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PROGNOSIS OF ENVIRONMENTAL IMPACT OF TRACE ELEMENTS FROM BROWN COAL-FIRED POWER PLANT "BEŁCHATÓW"

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Abstract: A forecast of the negative impact exerted on the environment by selected trace elements in "Bełchatów" Power Plant has been prepared on the basis of the results of investigations into these elements' distribution carried out as part of earlier research on coal from "Bełchatów" Field and the data on updated analyses of the content of these elements in 55 brown coal samples from test boreholes.

Work in "Bełchatów" Power Plant, which is supplied with coal from "Szczerców" Field, will be accompanied by trace elements transfer. On the basis of the conducted investigations it has been found that the biosphere is most threatened by mercury emissions. As shown by the presented results of analyses and calculations, the emissions of mercury in "Bełchatów" Power Plant are low. Mercury is accumulated chiefly in gypsum produced in the FGD plant. The content of mercury in slag and ash is low.

INTRODUCTION

There is a growing interest in hazardous substances emitted to the environment from power and industrial plants. Although introduced in relatively small amounts, these substances create a threat due to their dangerous properties. Their harmful effect is reflected in the destruction of immunological system, various toxic effects and a negative impact on the development of young organisms. The substances are known for their carcinogenic, mutagenic, teratogenic and genotoxic properties or there is a justified fear that they may have such properties. They penetrate into the human organism mainly via respiratory tracks, but also through the digestive track, participating in particular links of the food chain. Among numerous dangerous substances which contaminate the environment one should mention metals: beryllium, chromium, cadmium, cobalt, nickel, lead and mercury, as well as their compounds and semi-metals such as arsenic, boron and selenium as well as their compounds.

In Poland an inventory of emissions of this group of elements (under the name of heavy metals) from particularly arduous plants is taken, and the data is published in statistical yearbooks [5]. In 2011 the emissions of heavy metals from these plants (in kg/a) were determined as follows: arsenic – 1857, chromium – 5990, tin – 307, zinc – 81971, cadmium – 959, cobalt – 84, manganese – 7314, molybdenum – 8, nickel – 6218, lead – 40517 and mercury – 1220.

Being trace components of brown and hard coal, after the coal is burned, they escape with flue gas into the air and move towards other components of the environment with by-products captured in dust collectors and flue gas desulphurisation (FGD) plants. In Poland this problem is particularly important given the dominance of hard and brown coal in the domestic power industry and heat engineering. Therefore, selected power plants launched investigations into the distribution of trace elements in coal and slag as well as dedusting and flue gas desulphurization by-products: ash fly captured in dust collectors, gypsum produced in the desulphurization process and semi-dry scrubbing FGD products [9]. "Bełchatów" was one of the investigated power plants. The studies revealed that as a result of distribution in the coal combustion and flue gas desulphurization process, a dominant part of the stream of particular trace elements moves with waste and solid products, and emissions into the air are low [9].

"Bełchatów" Power Plant, which is the biggest in Poland and burns more than 30 Tg of brown coal annually, in the nearest 30 years will be supplied with coal from new "Szczerców" Field. This is taking place gradually due to exhaustion of previously exploited "Bełchatów" Field. Therefore, the power plant will influence the environment for the nearest several dozen years. This impact remains huge despite the fact that modern protective equipment is used.

The EEA technical report No. 15/2011 [3] published in 2011 presents an estimate in EUR of damage done to the environment due to emissions of air-contaminating substances as well as a ranking of the examined facilities. It was found that 191, i.e. ca 2% from among approximately 10,000 evaluated industrial plants cause as much as 50% of the estimated damage, which in the year 2009 ranged from 102 to 169 billion euros.

The list of the first 20 plants includes three Polish power plants: "Bełchatów" (1), "Turów" (10) and "Kozienice" (13). Bearing in mind the present and future significance of "Bełchatów" Power Plant, the change of coal burned and the authors' own results of previous studies [9], a decision was taken to start works aimed at evaluating the future emissions of selected trace elements into the air as well as their transfer to dedusting and flue gas desulphurization products, which may create a threat to other segments of the environment.

