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Management of mining waste and the areas of its storage – environmental aspects

Introduction

In the past, a commonly used method of neutralizing waste from bituminous coal mining in Poland was their deposition on dumping grounds. There are hundreds of objects constituting the location of coal mining waste in the coal basins around the world (Szczepańska and Twardowska 1999; Gawor 2014; Zástěrová et al. 2015). In China, the number of dumping grounds on which gangue from bituminous coal mines was deposited exceeds 1700, and their presence constitutes a significant environmental problem (Bian et al. 2009).

There are over 220 coal waste dumps in the Upper Silesian Coal Basin (USCB) (Gawor 2014; Marcisz et al. 2018). In terms of occupied space, one of the largest objects of this kind in the USCB is the central dumping ground in Przechlebie. It is located in the south of Poland, in the western part of the Silesian Province (Fig. 1). Mining waste from several bituminous coal mines and energy waste from the Rybnik, Zabrze, Miechowice and Szombierki power plants were deposited on this dumping ground.

The area of the Przechlebie dump has quite a rich history when it comes to its use (Fig. 2). In the years 1905–1955, sand mining was carried out there for the purpose of filling

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Fig. 1. Localization of the Przechlebie dumping ground

Rys. 1. Lokalizacja zwałowiska Przechlebie

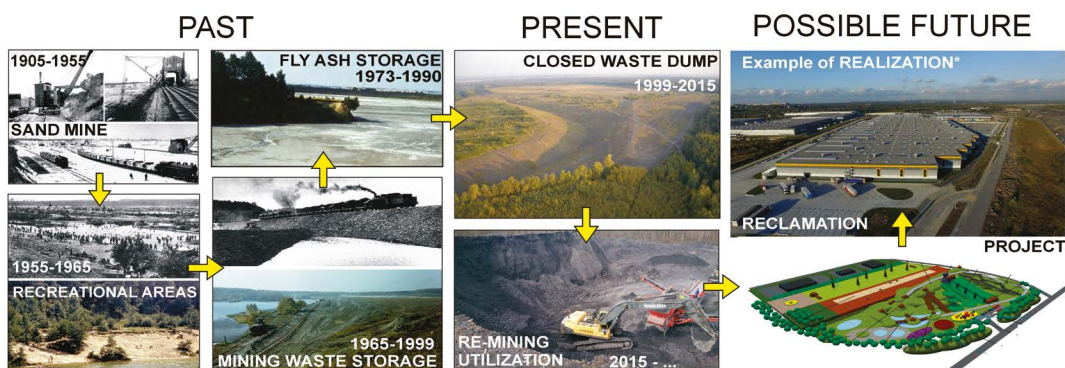


Fig. 2. Life cycle of the Przechlebie dumping ground

Sources: Róžański 2009; www.bagry.republika.pl

* logistics center built on the site prepared from the coal waste – phot. Depenbrock Polska

Rys. 2. Cykl życia zwałowiska Przechlebie

in post-mining voids in underground mining. The excavation created as a result of the sand extraction was filled with water and used as a place of recreation for the local population. In the 1960s, bituminous coal mining was gradually growing in the Polish mines. It was accompanied by the production of more and more waste. There was a growing demand for lands on which it was possible to deposit the generated coal waste. It was stated that water reservoirs in Przechlebie would constitute a significant reservoir for depositing gangue.

In the years 1965–1999 mining waste was deposited there. In parallel, energy waste was also deposited in the form of fly ash, the largest amounts of which were deposited in the years 1973–1990. As a result, a dumping ground with an area of nearly 150 ha was created, of which approx. 45% is occupied by a fly ash reservoir.

A dumping ground of mining and power plant waste can carry a number of negative effects on the environment (Carlson and Adriano 1993; Szczepańska and Twardowska 1999; Tiwary 2001; Sułkowski et al. 2008; Strzyszcz et al. 2009; Suponik and Blanco 2014). The large surface of the dumping ground facilitates contact with rainwater and air, which intensifies the process of leaching soluble components from the dumping ground. The leached substances (mainly chlorides, sulphates and heavy metals) can be a source of contamination of the surface waters, groundwaters and soils in the deposition areas. An adverse interaction between the collected mining and energy waste is also possible, which may increase the intensity of contamination leaching (Stefaniak et al. 2013). Fine-grained material present on the dumping ground, including fly ash, can cause pollution of the air. However, due to the content of flammable components (carbon, pyrite and others), there is a risk of self-ignition. This involves the emission of greenhouse and toxic gases into the atmosphere. In contrast to emissions from other post-mining sources, e.g. abandoned and liquidated ventilation shafts (Wrona et al. 2016; Wrona 2017), numerous toxic and odoriferous substances in fire gases exist, which are accompanied by a significant odor nuisance in the vicinity of the dumping ground (Róžański 2009; Róžański and Wrona 2010; Łączny et al. 2012; Fabiańska 2013; Stracher et al. 2014; Smoliński et al. 2016; Surovka et al. 2017; Plewa et al. 2017; Fabiańska et al. 2018).

In the article, the Przechlebie dumping ground is considered an anthropogenic source of raw materials. This approach allows for the introduction of subsequent stages in the life of the described area, such as re-mining, use of waste, reclamation of the dumping ground and its management (Fig. 2). This is related to the reduction of its impact on the environment, including the reduction of fire risk and a range of economic and social benefits, e.g. new work places. There are positive examples of the management of industrial waste dumping grounds in Poland and in the world, while the treatment of such objects as anthropogenic raw material deposits already dates back to the 1990s (Niec and Uberman 1995; Niec 1999). Currently, due to rising prices of raw materials and the increasing costs of their extraction, resources trapped in dumping grounds are being used more and more frequently. On the occasion of re-mining, the condition of the environment can be improved, and new functions can be given to the areas where they are located. Such objects do not have to pose a threat to the environment, but after undergoing appropriate treatment, they may constitute industrial monuments, recreation zones or investment areas (Uberman and Ostreęa 2004; Bian et al. 2009).

