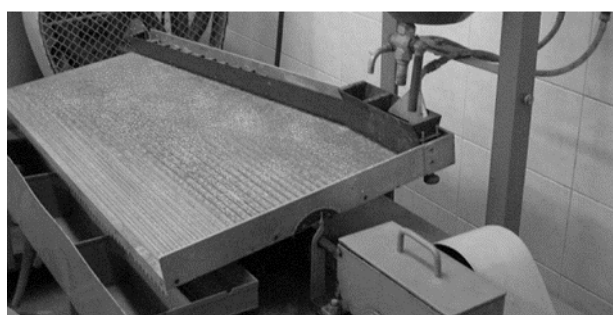


Figure 2. Concentration table.



Figure 3. Flotation machine.

The total contents of selected metals: Fe, Mn, Ti, Zn, Cd and Tl were assayed using X-ray fluorescence (XRF) and an Olympus X-5000 device. Determinations of sulphur and chlorine were carried out using the Eschka method [8, 9]. Determinations of the heat of combustion and the calorific value were done according to the standard [10]. In the mercury determinations a dedicated atomic absorption spectrometer AMA-254 (ALTEC company) was used.

The apparatus is a modification of classic AAS spectrometers and measures mercury contents of solid and liquid samples with a detection limit of few nanograms. The sample is mineralized within the analyzer itself, immediately prior to the detection step. This solution reduces losses of mercury that may be caused in the classic AAS devices.

3 Results

The coal waste represent a diversified assemblage of rocks predominantly sandstones, claystones and coal shales. The coal content was visually evaluated at 1–6%, and the pyrite content at 2–5%.

Environmental studies shown that the accumulated waste have a negative impact on the environment [11]. Some of the samples contain slag of an unknown origin, which reported to the gravity concentrates with the highest coal recovery and increased their ash content [12].

3.1 Chlorine and sulphur contents

The Cl contents of the concentrates are almost the same and range from 0.131 to 0.135 wt.% (Tab. 1). The higher value (0.135 wt.%) corresponds to the F sample (from flotation) and the lower (0.131 wt.%) to the CT sample (from the concentration table). Looking at the recommendations made by Sarna et al. [1] concerning the upper Cl limit (≤ 0.2 mass %) in the material that could be an alternative fuel, none of the samples exceeds this value.

Table 1. Contents of chlorine and sulphur in coal samples.

Sample	Cl	S
	[wt. %]	
CT	0.131	1.0484
P	0.132	0.7349
F	0.135	1.0335
\bar{x}	0.133	0.9389
σ	0.002	0.1768
V	0.016	0.1883
PLiF*	0.2	2.5

\bar{x} – arithmetic mean; σ – standard deviation, V – coefficient of variability (σ/\bar{x}), *PLiF – permissible level in fuels, according to [1]

The S content ranges from 0.7349 to 1.0484 wt.% (Tab. 1), being the highest in the CT sample (1.0484 wt.%) and the lowest in the P sample (0.7349 wt.%). According to Sarna et al. [1], the sulphur content of the potential alternative fuel should not exceed 2.5 wt.%, and even the highest sulphur value of the P sample is 2.5 times below this limit.

3.2 Heavy metal and mercury contents

The contents of individual metals are: Fe 3.76–5.25, Mn 0.037–0.132, Ti 0.325–0.493 Zn 0.113–0.329 and Hg 0.02689–0.2187 mg·kg⁻¹. They show a considerable

variability, expressed as the coefficient of variation V (the ratio of standard deviation to arithmetic mean). The spread of the values ranges from high Hg ($V=0.99$) to lesser Zn and Mn ($V= 0.62$ and 0.54 , respectively) and to low Ti and Fe ($V= 0.22$ and 0.17 , respectively).

The highest are contents of Fe ($5.255 \text{ mg}\cdot\text{kg}^{-1}$), Ti ($0.493 \text{ mg}\cdot\text{kg}^{-1}$) and Hg ($0.219 \text{ mg}\cdot\text{kg}^{-1}$) of the coal concentrate from the concentration table (CT). In the flotation concentrate (F) the highest are Mn ($0.132 \text{ mg}\cdot\text{kg}^{-1}$) and Zn ($0.329 \text{ mg}\cdot\text{kg}^{-1}$) contents.

The lowest contents of Fe ($3.76 \text{ mg}\cdot\text{kg}^{-1}$) and Ti ($0.325 \text{ mg}\cdot\text{kg}^{-1}$) occur in the flotation concentrate (F), whereas those of Mn ($0.037 \text{ mg}\cdot\text{kg}^{-1}$), Zn ($0.113 \text{ mg}\cdot\text{kg}^{-1}$) and Hg ($0.027 \text{ mg}\cdot\text{kg}^{-1}$) the jig concentrate (P). The range of the Hg determinations is from $0.02689 \text{ mg}\cdot\text{kg}^{-1}$ (P concentrate) to $0.21870 \text{ mg}\cdot\text{kg}^{-1}$ (CT concentrate). The Cd contents of the P and F concentrates are below the detection limit, while in the CT concentrate the Cd content is $0.021 \text{ mg}\cdot\text{kg}^{-1}$. The thallium content in all the concentrates is below its detection limit.

The values cited above do not exceed the upper limits of these metals set by Sarna et al. [1] for alternative fuels.

Table 2. Contents of selected elements in coal samples.

