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INVESTIGATION OF COAL SLURRY PROPERTIES DEPOSITED IN IMPOUNDMENTS LOCATED IN THE UPPER SILESIAN COAL BASIN

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Abstract: Results of investigation of physical, chemical and energetic properties of steam and coking coal slurries deposited in twenty Polish impoundments are presented in the paper. Coal slurry was sampled in accordance with a certain procedure from different locations and depths at each impoundment whereas laboratory investigation was performed on averaged samples. The performed investigation include determination of chemical composition, moisture content, volatile matter, sulfur and calorific value at various states. Additionally, properties of coal slurry of particle size below 0.1 mm are presented. The average content of this fraction is approximately 62% and ranges at individual impoundments from 28 to 79%. An average calorific value in analytical state of coal slurries deposited in impoundments in the fraction below 0.1 mm is rather high (12.01 MJ/kg on average) in comparison to the average calorific value of impoundments in analytical state i.e. 16.4 MJ/kg. Average ash and sulfur contents of the coal slurries in analytical state is on average: 42.5% and 1.0% respectively. Transient moisture content of coal slurries in the analytical state is on average 22%, whereas the average volatile matter content is 20.0% Chemical composition is typical for coal tailings with low Al_2O_3 and TiO_2 content. The results indicate considerable variations in the quality of coal slurries deposited in different impoundments due to different geology of coal deposits of the mines. For individual impoundment these differences are smaller which is demonstrated by a lower variation in the standard deviation.

key words: *coal slurry, tailings, chemical composition, impoundments*

1. Introduction

Coal industry generates wastes during exploration, mining and processing of coal. Several studies indicate that the waste generated during coal production accounts for 40% of the total amount which is extracted. The amount of waste which is produced depends on the type of deposit, mining technology, mine planning, processing technology and increasing customers quality requirements for the final product. In the case

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of coal, 94% of the waste consists of tailings i.e. waste which is generated during coal preparation. Such material is separated in coal preparation plants.

As a result of coal beneficiation, the following wastes are produced: coarse (200–20 mm), fine (20–0.5 mm), coal slurry and post-flotation mud with particle size of <1 (0.5) mm. Up to the thirties, i.e. the time of development and introduction of froth flotation technology, small size gangue was difficult to remove using conventional beneficiation methods. Its presence was significantly lowering the quality of coke. Therefore, particles smaller than 1 mm were treated as waste. The same situation was observed in the case of steam coal as it was impossible to burn small particles in stoker-fired boilers. Due to that fact coal slurry was stored on the surface in impoundments or ponds. Studies to recover coal from the waste material deposited in such impoundments are currently a subject of investigation due to high energetic potential (Miao et al. 2010, Anaç and Gitmez 2010). Coal slurries deposited in impoundments are hazardous for the environment as well. A recent helicopter electromagnetic surveys to identify potential hazards at coal waste impoundments in West Virginia was conducted by Hammack et al. (2010). The present paper concerns investigation of fine particle size tailings which were deposited in impoundments years ago. Fifty nine impoundments were identified and twenty nine were selected for thorough investigation of steam and coking coal slurry quality. Sample from the impoundments were collected according to the methodology developed at the initiation of the work. Sampling was done from the bore-holes drilled in the impoundments.

2. Investigation of coal slurry properties

Identification of coal slurry properties is crucial for the selection of a proper separation method (O'Brien et al. 2010). First stage of tests for averaged samples, i.e. samples that were mixed from all of the bore-holes in one impoundment was devoted to chemical composition analysis of the coal slurry. In the project, determination of the selected metals content as well as water leachate composition derived from compressive strength tests was done. After that, for each delivered sample, the following quality analysis were performed:

- transient moisture content W_{ex} and hydroscopic moisture content W_h,
- ash content: analytical A^a, as received A^r and on dry basis A^d,
- sulfur content: analytical S_t^a, as received S_t^r and on dry basis S_t^d,
- volatile matter content: analytical V^a, as received V^r and on dry basis V^d,
- calorific value: analytical Q^a, as received Q^r and on dry basis Q^d.