The purpose of the work was to assess the impact of the dumping ground and the material collected on it on the water and nature environment as well as to determine the possibilities of its use. Determining the properties of waste will allow to determine the possible directions of its management in the current deposition location or outside it. For the purposes of the study, tests were carried out on the coal waste dumping ground. The quality assessment

of the waste itself and the eluates resulting from their leaching were made. In addition, analysis on the chemical composition and physicochemical parameters of groundwater present in the dumping ground area were carried out. In order to assess the fire hazard, tests on the thermal state of the dumping ground were conducted as well.

1. Materials and methods

1.1. Sampling

Seven samples of primary coal waste were collected in the Przezchlebie dumping ground. The samples were collected from three existing mining excavations. The minimum weight of each sample amounted to 20 kg. A single sample consisted of material taken from different places at a one site.

The samples marked as S1 and S2 were collected from the bottom of an excavation located in the western part of the dumping ground. The samples marked as S3 and S4 were taken from a smaller excavation located in the central part of the object. The samples marked as S5, S6 and S7 were collected from a larger excavation located in the central part of the dumping ground. The depth of sampling measured from 3 to 9 m in relation to the top of the dumping ground. The samples were taken from a slope and a bottom of each excavation. The depth of western excavation was 9 m and the depth of central excavations was 6 m. Figure 3 shows the locations of the sampling sites.

Samples for analysis were prepared and averaged according to the [PN-G-04502:1990](#) standard. By mixing samples S1 and S2, sample S–I was created, samples S3 and S4 resulted in obtaining sample S–II, while samples S5, S6 and S7 collected in the largest central excavation were used to obtain sample S–III. Thus, 3 samples representing particular excavations were collected.

In order to assess the current impact of the dumping ground on groundwater, water samples from two piezometers W1 and W2 located within the dumping ground area at a distance of 40–50 m from its border were also collected for testing (location shown in Fig. 3).

A water table of quaternary level usually stands in this area. Naturally occurring sands and made soils (coal waste) within the dump are the aquifer. The flow of shallow groundwater occurs mainly in the south-west direction ([Kowalska 2012](#); [Chmura 1998](#)), which indicates that the piezometers were located on the outflow of water from the dump. The ordinates of the area where the piezometers were made correspond to 270.1 and 271.3 m a.s.l. respectively, and the depth at which the groundwater table was found is 17–18 m.

The samples in the amount of approx. 3 litres of water from each of the piezometers were collected using a sampler. During the collection, the depth of the groundwater table in both piezometers was also determined. The water samples were filtered using a microfiltration kit prior to the analysis.

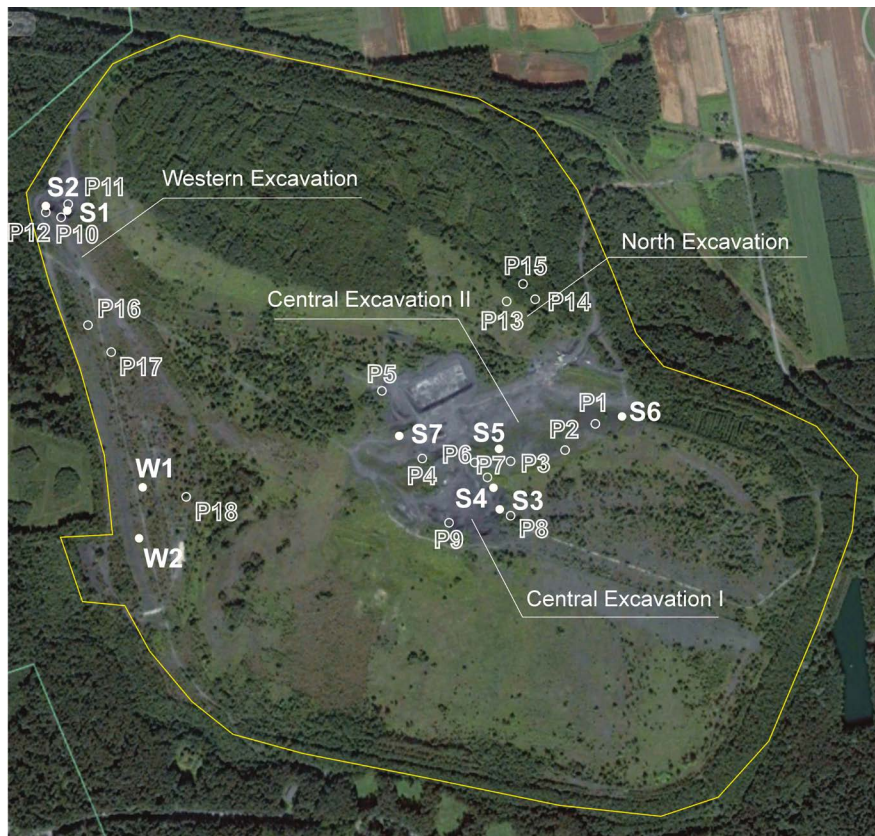


Fig. 3. Location of sampling sites and measurement points
 S1–S7 – samples of coal waste, W1–W2 – samples of groundwater,
 P1–P18 – points of temperature and gas concentration measurement)
 Source: own results using Google Maps

Rys. 3. Lokalizacja miejsc poboru próbek i punktów pomiarowych
 S1–S7 – próbki odpadów powęglowych, W1–W2 – próbki wód gruntowych,
 P1–P18 – punkty pomiaru temperatury i stężeń gazów

1.2. Coal waste chemical composition tests

In order to determine the chemical composition of the waste, an analysis of the samples was carried out according to the [PN-G-04528](#) standard. In particular, the following were marked: SiO_2 , Al_2O_3 , TiO_2 , Fe_2O_3 , CaO , MgO , $\text{K}_2\text{O} + \text{Na}_2\text{O}$, S_c , C. The determination of total sulphur S_t was carried out using the LECO SC–132 apparatus in accordance with the [PN-G-04584:2001](#) standard, whereas carbon C content was determined using the Tiurin oxidimetric method.

1.3. Analysis of water extract and groundwater

The leaching tests were carried out on coal waste from the dumping ground in accordance with the [PN-EN 12457-4:2006](#) standard. The liquid/solid waste (L/S) ratio in the leaching tests was 10:1.