RESEARCH PART: BROWN COAL IN POLISH POWER INDUSTRY. "BEŁCHATÓW" POWER PLANT

Characteristics and resources of brown coal in Poland

Poland belongs to European countries having the largest resources of brown coal. In Poland there are more than 150 coal beds and coal-bearing areas. Over 24.5 Pg of resources have been documented, including 14 Pg in guaranteed deposits, over 60 Pg in estimated deposits and more than 140 Pg in potential deposits [8]. The economic usefulness is determined by the overburden thickness to coal deposit ratio.

In recent years the role of brown coal as a fuel has increased. Other energy sources in the previously discovered deposits are depleting, and new deposits are characterized by worse mining-geological conditions. Brown coal occurs in abundance and its deposits are relatively easily accessible.

The most important is power coal characterised by ash content below 40%, expressed as dry coal A^{db}, and calorific value Q_i^{ar} above 6.7 MJ/kg, expressed as coal with total moisture content TM_T^{ar} reaching 50%. Power coal, containing more than 0.5% of alkalies ($Na_2O + K_2O$) expressed as dry coal, is included in the so-called saline coal.

In Poland, brown coal deposits are exploited solely by the open pit mining method, the oldest and most profitable system of obtaining resources from natural deposits [10]. Currently, electrical energy produced from brown coal is the cheapest and brown coal has been playing the role of a strategic fuel for many years.

"Bełchatów" Brown Coal Mine

"Bełchatów" brown coal deposit (Fig. 1) lies in the rift valley of Kleszczów, having the length of ca 40 km, the width ranging from 1.5 to 3.5 km and the depth of 150–350 m, within Szczecin-Łódź-Miechów synclinorium [6].

Within "Bełchatów" deposit, which is the subject of this study, three brown coal fields have been separated [1]:

„Bełchatów" Field – situated in the middle part of Kleszczów rift valley; its western part is Dębina salt dome. At present, „Bełchatów" field is being exploited – more than half of its resources have been already mined. The current state of the deposit reaches more than 400 Tg, and the end of exploitation is projected for the year 2019 [6].

„Szczerców" Field – is a western extension of „Bełchatów" Field, from which it is separated with a salt dome. Its western boundary is marked by natural dwindling of the coal bed. We can already talk about "Szczerców" Strip Mine, as since the year 2002 works making the bed available have been carried out, and the coal overburden is stored at an external dumping ground. Coal mining in this field, which began in 2007, will be continued until 2038.

There are plans to reclaim the post-mining heading in more distant future by building a water reservoir [12].

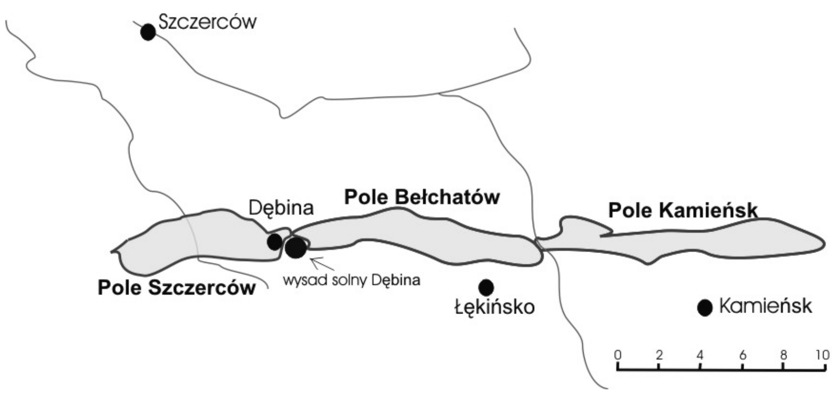

Fig. 1. Brown coal deposit – Bełchatów [6]

The geological structure of „Szczerców" Field is similar to that of "Bełchatów" Field, as it is a part of the same deposit.