Sample	Fe	Mn	Ti	Zn	Hg
	mg·kg ⁻¹				
CT	5.25	0.097	0.493	0.135	0.219
P	4.87	0.037	0.483	0.113	0.027
F	3.76	0.132	0.325	0.329	0.062
x	4.63	0.09	0.43	0.19	0.102
σ	0.78	0.05	0.09	0.12	0.02
V	0.17	0.54	0.22	0.62	0.99
PLiF*	-	-	-	-	10

x – arithmetic mean; σ – standard deviation, V – coefficient of variability (σ/x), *PLiF – permissible level in fuels, according to [1]

3.3 Heating and calorific value

Calorific value ranges from $13.588 \text{ kJ}\cdot\text{kg}^{-1}$ of the CT sample to $22.543 \text{ kJ}\cdot\text{kg}^{-1}$ for the P sample (Tab. 3). The calorific values show the same trend: from the lowest value of the CT sample ($13.446 \text{ kJ}\cdot\text{kg}^{-1}$) to the highest value of the P sample ($22.538 \text{ kJ}\cdot\text{kg}^{-1}$).

Table 3. Heating and calorific values of coal samples.

Sample	Heating value	Calorific value
	MJ·kg ⁻¹	
CT	13.59	13.45
P	22.54	22.54
F	20.64	20.61
x	18.92	18.87
σ	4.72	4.79
V	0.25	0.25
PLiF*	-	>14.00

x – arithmetic mean; σ – standard deviation, V – coefficient of variability (σ/x), *PLiF – permissible level in fuels, according to [1]

The sample obtained on the concentration table does not meet the minimum calorific value criterion of alternative fuels (i.e., $>14,000 \text{ kJ}\cdot\text{kg}^{-1}$), whereas the two other concentrates significantly exceed it.

3.4 Other parameters

The list of parameters that characterize any type of solid fuels includes also its contents of ash and volatile matter as well as of the humidity (Tab. 4).

The ash content varies from 21 to 26 wt.% in the concentrates P and F, while it is nearly doubled (55 wt.%) in sample CT. Ash contents $>20\%$ are obviously undesired in the heat generation, and may also affect the process of cement production [13, 14, 15].

The content of volatiles is the lowest (12 wt.%) in the CT sample, and in the remaining samples P and F is more than twice higher (31 and 28 wt.%, respectively). The moisture contents of the concentrates CT, F and P after their ageing (1 month, ambient temperature) are 13, 15 and 21 wt.%, respectively. High water contents of coal fuels is undesired because they lower calorific values. However, it should be explained why the jig concentrate (P) has the highest calorific value of the three samples despite its relatively high moisture value.

Table 4. Other parameters measured in tested samples of coal.

Sample	Parameters		
	Ash content	Volatile matter content	Wetness
	[%]		
P	21	31	21
CT	55	12	13
F	26	28	15
x	34	23.67	16.33
σ	18.35	10.21	4.16
V	0.54	0.43	0.25

x – arithmetic mean; σ – standard deviation, V – coefficient of variability (σ/x),

4 Conclusions and discussion

Two samples, i.e., P and F concentrates from jigging and flotation, respectively, meet the parameters required for alternative fuels in cement plants. The third one, obtained from a concentrating table, cannot be utilized in this way. The major reason is probably either its low coal content in the starting material that represented the fine-grained fraction or a low degree of preliminary treatment of the material, which undoubtedly contributed to the quality and ash content of the sample [9, 16].

In addition to the parameters determined in this paper, cement plants themselves check their internal, mainly operational parameters, which concern, e.g., emission standards, an impact of fuel on the cement quality, effects imparted by fuel on the kiln performance.

Comparing the results with the literature data on the quality of alternative fuels [17, 18], the concentrate obtained from jigging falls into the class II of such fuels. The requirements for this class are as follows: calorific value $\geq 20 \text{ MJ}\cdot\text{kg}^{-1}$, Cl content $\leq 0.6 \text{ \%wt.}$, Hg content $\leq 0.03 \text{ mg}\cdot\text{kg}^{-1}$. The concentrate obtained from flotation is classified as the class III of alternative fuels. The requirements of this class are: calorific value $\geq 15 \text{ MJ}\cdot\text{kg}^{-1}$, Cl content $\leq 1\%$, Hg content $\leq 0.08 \text{ mg}\cdot\text{kg}^{-1}$. The concentrate obtained from the concentration table meets the requirement of only the class V of alternative fuels: calorific value $\geq 3 \text{ MJ}\cdot\text{kg}^{-1}$, Cl content $\leq 3\%$, Hg content $\leq 0.5 \text{ mg}\cdot\text{kg}^{-1}$.

Summarizing, the following conclusions can be made:

- (1) The coal concentrates obtained using laboratory jigging and flotation meet the literature recommendation for alternative fuels of cement plants;
- (2) The contents of S and Cl in the concentrates do not exceed the limits for alternative fuels specified in the literature [1];
- (3) The Fe contents of the concentrates are much higher (up to about 130 times) than the contents of the remaining metals considered (Mn, Ti, Zn, Cd and Hg);
- (4) The highest is the content of Hg ($0.2187 \text{ mg}\cdot\text{kg}^{-1}$) of the sample obtained on the concentration table;
- (5) High heating and calorific value of jigging and flotation concentrates indicate that the two methods are effective in recovering coal from the waste accumulated on the dumps of coal mines;
- (6) All concentrates have high ash contents, which may be a problem if using the coal recovered as an alternative fuel in cement plants;
- (7) All concentrates have relatively low contents of volatiles;
- (8) All concentrates have high moisture contents after one-month ageing which would lower their calorific value if used as alternative fuels;
- (9) The concentrates meet the requirements of the alternative fuel of the class II (jig sample P), class III (flotation sample F) and class V (concentrate table sample CT).

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