Temperature, pH, reduction potential (ORP), electrolytic conductivity and TDS (sum of solutes) in eluates and groundwater samples were determined using electrometric methods (PORTAMESS 913 pH with SenTix 41 combined electrode; PORTAMESS 913 pH with POLYPLAST ORP electrode; PORTAMESS 913 Cound).

Using the UV-Vis DR5000 HachLange spectrophotometer, an analysis of the eluates generated during the leaching tests and groundwater samples was carried out. The concentrations of chromium (VI), sulphates, sulphides, total iron and iron (II), free cyanides, volatile phenols, ammonium, nitrate and ammonium nitrogen were determined. Chlorine concentrations were determined using the Mohr method in accordance with the [PN-ISO9297:1994](#) standard. Determinations of metal content (arsenic, barium, chromium, tin, zinc, aluminum, cadmium, cobalt, magnesium, manganese, copper, molybdenum, nickel, lead, mercury, vanadium, calcium, selenium, thallium, antimony, boron) were carried out by inductively coupled plasma atomic emission spectroscopy (ICP-AES) method, using the JY 2000 spectrometer. The hardness of water and the content of chlorides were determined using the versenate and Mohr method respectively, and the chemical oxygen demand (COD) using the dichromate method.

1.4. Thermal state tests

Tests of the thermal state of the dumping ground were carried out in accordance with the methods used, resulting from many years of experience of scientific units dealing with the problem of fire hazard on the coal waste dumps ([Łączny et al. 2012](#); [Jelínek et al. 2015](#); [Róžański et al. 2017](#)). They were carried out periodically in the years 2014–2018. The tests consisted in temperature measurements of waste material and gas concentrations. The following methods were used:

- ◆ non-contact temperature measurements of the dumping ground surface based on the infrared principle using a pyrometer and a thermal imaging camera,
- ◆ measurements of the temperature inside the dumping ground (at a depth of up to 1 m),
- ◆ checking the atmosphere composition inside the dumping ground (concentrations of O₂, CO, CO₂ at a depth of up to 1 m).

The following measuring apparatus was used:

- ◆ Flir E6 thermal imaging camera,
- ◆ RAYNGER MX4 pyrometer,
- ◆ HD9016 thermometer with K type thermocouple probes,

- ◆ Dräger X-am 7000 multi-gas analyzer,
- ◆ Kestrel 4500N multifunction meter (measurement of atmosphere parameters).

Thermovision studies mainly covered the slopes of existing mining excavations and the tops in their vicinity as areas most endangered by endogenic fire. Tests of the dumping ground interior were carried out at selected points whose location was shown in Figure 3.

2. Results and discussion

2.1. Chemical composition of coal waste

The chemical composition of coal waste in various regions, or the average composition of numerous regions or even the entire USCB, is given in by a number of authors in their publications (e.g. [Szczepańska 1987](#); [Skarżyńska 1995](#); [Stefaniak and Twardowska 2006](#); [Bzowski 2008](#); [Bojarska and Bzowski 2012](#)). The chemical composition of mining and power plant waste affects the formation of secondary products and the possibility of leaching soluble components into the water. The pH of the waste itself and the water infiltrating through the dumping ground is crucial ([Skarżyńska 1995](#)).

The main components in mining wastes sampled from the Przechlebie dumping ground are (in % \pm SD) $\text{SiO}_2 = 45.22 \pm 2.51$ and $\text{Al}_2\text{O}_3 = 18.48 \pm 1.20$. The average contents of other significant components amount to $\text{TiO}_2 = 0.99 \pm 0.03$; $\text{Fe}_2\text{O}_3 = 4.06 \pm 0.24$; $\text{CaO} = 1.40 \pm 0.42$; $\text{MgO} = 1.41 \pm 0.41$; $\text{K}_2\text{O} + \text{Na}_2\text{O} = 1.21 \pm 0.06$; $\text{S}_t = 0.442 \pm 0.21$; $\text{C} = 11.69 \pm 1.45$. The content of the presented substances for individual samples showed a similar level. A slight variation was noticed only in the case of content C, where the highest value reached almost 13% (for sample S–III).

As stated by [Bojarska and Bzowski \(2012\)](#), the nature of carboniferous waste results from the quantitative presence of quartz, feldspars and clay minerals in this waste. Quantities of basic minerals: quartz, kaolinite, illite and feldspars without the need for their testing are determined by the ratio of aluminum content to silica content $\text{Al}_2\text{O}_3/\text{SiO}_2$. The tested waste is characterized by the value of this indicator amounting to 0.409, which corresponds to a three-component mixture of quartz + kaolinite + illite in a 1:1:1 ratio.

Comparing the chemical composition of coal waste from the Przechlebie dumping ground with the values presented by [Skarżyńska \(1995\)](#), it can be stated that the composition of the tested waste does not differ from the composition of Polish carboniferous waste as well as waste from mines in other countries (Czech Republic, Slovakia, Spain, Great Britain, Brazil). In the last decades of the previous century, the ranges of content of the same components in waste from the Polish bituminous coal mining industry were as follows (in %): $\text{SiO}_2 = 35\text{--}60$, $\text{Al}_2\text{O}_3 = 17\text{--}28$, $\text{TiO}_2 = 0.1\text{--}1.7$; $\text{Fe}_2\text{O}_3 = 1.5\text{--}5.5$; $\text{CaO} = 0.3\text{--}1.8$; $\text{MgO} = 0.3\text{--}2.1$; $\text{K}_2\text{O} = 0.1\text{--}5.5$; $\text{Na}_2\text{O} = 0.01\text{--}0.7$ ([Skarżyńska 1995](#)).

The relatively low content of K_2O and Na_2O in the tested material means that in the case of its application for reclamation, it may require an additional supply of potassium as an important biogenic component. However, as experience shows, after the use of coal waste for reclamation, potassium activation takes place at the stage of weathering, which will increase its availability for plants. Observations of biologically reclaimed areas using carboniferous gangue in the area of the Upper Silesian Coal Basin indicate that the introduced plants usually sufficiently use the available amounts of potassium and do not suffer from its deficiency (Bojarska and Bzowski 2012).