Brown coal deposit in „Szczerców" Field:

- overburden thickness: 129.1 m
- seam thickness: 55.3 m
- floor depth: 179.5 m
- overburden to coal deposit ratio: 2.3:1
- geological resources: 891 Tg
- balance resources: 877 Tg
  - off-balance resources: 14 Tg
  - industrial resources: 620 Tg

Average parameters of coal from the open pit in „Szczerców" Field:

- calorific value: Q^{ar} – 7.42 MJ/kg
- moisture content: TM_T^{ar} – 51.16%
- ash: A^{ar} – 11.56%
- total sulphur: S_T^{ar} – 1.05%

[6, 12]

„Kamieńsk" Field is an eastern extension of „Bełchatów" Field. Currently there are no plans for its economic use due to the unfavourable overburden to coal ratio.

From „Bełchatów" and „Szczerców" Fields which have been made available a total of 39 Tg of brown coal can be mined annually until the year 2038. Resources in these fields reach 898 Tg, while in "Kamieńsk" Field – 402 Tg. The mined coal is delivered by belt conveyers to "Bełchatów" Power Plant where it is burned [4]. The participation of "Bełchatów" Field is decreasing, whereas that of "Szczerców" Field keeps growing, which has been presented in Table 1.

„Bełchatów" Power Plant

„Bełchatów" Power Plant is the biggest brown coal-fired powerhouse in Poland and Europe. The power of its power units reaches 4440 MW, which accounts for ca 15% of power installed in Polish professional power industry. The annual production of energy reaches an average of 27–28 TWh and accounts for ca 20% of the domestic production [11]. As a result of modernisation and the use of effective gas treatment technologies and low emission technologies, the emission of air-polluting substances has been significantly reduced in "Bełchatów" Power Plant.

Table 1. Output of brown coal for the needs of "Bełchatów" in Tg [7]

Years	„Bełchatów" Field	„Szczerców" Field
2010	25.1	7.0
2013	22.0	15.0
2017	12.1	23.2
2020	5.0	33.0
2025	–	36.5
2030	–	35.0

Dedusting and flue gas desulphurisation versus trace elements

Thanks to the advances in flue gas dedusting, the emissions of dust from coal-fired boiler furnaces fired with hard or brown coal have been reduced a few times. Additionally, the wide use of flue gas desulphurization units improved the situation. A flue gas desulphurization (FGD) plant, usually based on the wet limestone method, located behind the electrofilter also plays the role of second-stage dust containment with total filtration efficiency reaching 80%. Fly ash and slag captured in the boiler and dedusting equipment is utilized or stored at dumping grounds, and only 0.1% of the mineral substance contained in coal penetrates into the air.

Trace elements contained in coal escape into the air with flue gas from power sources or move towards other elements of the environment through by-products captured in dust containment equipment and flue gas desulphurisation plants. The existing knowledge of the distribution of frequently dangerous trace elements in these products is insufficient.

After analysing the research material (Tab. 2) from previous investigations [9] into coal from „Bełchatów" Field and combustion and gas desulphurisation products from „Bełchatów" Power Plant, the authors evaluated the distribution of selected trace elements: Cr, Cu, Hg, Mn, Ni, Pb and Zn, which penetrate into slag, ash captured in an electrofilter and gypsum, which is a flue gas desulphurization product (Tab. 3).

The effect of brown coal quality on the consumption of fuel and the amount of combustion and flue gas desulphurisation products

The use of coal from „Szczerców" Field, characterised by a higher content of mineral substance, and in consequence a lower calorific value and a higher content of sulphur

Table 2. Concentrations of selected trace elements in coal, slag, ash and flue gas desulphurisation products [9]

Type of sample	Cr, mg/kg	Cu, mg/kg	Hg, µg/kg	Mn, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg
brown coal	13.2	9.7	516	38.8	6.4	13.7	8.3
slag	91.5	46.6	32	115.1	30.1	20.9	65.9
ash	105.8	56.1	125	179.2	41.4	22.5	70.1
gypsum	3.1	3.0	2411	5.5	3.5	4.1	2.2
limestone	0.1	4.7	7	0.1	8.7	9.7	0.2

Table 3. Distribution of selected trace elements in slag, ash and gypsum from the FGD unit in "Bełchatów" Power Plant (K5–K8 boilers) [9]

Waste/product	Distribution of trace elements, %						
	Cr	**Cu**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
slag	4.9	4.6	0.1	3.7	3.9	4.5	5.3
ash	92.0	90.0	4.4	93.1	87.7	79.2	91.5
gypsum	3.0	5.4	95.5	3.2	8.3	16.2	3.2

compounds will result in an increased consumption of coal and a bigger amount of slag, ash and gypsum produced in the flue gas desulphurisation process. This is presented in a table with data computed for the basic type of boiler BB-1150 (Tab. 4).