After quality analysis, the particle size and density analysis were performed for averaged samples. For each particle size fraction and density fraction, the following parameters were determined:

- fraction yield,
- hydroscopic moisture content W_h,
- ash content: analytical A^a and on dry basis A^d,

- sulfur content: analytical S_t^a and on dry basis S_t^d,
- volatile matter content: analytical V^a and on dry basis V^d,
- calorific value: analytical Q^a and on dry basis Q^d.

The tests were performed in accordance with appropriate standards and procedures (Szpyrka and Lutyński 2012, Witkowska-Kita et al. 2012)

3. Results of coal slurry analysis

Sample chemical composition tests results are shown in Table 1. The rest of quality analysis results are presented in Tables 2 to 7.

Table 1. Results of basic chemical composition analysis of coal slurries deposited in impoundments

Impoundment	Content, %									
	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	C	P_2O_5
1	49.26	5.32	0.02	0.46	0.02	0.84	1.86	0.32	22.50	0.001
2	49.23	5.91	0.12	1.29	0.03	0.53	1.86	0.32	22.50	0.001
3	54.16	9.09	0.04	1.00	0.03	0.72	2.79	1.34	19.00	0.008
4	55.69	9.28	0.02	0.84	0.03	0.77	2.98	0.79	15.53	0.003
5	40.79	7.22	0.07	0.81	0.01	0.88	2.52	1.31	26.50	0.015
6	28.88	7.70	0.17	0.95	0.03	0.97	2.66	0.90	25.45	0.006
7	33.16	5.69	0.026	1.03	0.03	0.99	2.57	0.81	23.05	0.007
8	42.49	6.32	0.03	0.73	0.02	1.20	1.35	0.81	11.15	0.001
9	45.16	6.89	0.03	0.70	0.01	0.93	1.23	0.81	11.58	0.002
10	53.48	7.26	0.04	0.64	0.02	0.44	1.93	0.67	31.6	0.001
11	51.23	6.74	0.03	0.71	0.02	0.35	1.93	0.66	30.25	0.002
12	58.96	6.24	0.04	0.68	0.02	0.40	1.35	0.66	31.80	0.001
13	54.60	5.66	0.02	1.42	0.09	0.49	1.34	0.44	26.05	0.002
14	63.96	5.61	0.01	1.13	0.12	0.48	2.77	0.62	17.54	0.001
15	54.66	7.10	0.01	1.46	0.12	0.90	1.83	0.48	21.50	0.003
16	43.05	9.22	0.02	1.77	0.03	0.56	1.23	0.40	25.00	0.003
17	51.46	6.68	0.02	0.81	0.10	0.99	1.49	0.48	25.04	0.001
18	42.77	5.57	0.02	1.43	0.14	1.12	1.35	0.41	23.25	0.003
19	42.57	4.80	0.02	1.46	0.13	1.20	1.19	0.39	30.05	0.001
20	33.57	6.38	0.02	1.61	0.11	0.74	1.23	0.41	25.65	0.002
average	47.46	6.73	0.04	1.05	0.06	0.77	1.87	0.65	23.25	0.04
Standard dev.	9.11	1.29	0.04	0.38	0.05	0.27	0.82	0.29	5.94	0.01

In Tables 2 and 3 the results of analysis of sixteen and twenty two samples collected from two impoundment are presented. Samples were collected from different locations and depths of the impoundment.