In turn, Bzowski (2008) states that the content of elements: As, Ba, Cr, Zn, Co, Cu, Ni, Pb, Hg expressed in mg per kg of dried waste are contained respectively in the ranges of 2–5, 505–683, 89–144, 186–270, 35–54, 142–170, 30–67 and 38–76 for waste deposited on one of the dumping grounds in USCB. Table 1 presents the contents of the following elements: Ba, Cr, Zn, Co, Mn, Cu and Ni for the Przechlebie dumping ground. It can be noticed that concentrations of elements in waste deposited in the Przechlebie dumping ground overlap with the data presented by Bzowski (2008).

The stated content of carbon (10.08–12.91%) and sulphur (0.263–0.669%), mainly related to the presence of pyrite, creates a fire hazard in coal waste. This is a result of a natural oxidation process accompanied by the release of heat and gases into the atmosphere. Self-heating is a common environmental problem that occurs on this type of objects (Sułkowski et al. 2008; Róžański, 2009; Łączny et al. 2012; Fabiańska et al. 2013; Surovka et al. 2017). Therefore, the direct use of waste from the Przechlebie dumping ground in reclamation or other engineering works (land levelling, construction of embankments, etc.) requires fire prevention. The elimination of fire hazard and the improvement of waste properties, as well as the possibility of its use, will be positively influenced by the separation of coal from waste.

Table 1 presents concentrations of selected metals (mg/kg of dry weight), which pose a risk particularly important for the protection of the ground surface. The table also contains the permissible content of these substances in the soil, defined for the depth of 0–0.25 m below ground level, with the division including land groups distinguished on the basis of their use, and land subgroups distinguished on the basis of the soil properties determined for land group II (Ordinance ME 2016). Due to the content of the abovementioned metals, coal waste deposited on the examined dumping ground can be used on the group II–3, III and IV soils. Exceeding the content of barium and cobalt, for the most part, is the reason for limiting their wider use in other land groups. However, the increased barium content is natural for carboniferous waste in the entire USCB area.

As a result of the recovery of coal from the Przechlebie dumping ground, the content of the analyzed metals will increase. Assuming that it will be possible to recover coal at the level of 7.7% (Róžański et al. 2016), the content of metals in the material may increase even by 7.2% in relation to the values presented in Table 1. This may cause a reduction in the use of waste on group II–3 lands due to a small exceeding of the permissible concentration of barium and cobalt, the contents of which will amount to 617 and 52 mg/kg d.m. respectively.

Table 1. The content of selected metals in waste and permissible values
 Tabela 1. Zawartość wybranych metali w odpadach i wartości dopuszczalne

Metal	Mass content mg/kg dry weight (DW)				SD	The highest permissible value in grounds acc. Ordinance ME 2016, mg/kg (DW)						
	Sample S-I	Sample S-II	Sample S-III	Average		Group I	Group II			Group III	Group IV	
						II-1	II-2	II-3				
Ba	428	618	681	576	132	200	400	600	400	1 000	1 500	
Co	21	57	68	49	25	20	30	50	50	100	200	
Cr	59	80	88	76	15	150	300	500	200	500	1 000	
Cu	149	87	155	130	38	100	150	300	200	300	600	
Mn	1 941	1 108	1 671	1 573	425	–	–	–	–	–	–	
Ni	58	87	111	85	27	100	150	300	150	300	500	
Zn	191	110	201	167	50	300	500	1 000	300	1 000	1 000	

A vital problem when it comes to the possibility of using industrial waste is its radioactivity. Regarding the mining waste from the Przezchlebie dumping ground, the results of radioactivity tests were presented in the work (Skarżyńska et al. 1993). All samples from the dumping ground showed the concentration of radionuclides in the range of values for the lithosphere, e.g. 0–100 Bq/kg ^{226}Ra , 0–100 Bq/kg ^{228}Th and 0–780 Bq/kg ^{40}K . For comparison, the ranges of concentration values for soils in Poland are: 4.3–128.3 Bq/kg ^{226}Ra , 3.6–77 Bq/kg ^{228}Th and 63–924 Bq/kg ^{40}K (Isajenko et al. 2014). The contents of radionuclides in the waste deposited in Przezchlebie do not therefore constitute an obstacle to their use.

2.2. Properties and composition of water extracts

In order to assess the current impact of waste collected on the Przezchlebie dumping ground on the environment and the possibilities of its use, leaching tests were also carried out. The test results are summarized in Table 2.

The tests indicate that the eluates have a very low hardness level, and the pH of individual samples is slightly acidic – close to neutral (on average, the pH value amounted to 6.71). This is a favorable feature of the tested material from the point of view of the possibility of material utilization in biological reclamation. Most plants require a neutral or slightly acidic reaction for optimal growth and development (Klatka et al. 2017).

Concentrations of chlorides measuring the salinity of water extracts are significant from the point of view of their environmental impact (plants and waters). The tested samples showed a very low concentration of Cl^- , at the level of 5.55 mg/dm³ in the first sample, and below the limit of determination in the other two. Low values are probably the effect of water infiltrating the dumping ground at the sampling site. The sulphate concentration (41 mg/dm³ on average) is also well below the permissible value determined in the Journal of Laws (Ordinance ME 2014). Therefore, they should be considered harmless to plants introduced on substrates made of the tested waste. A low concentration of sulphates is also beneficial in terms of the suitability of the tested waste for the production of concrete or cement.

Among the elements tested in the water extract, only baron (average concentration of 11.3 mg/dm³) exceeds the permissible value given in the Journal of Laws Regulation (Ordinance ME 2014) several times. This is connected with naturally increased contents of this element in carboniferous rocks in the area of USCB.

The values of element concentrations in the eluates are definitely lower than the values of concentrations in the pore water presented in the work (Twardowska et al. 2004). It follows that as a result of many years of depositing on the dumping ground, the potential of waste related to metal leaching has been significantly reduced. On the other hand, slightly higher concentrations of TDS and SO_4^{2-} were observed in water extracts. In pore waters, the TDS content was 3.004–14.603 mg/dm³, whereas the concentration amounted to SO_4^{2-} 1.762–8.187 mg/dm³.