RESEARCH GOAL

The investigations are aimed at evaluating the size of harmful streams of selected trace elements from brown coal, penetrating into the air as a result of work in „Bełchatów" Power Plant in the years 2013–2030, which causes emission of dust and production of slag, ash and gypsum in the process of flue gas desulphurization. The results will be useful for an inventory of trace elements' emissions in the national, regional and global scale. The evaluation covers the period when the power plant will burn brown coal some properties of which are different compared to coal burned in the first period of the plant's activity.

CONCEPT AND SCOPE OF RESEARCH

In the years 2011–2030 ca 550 Tg of brown coal from „Szczerców" Field is planned to be burned in the power blocks of „Bełchatów" Power Plant. In the light of the conducted investigations [9], trace elements: Cr, Cu, Hg, Mn, Ni, Pb and Zn contained in coal transfer into slag, ash captured by an electrofilter and gypsum, which is a flue gas desulphurization product. Penetration into the air with the desulphurised flue gas, which is currently marginal, may also decrease after using the CCS technology. Given the fact that "Szczerów" and "Bełchatów" Fields are parts of the same coal bed, it may be assumed that the properties of chemical compounds in which trace elements in coal from both Fields occur are similar.

Such an assumption allows to evaluate the future impact of selected trace elements on the environment on the basis of the results of investigations into the distribution of these elements in previous studies [9] and the data obtained in current analyses of these elements' content in brown coal samples from 3 test boreholes. In the prognostic calculations as a content of mercury was assumed the arithmetic mean of the analysis of mercury in the three samples, which were created after averaging samples from all layer depth ranges taken from the three above-mentioned holes.

For the remaining elements there was established an upper and lower level content of the elements in coal, found in 80% of the tested samples. Using the lower and upper

Table 4. Consumption of coal, solid combustion and flue gas desulphurisation products in BB–1150 boiler in "Bełchatów" Power Plant, Mg/h

BB–1150	Coal	Slag*	Ash*	Dust emitted to the air	Gypsum from FGD
Coal from „Szczerców" Field	502	3.37	48.86	$48.86 \cdot 10^{-3}$	26.92
Coal from „Bełchatów" Field	423	2.16	31.34	$31.34 \cdot 10^{-3}$	16.98

* assuming that the fraction of slag and ash is the same

levels of the element in the calculation, the ranges, which include forecasted emissions and transfer were determined.

RESEARCH-ANALYTICAL PART

Research material

Table 5 presents a list of coal samples taken from "Bełchatów" Coal Brown Mine ("Szczerców" Field).

Methodology

Coal analysis

Coal from the western part of „Szczerców" Field is highly sulfated (S_T^{db} = 2.61%). The average ash content (A^{db}) is high, reaching 29.3%. The calorific value Q_i^{ar} = 7.42 MJ/kg is low compared to „Bełchatów" Field and the eastern area of „Szczerców" Field, where it is 8.8 MJ/kg.

Manner of sample taking and sample preparation for tests and analyses

The research material was taken, separated or processed in a proper way, by using appropriate methods and procedures so as to prepare samples for further tests and analyses [13]. As required, by averaging and grinding the original samples of brown coal, 52 analytical samples from particular depth ranges of the layer taken from the holes were prepared for analysis. Moreover, 3 averaged samples of coal from all depth ranges of the layer taken from the holes were prepared.

Table 5. A list of coal samples from „Bełchatów" Brown Coal Mine ("Szczerców" Field)

Type of hole	Sample No.	Number of samples	Layer depth range [m]
observation	PS 173/1 ÷ PS 173/11	11	113.7 – 140.0
observation	PS 52–2/1 ÷ PS 52–2/10	10	23.5 – 55.0
pilot	K46P/1 ÷ K46P/31	31	140.8 – 237.2

Table 6. Selected data of brown coal characteristics

Field	Total sulphur content	Ash content	Total moisture content
	S_T^{ar}	A^{ar}	TM_T^{ar}
	% mass		
Szczerców	1.05*	11.56	51
Szczerców – western part	1.27*	14.3	51
Bełchatów	0.50–0.83**	8.80	53

* [6], ** [2]

Analytical methods

Determination of mercury in coal

Mercury in the tested samples was determined with a MA-2 mercury analyser produced by Nippon Instruments Corporation [9]. Table 8 presents average values from three analyses.

