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Cooper Removal and Recovery from Aqueous Solutions by Using Selected Synthetic Ion Exchange Resins (Part I)

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Abstract

The paper presents results of research on removal of Cu^{2+} ions from aqueous solutions by ion exchange method in concentration range of 10–1000 mg/L. For this purpose, following Purolite synthetic ion exchange resins were used: S 910, S 930, S 940, S 950 and C 160. The obtained results were interpreted based on the degree of solution purification and microstructural investigations. The regeneration possibility of used ion exchangers with a 10% hydrochloric acid solution was also investigated.
Based on obtained results, it was determined that studied ion exchangers efficiently removed copper(II) ions from aqueous solutions, especially in low concentrations. Microstructural investigation made for tested materials after the sorption process clearly indicate that Cu^{2+} ions removal process was in accordance with ion exchange mechanism, which was confirmed by recorded SEM images.
All ion exchangers except S 910, purified solutions from Cu^{2+} ions with an efficiency greater than 90% up to a concentration of 100 mg/L. In case of S 930 and S 940 ion exchangers, their efficiency was close to 100%. For higher concentrations, efficiency of studied ion exchangers decreased significantly. The lowest decrease in degree of copper(II) S 910 chelating resin with amidoxime groups was the least efficient. All studied ion exchangers can be regenerated with a 10% hydrochloric acid solution. The efficiency of this process varies from 53.1% to 80.5% depending on the used resins.

Keywords: *copper ions, ion exchange, ion exchanger resins, microstructural research*

Introduction

Copper belongs to the 11th group of periodic table and it's average content in Earth's crust is approx. 0.0055%. In the nature it occurs mainly in form of sulfide minerals (chalcocite – Cu_2S, covellite – CuS, chalcopyrite – $CuFeS_2$), oxide minerals (carmite – Cu_2O), carbonate minerals (malachite – $Cu_2(OH)_2CO_3$, azurite – $Cu_3(OH)_2(CO_3)_2$) and less frequently silicate minerals (Bielański 2013). About 1% of total copper amount is in its native form. Its content in ores is estimated at about 6% (Seńczuk 2017). In pure natural waters, copper compounds are relatively rare, wherein water from wetlands or peat lands may contain traces of it – up to about 0.01 mg/L. Most of dissolved copper is bound in stronger complexes with various inorganic as well as organic ligands. In natural water, insoluble copper compounds, such as sulfides hydroxides or carbonates, may also occur (Hermanowicz et al. 1999).

Copper is considered to be an essential element for human body, however its excessive doses may cause various disease (Ogórek et al. 2017). This element shows a particularly high susceptibility to bioaccumulation from aquatic environment. Its toxicity in water depends on: pH, water hardness, dissolved oxygen concentration, presence of chelating agents, presence of humic acids, content of suspended solids and interactions between individual metals (Piontek et al. 2014). In surface waters elevated amounts of copper compounds usually are caused by wastewater from metallurgical, paint, textile and chemical industries (Thomas et al. 2014). It can also penetrate into water from installations made of copper, brass or bronze as a result of its corrosive action. The conditions that should be met while disposing of sewage into natural environment, define that concentration of copper ions cannot exceed 0.1 mg/L for wastewater from the ceramic industry and 0.5 mg/L for other types of wastewater (Dz. U. 2014.1800).

In order to remove, concentrate and recover metal ions, various physicochemical methods are used, e.g. chemical precipitation and coprecipitation (Lundström et al. 2016; Zhou et al 2018), coagulation (Chang and Wang 2007; El Samrani et al. 2008; Heredia and Martín 2009), solvent extraction (Wanga et al 2018; Elizalde et al 2019), electrochemical and membrane processes (Ahmad ang Ooi 2010; Jack et al. 2014; Rincón and La Motta 2014; Li et al. 2017; Hosseini et al. 2018), adsorption (Prakash and Arungalai Vendan 2016; Shahamirifard et al. 2016; Dil et al. 2017), ion exchange (Gurnule and Dhote 2012; Kuz'min and Kuz'min 2014; Al-Saydeha et al. 2017) and biotechnological processes (Foroutana et al. 2017; Wena et al. 2018; Nancharaiah et al. 2019). Selection of method depends on type and composition of sewage, form and concentration of removed components and desired degree of purification. Effectiveness and cost of method are also taken into account.

For this purpose, there are often used, methods based on ion exchange, due to its advantages, among which there is high selectivity in removing impurities, as well as vast diversity of used ion exchangers, both: synthetic and natural (Alyüz and Veli 2009; Naushad 2009). Thanks to ion exchange, all ions can be removed from solution or one substance can be separated from other one. Choosing one of these options depends, most of all, on composition of solution, as well as on desired level of purification. Ion exchange process involves substitution of ions being a part of the ion exchanger, for equivalent quantity of other ions of the same charge that are included in

Tab. 1. The review of studies concerning removal of Cu^{2+} with use of different ion exchangers
Tab. 1. Przegląd badań dotyczących usuwania jonów Cu^{2+} za pomocą różnych wymieniaczy jonowych