Table 2. Properties of coal slurry from KX impoundment

Sample	Transient moisture content [%]	Hydroscopic moisture content [%]	Ash content [%]			Sulfur content [%]			Volatile matter content [%]			Calorific value [MJ/kg]		
	W_{ex}	W_h	A^a	A^r	A^d	S_t^a	S_t^r	S_t^d	V^a	V^r	V^d	Q^a	Q^r	Q^d
1	24.77	1.31	37.75	28.89	38.25	0.89	0.68	0.90	19.85	15.19	20.11	19.06	14.59	19.32
2	25.35	1.25	37.19	28.23	37.66	0.87	0.66	0.88	20.36	15.45	20.62	19.41	14.74	19.66
3	23.83	1.40	37.87	29.37	38.41	0.85	0.66	0.86	20.43	15.85	20.72	18.68	14.49	18.94
4	23.41	1.44	39.47	30.80	40.05	0.84	0.66	0.85	19.92	15.54	20.21	17.22	13.44	17.48
5	25.81	1.23	35.38	26.68	35.82	1.07	0.81	1.08	21.09	15.91	21.35	20.40	15.38	20.65
6	23.09	1.46	35.59	27.89	36.12	1.01	0.79	1.02	20.97	16.43	21.28	19.80	15.52	20.09
7	24.63	1.33	35.46	27.20	35.94	0.86	0.66	0.87	20.27	15.55	20.54	19.76	15.16	20.03
8	22.16	1.35	43.25	34.25	43.84	0.76	0.60	0.77	19.73	15.62	20.00	17.25	13.66	17.49
9	21.46	1.31	37.90	30.26	38.40	0.76	0.61	0.77	20.87	16.67	21.15	19.23	15.36	19.49
10	24.26	1.28	37.76	29.08	38.25	0.87	0.67	0.88	21.15	16.29	21.42	19.55	15.06	19.80
11	23.20	1.26	36.03	28.13	36.49	0.93	0.73	0.94	21.17	16.53	21.44	19.86	15.50	20.11
12	23.34	1.21	37.44	29.15	37.90	0.89	0.69	0.90	21.19	16.50	21.45	19.05	14.83	19.28
13	20.15	0.74	59.52	47.97	59.96	1.35	1.09	1.36	12.46	10.04	12.55	13.10	10.56	13.20
14	26.18	1.10	34.54	25.88	34.92	0.97	0.73	0.98	21.05	15.77	21.28	21.21	15.89	21.45
15	22.56	1.24	37.79	29.73	38.26	0.91	0.72	0.92	21.14	16.63	21.41	19.42	15.28	19.66
16	24.56	1.11	38.40	29.40	38.83	1.15	0.88	1.16	20.88	15.98	21.11	19.21	14.70	19.42

Table 3. Properties of coal slurry from KY impoundment

Sample	Transient moisture content [%]	Hydroscopic moisture content [%]	Ash content [%]			Sulfur content [%]			Volatile matter content [%]			Calorific value [MJ/kg]		
	W_{ex}	W_h	A^a	A^r	A^d	S_t^a	S_t^r	S_t^d	V^a	V^r	V^d	Q^a	Q^r	Q^d
1	22.77	5.80	55.53	46.11	58.95	0.73	0.61	0.77	16.85	13.99	17.89	9.84	8.17	10.45
2	25.86	4.74	53.60	42.28	56.27	0.63	0.50	0.66	18.05	14.24	18.95	10.78	8.50	11.32
3	17.83	7.11	46.74	41.73	50.32	0.90	0.80	0.97	19.11	17.06	20.57	12.13	10.83	13.06
4	22.40	7.42	40.98	34.84	44.26	1.01	0.86	1.09	21.41	18.20	23.13	14.11	12.00	15.24
5	16.45	6.04	48.90	43.81	52.04	0.99	0.89	1.05	18.69	16.75	19.89	13.21	11.83	14.06
6	17.55	6.19	50.12	44.43	53.43	1.04	0.92	1.11	18.24	16.17	19.44	13.02	11.54	13.88
7	27.87	6.09	47.77	37.36	50.87	0.83	0.65	0.88	19.26	15.06	20.51	13.33	10.43	14.20
8	28.05	5.49	52.87	40.94	55.94	0.84	0.65	0.89	17.66	13.68	18.69	12.25	9.49	12.96
9	25.95	6.69	42.73	34.50	45.79	0.72	0.58	0.77	20.93	16.90	22.43	14.65	11.83	15.70
10	15.70	6.09	48.29	43.65	51.42	1.17	1.06	1.25	18.76	16.96	19.98	11.99	10.84	12.77
11	19.92	5.91	50.23	43.19	53.39	0.95	0.82	1.01	18.44	15.86	19.60	12.86	11.06	13.67
12	27.54	6.46	44.59	35.19	47.67	0.73	0.58	0.78	20.49	16.17	21.91	15.08	11.90	16.13
13	27.53	4.82	56.46	43.64	59.32	0.56	0.43	0.59	16.69	12.90	17.54	10.70	8.27	11.24
14	28.47	4.96	56.59	43.28	59.54	0.76	0.58	0.80	16.12	12.33	16.96	11.78	9.01	12.40
15	18.94	5.95	51.05	44.42	54.28	0.76	0.66	0.81	18.40	16.01	19.56	12.88	11.20	13.69
16	25.20	5.29	55.24	44.24	58.33	0.65	0.52	0.69	17.51	14.02	18.49	11.33	9.07	11.96
17	14.29	7.11	40.97	38.03	44.11	1.13	1.05	1.22	21.00	19.49	22.61	16.74	15.53	18.02
18	22.51	5.69	51.08	42.49	54.16	0.91	0.76	0.96	17.99	14.96	19.08	15.62	12.99	16.56
19	15.26	1.39	41.07	35.37	41.65	2.14	1.84	2.17	15.55	13.39	15.77	19.72	16.98	19.99
20	26.26	5.46	58.76	46.54	62.15	0.39	0.31	0.41	15.85	12.55	16.77	10.31	8.16	10.90
21	22.46	5.11	44.64	36.90	47.04	0.90	0.74	0.95	21.61	17.86	22.77	16.96	14.02	17.87
22	28.58	5.93	50.36	38.95	53.53	0.63	0.49	0.67	18.44	14.26	19.60	13.25	10.25	14.09