Determination of As, Be, Cd, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in coal

Solid samples were dissolved under high pressure (max. pressure 60 bar) and at high temperature (max. temperature 260°C) in a Multiwave 3000 microwave mineralization unit produced by Anton Paar, in an appropriate mixture of acids which allowed to obtain a clear solution. A mixture of 65% nitric acid – 6 ml, 70% perchloric acid (VII) – 1 ml and 40% hydrofluoric acid – 1 ml was used. After dissolving, the whole amount of the solution was poured into a 50 ml measuring flask and filled up with deionised water to nominal volume.

In so obtained solutions the concentrations of selected trace elements were determined using the ICP MS method, by means of an Elan DRC-e 6100 spectrometer produced by Perkin-Elmer. The reagents for trace analysis produced by Sigma-Aldrich were used to prepare the samples and reference samples.

Each sample was mineralised and analysed three times.

The extended uncertainty of the determined analytes using ICP-MS technique, composed of the uncertainty of the reference sample, the uncertainty of weighing, the uncertainty of calibration, the uncertainty of intermediate precision and the limits of detectability and determinability, (Table 7) was established.

Analysis results

Table 8 presents the results of determinations of mercury concentrations in averaged coal samples from the examined observation and pilot holes from „Szczerców" Field, as well as upper and lower levels of the analyzed elements in coal. The results of the analyzes were developed as described in "Concept and scope of research" above.

Table 7. The extended uncertainty as well as the limits of detectability and determinability of analytes

Isotope	Uncertainty [%]	Detectability limit (LOD) [μg/l]	Determinability limit (LOQ) [g/l]
^{75}As	14.5	0.20	0.60
^{9}Be	15.5	0.09	0.27
^{114}Cd	5.1	0.03	0.09
^{59}Co	4.1	0.01	0.03
^{55}Mn	4.5	0.03	0.09
^{60}Ni	10.5	0.05	0.15
^{66}Zn	15.4	0.18	0.54
^{65}Cu	5.1	0.06	0.18
^{51}V	5.7	0.03	0.09
^{208}Pb	6.0	0.02	0.06
^{53}Cr	11.5	0.04	0.16

Table 8. The upper and lower levels of the examined elements' concentration in coal from „Szczerców" Field

	Component [mg/kg]											
Level	As*	Be*	Cd*	Co*	Cr	Cu	Hg	Mn	Ni	Pb	V*	Zn
Lower	4.74	0.59	0.30	4.56	25.79	6.57	0.39	64.60	11.73	4.18	31.27	52.05
Upper	12.40	1.90	1.60	14.85	79.47	23.48		143.08	48.84	20.02	83.79	182.62

* elements were determined in coal samples, but their emissions and transfer into the environment segments were not analysed

RESEARCH-PROGNOSTIC PART

Methodology of forecasting the emissions and transfer

On the basis of data from Table 1, calculations of emissions and transfer for five timespans, namely for the years 2013, 2017, 2020, 2025 and 2030, were made. Coal from "Bełchatów" and "Szczerców" Fields is projected to be burned until 2020, with an increasing stream from the latter. After 2020 "Bełchatów" Power Plant will burn coal from "Szczerców" Field. Calculations were based on the assumption that the whole coal mined at "Bełchatów" Coal Mine will be burned in "Bełchatów" Power Plant. The results have been given in Table 10.

Calculations of combustion and flue gas desulphurisation products mass streams as well as emissions and transfer of trace elements into the environment segments

Calculations were based on the projected masses of fuels and products in figures rounded up to 1 Mg/a. Basing on the data on the content of ash A^{ar}, the amount of solid combustion products and next the amounts of slag and fly ash were calculated by using mass fractions of slag (0.058) and fly ash (0.942). As a result of containment in an electrofilter, 99.6% of fly ash is arrested in the form of ash. 0.4% of fly ash penetrates through the electrofilter and with the dedusted flue gas moves to an FGD absorber, in which 75% of residual fly ash is captured. Hence, the total flue gas dedusting efficiency reaches 0.999%.