Table 2. Properties and chemical composition of water extract from mining waste

Tabela 2. Właściwości i skład wyciągu wodnego z odpadów

Parameter	Unit	Value in the leachate (L/S) = 10, dm ³ /kg				Highest permissible limit acc. Ordinance ME 2014
		Sample I	Sample II	Sample III	Average	
Temperature	°C	19.5	19.8	19.8	19.7	–
pH	–	6.78	6.67	6.67	6.71	6.5–9
Electrolytic conductivity	µS/cm	184.9	172.3	180.7	179.3	–
Total dissolved solids TDS	mg/dm ³	93	86	90	89.7	–
Salinity	g/kg	BDL*	BDL*	BDL*	BDL*	–
Redox potential ORP	mV	110	155	166	144	–
Carbonate hardness	mmol/dm ³	0.50	0.32	0.50	0.44	–
Total hardness	mmol/dm ³	0.66	0.57	0.59	0.61	–
Calcium hardness	mmol/dm ³	0.38	0.36	0.38	0.37	–
Magnesium hardness	mmol/dm ³	0.28	0.21	0.21	0.24	–
O ₂	mg/dm ³	8.8	8.7	8.7	8.7	–
Cl ⁻	mg/dm ³	5.55	<5	<5	<5.55	1 000
SO ₄ ²⁻	mg/dm ³	40	39	43	41	500
Ca	mg/dm ³	15.23	14.43	15.23	14.96	–
Mg	mg/dm ³	8.76	6.81	6.86	7.48	–
As	mg/dm ³	0.012	0.012	0.014	0.013	0.1
Ba	mg/dm ³	11.0	8.0	15.0	11.3	2
Cd	mg/dm ³	<0.001	<0.001	<0.001	<0.001	0.4
Co	mg/dm ³	<0.01	<0.01	<0.01	<0.01	1
Cr	mg/dm ³	0.05	0.01	0.03	0.03	0.1
Cr(VI)	mg/dm ³	0.011	0.009	0.008	0.009	0.1
Cu	mg/dm ³	0.03	0.01	0.04	0.03	0.5
Fe	mg/dm ³	0.04	0.03	0.01	0.03	10
Mn	mg/dm ³	0.016	0.009	0.017	0.01	–
Mo	mg/dm ³	0.016	0.020	0.016	0.017	1
Ni	mg/dm ³	0.014	0.018	0.015	0.02	0.5
Pb	mg/dm ³	<0.005	<0.005	<0.005	<0.005	0.5
Zn	mg/dm ³	0.51	0.07	0.99	0.52	2

* BDL – below the detection limit.

3.3. Properties and composition of groundwater in the dumping ground area

The results of underground water tests collected from two piezometers: W1 and W2 (location in Fig. 3) are presented in Table 3. The foundation ordinates of both piezometers were: at 270.10 m and 271.35 m above sea level, the water table stabilized in piezometers near the thrill of the dumping ground at the level of the native land, respectively at depths of 17.9 m below ground level and 16.6 m below ground level. The difference between the water tables in piezometers W1 and W2 is 2.55 m.

Table 3. Properties and composition of groundwater

Tabela 3. Właściwości i skład wód gruntowych

Parameter/Component	Unit	Values for piezometer		Highest permissible limit acc. Ordinance ME 2014
		W1	W2	
Temperature	°C	22.0	21.6	–
pH	–	8.76	7.90	6.5–9
Electrolytic conductivity	mS/cm	1.798	1.985	–
Total dissolved solids (TDS)	mg/dm ³	998	1114	–
Chemical oxygen demand (COD)	mg O ₂ /dm ³	<10	<10	125
Volatile phenols (phenol index)	mg/dm ³	<0.05	<0.05	0.1
Ammonium nitrogen	mgNH ₄ ⁺ /dm ³	0.17	0.21	10
Nitrate nitrogen	mgNO ₃ ⁻ /dm ³	<0.1	<0.1	30
Nitrite nitrogen	mgNO ₂ ⁻ /dm ³	0.038	<0.002	1
Total hardness	mmol/dm ³	7.20	10.20	–
Carbonate hardness	mmol/dm ³	3.07	3.64	–
Non-carbonate hardness	mmol/dm ³	4.14	6.56	–
Calcium hardness	mmol/dm ³	3.80	8.18	–
Magnesium hardness	mmol/dm ³	3.41	2.01	–
Free cyanide	mgCN ⁻ /dm ³	<0.002	<0.002	0.1
Cl ⁻	mgCl ⁻ /dm ³	71.1	319.5	1 000
SO ₄ ²⁻	mgSO ₄ /dm ³	906	1024	500
S ²⁻	mgS ²⁻ /dm ³	<0.005	<0.005	0.2
Ca	mg/dm ³	145.8	202.1	–
Mg	mg/dm ³	50.4	92.5	–

Table 3. cont.

Tabela 3. cd.

Parameter/Component	Unit	Values for piezometer		Highest permissible limit acc. Ordinance ME 2014
		W1	W2	
Al	mg/dm ³	0.902	1.7	3
As	mg/dm ³	0.014	0.019	0.1
B	mg/dm ³	1.21	2.34	1
Ba	mg/dm ³	0.144	0.155	2
Cd	mg/dm ³	<0.001	<0.001	0.4
Co	mg/dm ³	<0.004	<0.004	1
Cr	mg/dm ³	<0.003	0.043	0.1
Cr(VI)	mg/dm ³	0.014	<0.01	0.1
Cu	mg/dm ³	0.015	0.016	0.5
Fe(II)	mg/dm ³	<0.02	0.40	–
Fe _{total}	mg/dm ³	0.04	5.66	10
Hg	mg/dm ³	<0.017	0.002	0.06
Mn	mg/dm ³	<0.001	0.022	–
Mo	mg/dm ³	0.009	0.012	1
Ni	mg/dm ³	<0.007	0.011	0.5
Pb	mg/dm ³	<0.005	<0.005	0.5
Sb	mg/dm ³	0.009	0.013	0.3
Se	mg/dm ³	0.019	0.021	1
Sn	mg/dm ³	<0.005	<0.005	2
Tl	mg/dm ³	<0.005	<0.005	1
V	mg/dm ³	0.010	0.011	2
Zn	mg/dm ³	0.505	0.802	2