In Tables 4, 5 and 6 a summary of coal slurry properties is presented as statistical average and their standard deviations for twenty two impoundments. Table 4 shows results of transient and hydroscopic moisture content analysis of coal slurries. In Table 5 quality parameters for analytical state are presented, whereas in Table 6 these parameters are presented on the "as received" basis.

The particle size analysis of coal slurries confirmed previous investigations that the majority of particles is in the fraction below 0.1 mm. In the case of coal slurries from each impoundment, 62.27% of particles is in the fraction below 0.1 mm and ranges for particular impoundments from 27.90 to 78.93% with standard deviation of 14.26%. In three impoundments the share of this fine fraction was below 50%.

Due to that fact, an in-depth analysis of this fraction was performed. Results of these analyses (see Table 7) are crucial due to the possibility of upgrading of this fraction as a high quality component of coal mixes (Figure 1). An in-depth study of coal slurry beneficiation from these impoundments was investigated by Szpyrka and Lutyński, 2012.

Table 4. Transient moisture content and hydroscopic moisture content in coal slurries at impoundments

Impoundment	Transient moisture content [%]	Standard dev. of transient moisture content [%]	Hydroscopic moisture content [%]	Standard dev. of hydroscopic moisture content [%]
1	24.75	3.94	7.00	0.29
2	27.69	1.32	7.92	0.40
3	23.05	1.79	5.25	0.73
4	20.69	1.99	3.73	0.97
5	19.47	2.42	4.66	2.40
6	22.61	4.86	5.71	1.21
7	27.25	4.19	2.15	0.40
8	11.69	6.79	1.77	1.60
9	17.66	3.58	1.27	0.19
10	18.57	3.66	1.69	0.22
11	18.77	2.46	1.58	0.11
12	17.28	4.72	1.66	0.11
13	25.01	0.92	1.14	0.12
14	24.53	2.57	2.23	0.22
15	34.48	3.85	3.17	0.77
16	22.45	3.98	1.23	0.31
17	24.67	1.58	1.29	0.07
18	25.45	1.36	1.04	0.08
19	24.63	1.07	1.20	0.12
20	23.67	1.60	1.25	0.17
average	22.70	–	2.85	–
standard dev.	4.92	–	2.13	–

Table 5. Quality parameters summary for analytical state of coal slurry at impoundments