The amount of produced gypsum was calculated on the basis of the amount of burned coal, the content of total sulphur S_T^{ar} = 1.05% (wt%), desulphurisation efficiency η_{FGD} (0.95) and F_G coefficient (5.375) – yield of gypsum $CaSO_4 \cdot 2H_2O$ from a unit of SO_2 mass in the SO_2 and $CaCO_3$ reaction in the flue gas desulphurization process by the wet limestone method.

Table 9 presents the calculated combustion and flue gas desulphurisation products' mass streams.

The calculations of the emissions and transfer of element *i* into the air, gypsum, ash and slag were made on the basis of data on the amount of combustion and flue gas desulphurization products obtained in the combustion of 1 Tg/a of coal from "Szczerców" Field, the content of element *i* in the burned coal from "Szczerców" Field (Table 8), the fractions* of element *i* in slag, ash and gypsum from the FGD plant in the process of

* As fractions of element the values of distribution were assumed.

Table 9. Combustion and flue gas desulphurisation products' mass streams obtained in the combustion of 1 Tg/a of brown coal from „Szczerców" Field in Mg/a

Product	**„Szczerców" Field**
ash	108459
emitted dust	109
slag	6705
flue gas desulphurisation gypsum	53616

Table 10. Emissions and transfer of trace elements in the years 2013–2030 as a result of burning coal from „Szczerców" Field

projected coal mass, [Tg]	**projected ash mass, [Mg]**	**projected mass of emitted dust, [Mg]**	**projected gypsum mass, [Mg]**	**projected slag mass, [Mg]**			**Cr [Mg]**	**Cu [Mg]**	**Hg [kg]**	**Mn [Mg]**	**Ni [Mg]**	**Pb [Mg]**	**Zn [Mg]**
547.9	59424916	59721	29376206	3673670	**ash**	**min.**	1410	333	958	3391	580	187	2686
						max.	4345	1192		7512	2415	894	9423
					emitted dust	**min.**	1	below 1	1	3	1	below 1	3
						max.	4	1		8	2	1	9
					gypsum	**min.**	23	10	10831	61	29	20	49
						max.	70	37		135	119	95	172
					slag	**min.**	5	1	1	9	2	1	10
						max.	14	4		19	7	3	36

burning coal from "Szczerców" Field (Table 3) and on the amount of brown coal from "Szczerców" Field burned in particular years (according to Table 1).

Forecast emissions and transfer of selected trace elements as a result of simultaneous burning of coal from „Szczerców" and „Bełchatów" Fields in the years 2013−2030

On the basis of the presented assumptions and the method of calculation, prognostic calculations were made, which are presented in Table 10.

DISCUSSION OF RESULTS

After comparing basic properties of coal from „Szczerców" and „Bełchatów" Fields, it was found that coal from "Szczerców" Field contains more mineral substance and sulphur compounds. This observation is concurrent with previous publications. It should be emphasized that the comparison is only an estimate, as in the case of "Szczerców" Field averaged samples from the above mentioned pilot holes were investigated, whereas in the case of "Bełchatów" Field the authors had access to the results of previous analyses of coal taken by an automatic sample taker from the system of three boilers carburizing in 24-h cycles – the coal was averaged and prepared for analysis.

In coal from „Szczerców" Field the following were determined: As, Be, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, V and Zn.

In coal from „Bełchatów" Field in previous studies there were determined: Cr, Cu, Hg, Mn, Ni, Pb i Zn.

The evaluation of the results of 55 samples analysis reveals a high differentiation of the level of particular trace elements' concentrations: the level of mercury concentration is the lowest – below 0.5 mg/kg, beryllium and cadmium – below 2 mg/kg, arsenic, cobalt, copper and lead – below 30 mg/kg, chromium, nickel and vanadium – below 100 mg/kg, whereas manganese and zinc – below 200 mg/kg. A comparison of the levels of selected trace elements' concentrations in coal from "Szczerców" and "Bełchatów" Fields shows a close similarity in the case of copper and lead, a certain similarity but with higher concentrations in coal from "Szczerców" Field in the case of chromium, mercury and nickel and a considerable difference in the case of zinc, the concentration of which is higher in coal from "Szczerców" Field.