The groundwater pH in piezometers W1 and W2 amounted to 8.76 and 7.90 respectively, while the electrical conductivity, as well as chloride and sulphate concentrations, were 1.985 mS/cm, 319.5 mg/dm³, 1024 mg/dm³ and 1.798 mS/cm, 71.1 mg/dm³, 906 mg/dm³ respectively. According to the Journal of Laws Regulation (Ordinance ME 2014), the values of sulphate concentrations were exceeded. Underground waters are characterized by high carbonate hardness and very high general hardness as well as high concentrations of calcium and magnesium. The reason for higher pH values is probably the

presence of calcium carbonates causing carbonate hardness for W1 and W2 piezometers at the levels of 3.07 mmol/dm^3 and 3.64 mmol/dm^3 respectively. This is characteristic of fly ash leachates.

Considering the examined groundwater, the content of sulphates was many times higher than the values observed in water extracts. This probably results from the presence of a reservoir of fly ash within the Przechlebie dumping ground.

Low values of ammonium, nitrate and nitrite nitrogen, as well as chemical oxygen demand (COD) and volatile phenols, indicate the lack of organic waste in the dumping ground (e.g. coking industry waste, municipal waste). The sulphide content, determined to be lower than the detection of the measuring device, indicates the lack of hydrogen sulphides (H_2S , HS^-) and sulphides of some metals in the water. These compounds are mainly formed as a result of the anaerobic decomposition of organic compounds. This fact confirms that this type of substances is missing in the Przechlebie dumping ground.

Among the analyzed metals, only boron exceeds the permissible values given in the Journal of Laws Regulation (Ordinance ME 2014). As a result of the analyses, small concentrations of arsenic, barium, zinc, aluminum, copper, molybdenum, selenium and antimony were also identified. These substances could leach from the fly ash present in the piezometers area much easier in the case of a decrease in the pH of waters in contact with waste. This could take place, for instance, as a result of locating bituminous coal mining waste, containing larger quantities of sulphide minerals than stated, on the surface of a fly ash dump.

2.4. Thermal state test results

Systematically conducted measurements of waste material temperature and gas concentrations allowed to assess the thermal state of the dumping ground on an ongoing basis. The research was carried out in the vicinity of the existing mining excavations as places most at risk of self-heating and spontaneous ignition.

One of the thermovision tests were carried out in the winter (December 2, 2015). During the test, the following meteorological conditions were present: air temperature (3°C), relative humidity – from 75 to 65%, no clouds, no insolation (sunrise – the examined slopes still remained in the shadow zone), weak wind, no precipitation, dry surface of the dumping ground, CO_2 concentration background – 0.05% vol.

As part of the tests, the temperature distribution over the entire length of the excavation slopes and the top in their vicinity was observed. An infrared image was observed with the location of the maximum temperature values of the tested surfaces. The maximum and average values of the surface temperature of the slopes and the top of the dumping ground in the area of the carried out excavation, recorded during thermographic studies, fluctuated in the following ranges:

- ◆ central excavation I – max. from 0.64 to 3.73°C ; average from -3.13 to 0.69°C ,
- ◆ central excavation II – max. from 0.71 to 5.77°C ; average from -2.62 to 1.66°C ,

- ◆ western excavation – max. from 7.15 to 8.46°C; average from 0.96 to 2.79°C (measurement at insolation).

Thermovision studies showed that the surface temperature of slopes within individual excavations was characterized by a low variability. Considering the ambient temperature, no significant surface temperature anomalies were found.

The surface temperature values of the dumping ground measured with the use of a pyrometer at selected points P1–P12 (location in Fig. 3) were in the range from 2.1 to 8.2°C. The values of the internal temperature (depth up to 1m) specified in these points were in the range from 8.6 to 14.9°C (Table 4). At the measurement points, no CO carbon monoxide

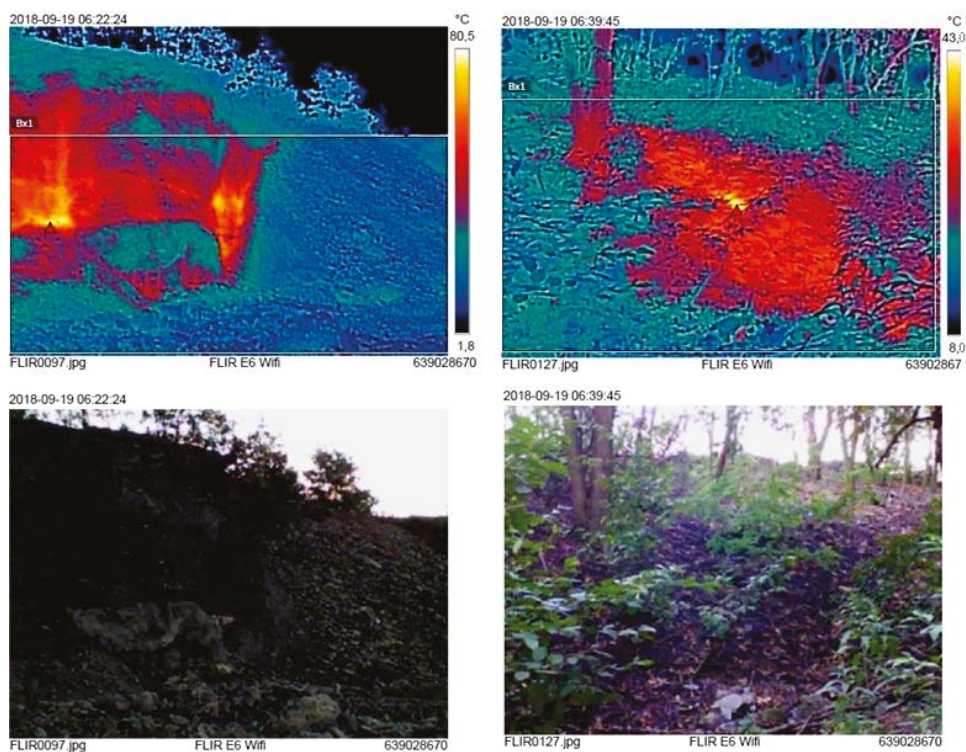
Table 4. Selected results of temperature and gas concentration measurements inside the dumping ground