Impoundment	Ash content [%]	Ash content standard deviation [%]	Sulfur content [%]	Sulfur content standard deviation [%]	Volatile matter content [%]	Volatile matter content standard deviation [%]	Calorific value [MJ/kg]	Calorific value standard deviation [MJ/kg]
1	27.47	2.99	1.90	0.84	28.50	4.32	15.10	1.51
2	32.98	2.58	0.72	0.03	23.85	0.41	15.65	0.83
3	41.36	1.41	0.86	0.10	21.31	1.25	14.81	0.58
4	63.96	9.06	0.57	0.16	14.38	2.55	9.33	2.05
5	63.04	17.76	0.64	0.25	14.39	5.47	10.07	2.75
6	49.48	5.39	0.88	0.34	18.50	1.76	13.30	2.41
7	60.43	10.56	0.70	0.20	16.41	3.13	9.27	3.50
8	45.90	12.59	2.98	1.27	18.01	2.23	14.88	5.98
9	58.34	8.24	2.26	0.67	14.29	1.17	12.30	2.80
10	28.41	4.23	0.95	0.11	23.47	1.33	22.81	1.54
11	26.98	3.46	0.95	0.15	23.77	0.75	23.29	1.44
12	27.89	0.32	0.97	0.13	23.79	0.71	22.94	0.59
13	47.22	2.55	0.59	0.11	18.89	0.29	15.81	0.94
14	31.84	4.51	0.79	0.13	23.85	1.25	20.83	2.07
15	53.79	5.17	1.21	0.19	16.99	1.52	12.05	1.50
16	42.86	13.10	1.09	0.38	16.89	2.30	17.80	5.35
17	37.59	1.44	0.94	0.08	20.64	0.87	19.40	0.65
18	35.22	1.28	0.97	0.02	21.54	0.40	20.35	0.84
19	37.33	1.29	0.92	0.06	20.72	0.54	19.67	0.77
20	38.83	5.88	0.94	0.15	20.16	2.12	18.89	1.83
average	42.55	–	1.09	–	20.02	–	16.43	–
standard deviation	12.28	–	0.60	–	3.85	–	4.52	–

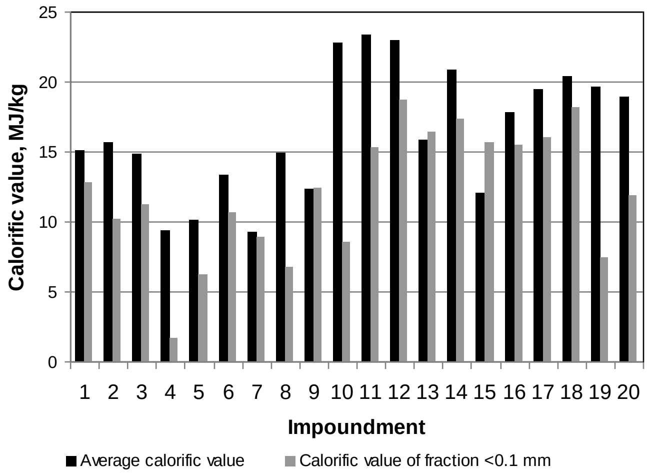

Fig. 1. Average calorific value (at analytical state) of coal slurry at individual impoundment in comparison with fraction <0.1 mm

Table 6. Quality parameters summary on "as received" basis of coal slurry at impoundments