The level of selected trace elements' concentrations is considerably different in a vertical distribution.

Due to the use of coal from „Szczerców" Field, characterised by a higher content of mineral substance, and in consequence a lower calorific value as well as a higher content of sulphur compounds, the consumption of coal and the amount of slag, fly ash and gypsum produced in the flue gas desulphurisation process will increase. It is assumed that by the year 2030 a basic boiler in the power blocks of "Bełchatów" Power Plant will be BB-1150 boiler, probably modernized. For prognostic purposes basic data were calculated, namely the streams of coal used, produced slag, fly ash, emitted dust and gypsum produced in the FGD unit. Throughout the whole evaluated period the same values $A^{ar} = 11.56\%$ and 1.05% S_T^{ar} and the same calorific value were applied for coal from „Szczerców" Field, resulting in the same burned coal mass stream. *Solid combustion products: slag*, carried off directly from the boiler furnace and *flue dust*, carried away from the boiler in a flue gas stream, which are produced from mineral substance in coal in the coal combustion process have mass fractions: 0.058 and 0.942 respectively. Analyzing action of EF and FGD it may be assumed that 0.1% of fly ash is introduced into the air with the desulphurised flue gas as emitted dust, and 0.3% of fly ash mixes with gypsum from the FGD unit and becomes its contamination. Calculations of the amount of gypsum were based on the assumption that the content of sulphur compounds in coal was total sulphur and flue gas desulphurization efficiency reached 95%. A coefficient according to a stoichiometric equation of the reaction of sulphur dioxide and calcium carbonate with the production of calcium sulphate dihydrate was applied. The calculated mass of *gypsum* is pure $CaSO_4 \cdot 2H_2O$, without admixtures in a form of excess calcium carbonate, calcium sulphate and residual fly ash.

Calculations of the mass of combustion and flue gas desulphurization products carried out in relation to 1 Tg of burned coal from "Szczerców" Field gave the following results (in Mg): ash – 108459, slag – 6705, gypsum – 53616 and emitted dust – 109.

For the needs of investigations, a distinction was made between emission and transfer. Emission refers to the introduction of contaminating substances which occur in the solid phase into the air along with waste gas. Transfer is the moving and penetration of contaminating substances into solid products of coal combustion, dedusting and flue gas desulphurization.

It was assumed that the properties and contents of selected trace elements in coal from two observation holes and one pilot hole are representative for whole „Szczerców" Field. The obtained results make it possible to conduct a preliminary evaluation of the emission of selected trace elements into the air and refer the results to the data on estimated emissions of heavy metals in Poland quoted in GUS (Central Statistical Office) yearbooks.

The projected emissions of selected trace elements with dust will reach a peak in the year 2005, in which „Bełchatów" Power Plant will use 36.5 Tg of coal from „Szczerców" Field, reaching the following probable values in kg/a: chromium – up to 291 (4.86), copper – up to 84 (no data available), mercury – up to 0.07 (0.006), manganese – up to 529 (7.23), nickel – up to 170 (2.73), lead – up to 63 (0.16) and zinc – up to 664 (0.81). In relation to the reported emissions of heavy metals, in "Bełchatów" Power Plant the highest emission is forecast for manganese, chromium and nickel. However, it does not exceed 7.3%. The forecast emission is a percentage value in relation to the national emission of heavy metals in 2011 reported by GUS, which has been given in brackets next to the previously quoted values.