Tabela 4. Wybrane wyniki pomiarów temperatury i stężeń gazów we wnętrzu zwałowiska

Point	Excavation	Ambient temperature (°C)	Waste temperature (°C)		Gas concentration (% vol.)		
			on the surface	at a depth of 1 m	O ₂	CO	CO ₂
December 2, 2015							
P1	central I	3.0	3.5	8.6	20.6	0.0000	0.130
P2			2.6	10.5	20.6	0.0000	0.075
P3			2.1	10.0	15.2	0.0000	2.400
P4			2.6	10.9	20.6	0.0000	0.213
P5			2.7	11.0	20.4	0.0000	0.430
P6			7.6	12.9	20.6	0.0000	0.063
P7	central II		8.6	14.9	20.7	0.0000	0.161
P8			2.3	9.8	20.7	0.0000	0.068
P9			2.1	9.6	20.8	0.0000	0.066
P10	western		2.2	9.3	20.9	0.0000	0.067
P11			8.2	11.7	20.9	0.0000	0.060
P12			3.0	10.9	20.9	0.0000	0.062
September 19, 2018							
P13	north	13.0	19.5	27.0	12.0	0.0000	10.0
P14			30.1	53.2	6.0	0.2000	14.0
P15			17.4	24.0	19.0	0.0000	2.0
October 4, 2018							
P16	western	12.5	14.4	18.7	16.1	0.0000	2.28
P17			13.6	17.6	19.4	0.0006	0.89
P18			14.1	18.5	19.1	0.0000	1.66

was found, while CO₂ carbon dioxide concentration was between 0.06 to 2.4% vol., which indicates the occurrence of natural oxidation of coal contained in the waste. However, it did not bear a significant thermal effect. Temperature anomalies reached a maximum of 5°C on the surface.

Research conducted in subsequent years (2016–2017) confirmed the stable thermal state of the dumping ground. No thermal anomalies indicating the possibility of spontaneous ignition were noted. However, as part of the research carried out in 2018, places with increased



IR info	Value
Emissivity	0.95
T _{ambient}	13.0 °C
T _{max}	80.6 °C
T _{min}	9.8 °C
T _{avg}	18.8 °C
T _{max} - T _{ambient}	67.6 °C

IR info	Value
Emissivity	0.95
T _{ambient}	13.0 °C
T _{max}	43.1
T _{min}	13.6
T _{avg}	16.0
T _{max} - T _{ambient}	30.1

Fig. 4. Sample photos of the dumping ground surface in the infrared and visible band together with the measurement results (September 19, 2018). Phot. Z. Róžański

Rys. 4. Przykład zdjęć skarp zwałowiska w podczerwieni i zakresie widzialnym wraz z wynikami pomiarów (19 września 2018). Fot. Z. Róžański

temperature and gas concentrations in relation to the environment were located. This was accompanied by a significant loss of oxygen inside the dumping ground. These places were located on a slope and in the vicinity of the existing excavations, mainly in the northern part of the dumping ground. The area was reclaimed into a forest in the past.

The article presents examples of selected zones, the photos of which were also taken in the visible spectrum (Fig. 4). Each thermogram was subject to the analysis, the results of which are shown in Figure 4. On the thermograms, zones showing the temperature distribution of the examined slopes or tops were distinguished. The maximum, minimum and average values within the separated zone were determined. The maximum temperature of the slope surface was 80.6°C at the ambient temperature of 13°C.

Selected results of measurements conducted in 2018 in P13-P18 1-meter holes are presented in Table 4. They indicate significant processes of coal oxidation in some areas of the western part of the tip as well as thermal activity near the northern excavation in which mining was temporarily stopped. At P14, the temperature at a depth of 1.0 m exceeded 50°C with high concentrations of CO and CO₂ and very low O₂ concentrations.

An increase in the fire hazard on the coal waste dumps reclaimed into a forest has been confirmed. The growing root system of trees may loosen the dump and facilitate the access of air to the inside of the dumping ground. This is confirmed by the experiments conducted both by the authors of this study and other researchers engaged in fire issues on the mining waste dumps or in the areas of shallow deposits of hard coal, brown coal and lignite as well as issues related to leaching of pollutants (among others [Twardowska et al. 2004](#); [Stracher et al. eds. 2014](#)). In other parts of the Przechlebie dumping ground where no trees were planted, thermal activity, despite the mining conducted, was not observed.

Conclusions

The presented results of investigations of the chemical composition of waste from bituminous coal mines accumulated in Przechlebie indicate that this composition does not differ from the chemistry of the coal rocks of the Upper Silesian Coal Basin. The main components are SiO₂ = 45.22% and Al₂O₃ = 18.48%. The total content of metal impurities in the tested waste is lower than the permissible values in soils of areas included in groups II–3, III and IV in the Regulation of the Minister of Environment of September 1, 2016 on the method for assessment of land surface contamination ([Ordinance ME 2016](#)). Low concentrations of radioactive radionuclides in this waste do not pose a threat to the natural environment.

The reaction close to inert (average pH = 6.71) and the chemical composition of the water extracts obtained from the tested waste allow to state that it is possible to use mining waste from the Przechlebie dumping ground in the preparation of substrates for technical and even biological reclamation and natural management on the site or outside the dumping ground. However, due to the content of a significant amount of carbonaceous substance, this requires the preservation of fire prevention measures.

A significant content of sulphates in groundwater is probably caused by the presence of fly ash on the Przechlebie dump. It is necessary to conduct further analyses related to the assessment of the impact of power plant waste on the quality of groundwater in the vicinity of the dump.