Impoundment	Ash content [%]	Ash content standard deviation [%]	Sulfur content [%]	Sulfur content standard deviation [%]	Volatile matter content [%]	Volatile matter content standard deviation [%]	Calorific value [MJ/kg]	Calorific value standard deviation [MJ/kg]
1	24.31	3.37	1.58	0.73	23.49	4.25	12.38	0.67
2	26.46	1.94	0.58	0.01	19.14	0.61	12.55	0.61
3	34.01	1.69	0.70	0.07	17.53	1.33	12.18	0.57
4	53.11	7.60	0.48	0.14	11.95	2.14	7.74	1.67
5	53.68	15.08	0.55	0.22	12.26	4.70	8.59	2.37
6	40.99	3.88	0.74	0.31	15.40	1.94	11.09	2.32
7	45.46	10.20	0.52	0.13	12.24	1.73	6.87	2.27
8	41.91	13.53	2.71	1.26	16.22	2.59	13.12	4.66
9	49.00	8.53	1.91	0.62	11.92	0.71	10.21	1.98
10	23.55	3.20	0.79	0.10	22.47	1.33	18.98	1.73
11	22.36	3.05	0.79	0.13	19.69	0.87	19.29	1.29
12	23.55	1.62	0.81	0.06	20.05	0.70	19.35	1.06
13	35.95	1.95	0.45	0.09	14.38	0.30	12.04	0.73
14	24.81	4.26	0.61	0.12	18.51	0.78	16.16	1.39
15	37.00	4.78	0.83	0.16	11.65	1.04	8.26	0.97
16	33.62	11.40	0.86	0.35	13.05	1.58	13.65	3.63
17	28.79	1.08	0.72	0.06	15.82	0.89	14.87	0.68
18	26.62	0.89	0.73	0.02	16.28	0.57	15.39	0.76
19	28.59	1.25	0.70	0.04	15.87	0.47	15.06	0.46
20	30.18	5.11	0.73	0.12	15.62	1.56	14.63	1.27
average	34.19	–	0.88	–	16.18	–	13.12	
standard deviation	10.12	–	0.55	–	3.54	–	3.72	

4. Conclusions

The following can be concluded taking into account the obtained results:

- chemical composition of coal slurries is typical for fine particle tailings of coal (Blaschke, 2005; Grudziński, 2005; Strzyszcz and Łukasik, 2008). Low Al_2O_3 and TiO_2 content is a departure from the literature data,
- average calorific value in analytical state of coal slurries deposited in impoundments ranges from 9.26 to 23.29 MJ/kg with standard deviation ranging from ±0.58 to ±5.98 MJ/kg,
- average ash content in analytical state of coal slurries deposited in impoundments ranges from 26.98 to 63.96% with standard deviation ranging from ±1.28 to ±17.76%,

Table 7. Physicochemical analysis of coal slurries from all impoundments for particle size fraction <0.1 mm for analytical state and dry basis

Impoundment	Fraction <0.1 mm yield [%]	Hydroscopic moisture content [%]	Ash content [%]	Sulfur content [%]	Volatile matter content [%]	Calorific value [MJ/kg]

- average sulfur content in analytical state of coal slurries deposited in impoundments ranges from 0.57 to 2.98%. with standard deviation ranging from ±0.03 to ±1.27%,
- average transient moisture content of coal slurries deposited in impoundments ranges from 11.69 to 34.48%. with standard deviation ranging from ±1.07 to ±4.89%,
- average hydroscopic moisture content of coal slurries deposited in impoundments ranges from 1.04 do 7.92%. with standard deviation ranging from ±0.07 to ±2.40%,
- average volatile matter content in analytical state of coal slurries deposited in impoundments ranges from 14.29 do 28.50%. with standard deviation ranging from ±0.40 to ±5.47%,
- particle size analysis of coal slurries revealed that the majority of particle is in the fraction below 0.1 mm. On average, 62.27% of particles has a size below 0.1 mm and ranges from 27.90 to 78.93% for particular impoundments with standard deviation of ±14.26%. In three impoundments this share is below 50%,
- average calorific value in analytical state of coal slurries deposited in impoundments in fraction below 0.1mm is rather high (12.01 MJ/kg on average) and ranges from 1.68 to 18.70 MJ/kg with standard deviation of ±4.58 MJ/kg,
- particle size fraction <0.1 mm has a higher ash and sulfur content.

Presented results indicate considerable variations in the quality of coal slurries deposited in different impoundments which is obvious taking into account different geology of coal deposits of the mines. At individual impoundment these differences are smaller which is demonstrated by the lower variation in the standard deviation.

Qualitative and quantitative analyses of coal slurries deposited in impoundments demonstrate a significant energetic potential which can be utilized by applying proper upgrading technology.

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