Among the investigated trace elements the greatest threat to the biosphere is posed by mercury emitted into the air. As shown by the presented data, mercury emissions in "Bełchatów" Power Plant are marginal. Prognostic calculations for the products of combustion and flue gas desulphurization which are not emitted into the air should not give cause for concern, as it was found [9] that mercury accumulates chiefly in gypsum produced in the FGD plant. The content of mercury in slag and fly ash is low. This results from the properties of mercury compounds, which in the process of coal combustion escape with flue gas in a gaseous form as mercury vapours or its volatile compounds. In an FGD absorber the sorption of mercury in the gaseous phase as well as mercury and its compounds adsorbed on the surface of fly ash particles takes place. In the desulphurization process, mercury present in flue gas transfers into gypsum and leaves the FGD absorber as gypsum contamination or a component of sewage from the process of gypsum dehydration and washing in a vacuum filter. The probability of dangerous mercury amounts being present in desulphurised flue gas is minimal. However, due to the lack of measurement data, gypsum and sewage should be subjected to analysis, including speciation analysis, and the release of mercury from gypsum by washing out and evaporating at an increased temperature should be examined. Such investigations should also be conducted for fly ashes and slag.

The output reaching ca 550 Tg of coal from „Szczerców" Field in the years 2013–2030 and its burning in the power blocks of "Bełchatów" Power Plant, which will be accompanied by the presence of combustion and flue gas desulphurization products, is a rare enterprise. The projected amounts of ash produced with such consumption of coal reach 59.4 Tg, slag – 3.7 Tg, gypsum – 29.4 Tg and the forecast emission of fly ash is 59721 Mg. The work of "Bełchatów" Power Plant, supplied with coal from "Szczerców" Field, will be accompanied by a transfer of trace elements. The transfer of Cr, Cu, Hg, Mn, Ni, Pb and Zn into ash is of considerable importance. The transfer of mercury into ash will reach ca 1 Mg, copper and lead – ca 1000 Mg, nickel – over 2000 Mg, chromium – above 4000 Mg, manganese – 7500 Mg, and zinc – nearly 10000 Mg. The transfer of these elements into gypsum, excluding mercury, is several dozen times lower. The most important is the transfer of mercury into gypsum, which in the evaluated period will reach 11 Mg.

Special attention should be paid to the transfer of trace elements. Microcomponents will move from coal, where they existed in stable forms in the organic and inorganic substance of brown coal, to the above mentioned products, from which they may migrate at particular conditions. It is impossible to evaluate these processes without knowing the speciation of these elements' compounds in products and their behaviour in the process of using the products. These investigations are extremely significant for the selection of proper solutions. It is not certain whether gypsum from the FGD plant will in the future be used for the production of building materials due to changes in the construction technology and demand for gypsum products, or in what way and in what quantities solid products of coal combustion will be utilized. Ash and slag should not be stored in the headings after coal has been mined, if there are plans to flood these headings and create artificial reservoirs the scale of which will resemble that of the Solina Lagoon (Zalew Soliński). Neither should it be stored at dangerous dumping grounds.

Emissions to the air are reduced to the extent allowed by the best currently available technology. However, it should be emphasized that the conducted calculations of dust emissions, based on the assumption that the total (EF and FGD) dedusting efficiency reaches η = 99.9%, are higher compared to the data of "Bełchatów" Power Plant, based on the dust emission indicator 0.06 kg/MWh. Further reduction of dust emissions is possible after introducing basic technological changes, such as CCS or coal gasification. Given a minimum double increase in the cost of produced electrical energy, it is difficult to evaluate the plausibility of such technological changes.

CONCLUSIONS

- The output of ca 550 Tg of coal from „Szczerców" Field and its burning in the power blocks of „Bełchatów" Power Plant in the years 2013–2030 is a rare enterprise. It will be accompanied by a transfer of trace elements into ash, slag and gypsum from the FGD unit and emissions with the emitted dust into the air. The evaluation of the influence of these processes on the biosphere requires research into the speciation and migration of harmful trace elements in the conditions of work of "Bełchatów" Brown Coal Mine and "Bełchatów" Power Plant.
- The emissions of trace elements into the air are effectively limited due to the use of electrofilters and the wet limestone method of flue gas desulphurisation.
- Mercury emissions into the air are low due to the transfer to gypsum in the flue gas desulphurisation process.
- Potential susceptibility to the washing out and volatilization of mercury contained in gypsum which is currently processed into building materials should be investigated.
- It is necessary to assess the prospects of the previously applied methods of slag, ash and FGD gypsum utilization, taking into consideration the accumulation of trace elements from the burned brown coal.

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