The current carbon content disqualifies the tested waste for some applications such as road aggregate. According to the PN-S-02205:1998 standard, they can only be used on the lower layers of embankments below the freezing zone (provided that the intergranular space is filled with fine-grained material). It will, therefore, be beneficial to separate coal from the tested waste. This will completely eliminate the risk of self-ignition and increase the range of waste utilization possibilities while obtaining economic benefits. After the separation of coal, it will be possible to consider a wider application in road engineering. A number of studies indicate that due to geotechnical properties, coal waste from USCIB can usually be a substitute for natural sands and can be successfully used in civil engineering (Skarżyńska 1995). However, it will be necessary to carry out additional waste tests for properties important for the stability and durability of buildings erected with their participation.

Until 2018, no concerning thermal phenomena were observed on the Przechlebie dumping ground. No temperature anomalies combined with the low content of carbon oxidation products (CO, CO₂) indicated a stable thermal state. Thermal phenomena observed in September 2018 prove, however, that the carbon content in the waste on the Przechlebie dumping ground is sufficient for self-heating. Fire hazard can additionally be compounded by improper mining and the growing root system of trees present mainly in the northern part. In the case of an uncontrolled endogenic fire of the dumping ground unfavorable effects such as gas and dust emission into the air, fragrance discomfort and a threat to the safety due to high temperatures will appear.

Due to the possibility of an intensification of the oxidation processes of coal and pyrite contained in the waste because of opening the dumping ground mass, the thermal state of the object should be checked periodically. The detection of thermal activity at an early stage of its development will avoid costly and labor-intensive activities related to the elimination of a fire.

In conclusion, it can be stated that rock waste deposited on the Przechlebie dumping ground affects the aquatic environment to a small extent. The risk of negative impacts on the natural environment, which at present mainly result from fire hazard, can be reduced by introducing coal recovery. This will allow for the multidirectional use of the tested waste. However, the fact that an increase in the impact of the material accumulated on the dumping ground, i.e. increase in pollution, a temporary increase in fire hazard due to the opening of the dumping ground body and more intensive leaching of contamination by infiltrating water than at present during the re-mining of the dumping ground, must be taken into account. Selecting the right technology of operation and monitoring the thermal state will allow these threats to be controlled. On the other hand, re-mining will allow for the reconstruction of the dumping ground, planning and shaping it for the target development in accordance with the current needs of the municipality where the analyzed object is located.

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MANAGEMENT OF MINING WASTE AND THE AREAS OF ITS STORAGE – ENVIRONMENTAL ASPECTS

Keywords

anthropogenic deposit, recovery of raw materials, fire hazard, coal waste dumping ground

Abstract

There are approx. 250 coal waste dumping grounds in Poland, yet there are countries in which this number is even higher. One of the largest sites for depositing mining and power plant waste in the Upper Silesian Coal Basin is the Przechlebie dumping ground. In the article, it is considered as a secondary deposit of raw materials. An assessment of mining waste collected on the Przechlebie dumping ground was carried out in terms of its impact on the environment and the possibility of its use. Mining waste samples were tested to determine their chemical composition. Physicochemical properties and chemical compositions of water extracts obtained from the investigated waste and groundwater in the vicinity of the dumping ground were analyzed. Due to the fire hazard resulting from the natural oxidation process of chiefly carbonaceous matter and pyrite, the thermal condition of the dumping ground was assessed. The results of the obtained tests confirmed the slight impact of mining waste deposited on the Przechlebie dumping ground on the environment. The chemical composition, low radioactive activity of waste itself and the results of water extract tests referred to the permissible values according to the Polish Journal of Laws allow for multi-directional waste management. Due to the significant carbon content, the risk of self-ignition poses a significant threat on the dumping ground. Re-mining of the dumping ground and the recovery of raw materials, including coal contained in waste, will eliminate the risk of fire, allowing for a wider use of waste and, at the same time, will allow for other benefits, e.g. in the form of financial resources and the possibility of managing the dumping ground area.

**ZAGOSPODAROWANIE ODPADÓW GÓRNICZYCH
I TERENÓW ICH SKŁADOWANIA – ASPEKTY ŚRODOWISKOWE**

Słowa kluczowe

zagrożenie pożarowe, zwałowisko odpadów powęglowych,
złóże antropogeniczne, odzysk surowców mineralnych

Streszczenie

Kopalniom w zagłębiach węglowych i na świecie towarzyszy duża liczba zwałowisk odpadów powęglowych. W Polsce znajduje się około 250 tego typu obiektów, ale są kraje, w których ta liczba jest jeszcze większa. W artykule jedno z największych miejsc zdeponowania odpadów wydobywczych i energetycznych w GZW, jakim jest zwałowisko Przechlebie, rozpatruje się jako wtórne złóże surowców. Dokonano oceny odpadów wydobywczych zgromadzonych na zwałowisku Przechlebie

pod kątem oddziaływania na środowisko i możliwości ich wykorzystania. Próbki odpadów górniczych poddano badaniom w celu określenia ich składu chemicznego. Wykonano badania własności fizykochemicznych i składu chemicznego wyciągów wodnych uzyskanych z badanych odpadów oraz wód podziemnych znajdujących się w sąsiedztwie zwałowiska. Ze względu na zagrożenie pożarowe wynikające z naturalnego procesu utleniania głównie substancji węglowej i pirytu dokonano oceny stanu termicznego zwałowiska. Wyniki uzyskanych badań potwierdziły nieznaczny wpływ odpadów górniczych zdeponowanych na zwałowisku Przechlebie na środowisko. Skład chemiczny, niska aktywność promieniotwórcza samych odpadów oraz wyniki badań wyciągów wodnych pozwalają na wielokierunkowe zagospodarowanie odpadów. Ze względu na znaczącą zawartość substancji węglowej (do 13%) istotnym zagrożeniem występującym na zwałowisku jest ryzyko samozapłonu. Reeksploatacja zwałowiska i odzysk surowców, w tym węgla zawartego w odpadach, zredukuje zagrożenie pożarowe, pozwoli na szersze wykorzystanie odpadów, a jednocześnie pozwoli na uzyskanie innych korzyści np. w postaci środków finansowych i możliwości zagospodarowania terenu zwałowiska.