Chelating ion exchanger	Characteristics of the ion exchange resin	Dose [g/L]	The initial concentration of Cu^{2+} ions [mg/L]	pH	The maximum sorption capacity [mg/g]	Degree of purification [%]	Reference
Purolite S 930	Macroporous polystyrene based chelating resin with iminodiacetic groups	0.2–4	10–300	2–5	104.2 for pH = 2 163.6 for pH = 5	35 for pH = 2 54.8 for pH = 5	Bulai et al. 2009
Chelit P Dowex M-4195 Diphonix	Ion exchanger containing functional groups: aminomethylphosphonic (Chelit P), bis(2-pyridylmethyl)amino (Dowex M-4195) and diphosphonic/sulfonic/carboxylic (Diphonix)	10	0.0635	2–8	37.04 for Chelit P 40.81 for Dowex M-4195 24.82 for Diphonix	n.d.	Kołodyńska 2009
Amberlite IRA-958 Amberlite IRA-958-SPADNS	Acrylic, strongly alkaline anion exchanger with a macroporous structure with quaternary ammonium groups	10	n.d.	n.d.	23.32 for Amberlite IRA-958 777.81 for Amberlite IRA-958-SPADNS	n.d.	Greluk and Hubicki 2011
Lewatit TP 207 Lewatit TP 208	Chelating ion exchangers with the iminodiacetate functional groups (IDA)	20	6.35	1–7	n.d.	44.8 for pH = 1 99.0 for pH = 7	Rudnicki et al. 2014
Purolite C 160	Polystyrenic macroporous strong acid cation exchange resin	5	6.25–109.38	4	468.42	> 92	Bożęcka et al. 2016
DOW XUS 43578 Diaion CR 11 Dowex HCR-W2 Purolite C 160	Chelating resins: XUS 43578 and CR 11 Strong acid cation exchange resins: HCR-W2 and C 160	0.4–4	0.2	1–5	166.3 for XUS 43578 167.4 for CR 11 167 for HCR-W2 166 for C 160	83–97 pH = 5	Edebali and Pehlivan 2016

purified water solution. Ion exchangers are macromolecular substances, practically insoluble in water, which have ability to exchange positively or negatively charged ions from electrolyte solution to equivalent amounts of ions contained in ion exchangers (Inamuddin and Luqman 2012).

Among wide group of ion exchangers, chelating resins have great practical importance. Their unique feature distinguishing them from other types of sorbents is presence in their polymer matrix of chemically active functional groups, which are capable to interact with metal ions found in solution and forming chelated complexes as a consequence. Sorption abilities of chelating resins depend mainly on nature of functional groups, and with lesser extent on size of grain or other physical properties. They are characterized by a much higher ability of selective sorption of one ion in presence of other ones, in comparison to typical ion exchangers. Thanks to that, they are used in recovery of precious metals from sludges, as well as in removal of toxic heavy metals from surface water and wastewater (Bożęcka and Sanak-Rydlewska 2018). In particular, they enable selective sorption of transition metal ions from wastewater containing large amounts of sodium ions. Most of ion exchangers can be regenerated with mineral acids, which result in obtaining concentrates of adequate salts that can be then reused in technological processes. The high selectivity of chelating ion exchangers on selected metal ions allows their use in industrial conditions, where concentrations of adsorbed ions are very low compared to concentrations of accompanying ions. This is a significant advantage compared to traditional liquid-liquid or liquid-solid extraction methods, where it is necessary to use strong acids or solvents that are harmful to the environment.

The use of ion exchangers to remove copper(II) ions from water and sewage is subject of many scientific studies, including (Bulai et al. 2009; Kołodyńska 2009; Greluk and Hubicki 2011; Rudnicki et al. 2014; Bożęcka et al. 2016; Edebali and Pehlivan 2016). Results of mentioned studies are summarized in Table 1.

Materials and methods

The aim of this study was to compare degree of purification of aqueous solutions from copper(II) ions using different Purolite ion exchangers. The possibility of their regeneration and ability to recover copper was also examined. In addition, surface morphology of used ion exchangers was determined using a Scanning Electron Microscope (SEM). These analyses have been extended with chemical research in micro areas (EDS).

Five different synthetic ion exchange resins from Purolite were used for research. Four of them are chelating resins: S 910, S 930, S 940, S 950 and one is strongly acid cation ion exchanger C 160. Table 2 presents their physicochemical characteristics. A crucial step in the preparation of resins for this research was to subject it to swell in deionized water for 24 hours.

The 0.5 g sample of ion exchange were used for studies. Range of initial concentrations of Cu^{2+} ions in tested solutions ranged from 10 to 1000 mg/L. Copper solutions were prepared from hydrated copper(II) nitrate(V), $[Cu(NO_3)_2 \cdot 3H_2O]$, by ACROS ORGANICS. The pH of studied solutions was 4.0 (± 0.1). For the pH adjustment 0.02 M HNO_3 had been used.

Ion exchange processes were carried out with a dynamic method using laboratory shaker. For this purpose, 100 ml of the solution with ion exchanger was placed in a 250 ml Erlenmeyer flasks and shaken with a constant speed of 180 rpm. Sample for analysis was collected after one hour (at that time system reached equilibrium). Solutions after ion exchange processes were filtered to isolate solid particles.

Final concentration of Cu^{2+} ions in solutions was determined with cuprizone method using a UV-VIS spectrophotometer Cadas 200 Dr. Lange. Analysis were carried out in an ammonia-citrate medium at pH 8.0–9.5. The absorbance of the solutions was measured at 600 nm wavelength.

The degree of purification of studied solutions from copper(II) ions, X (%), was calculated using Formula 1:

Tab. 2. Physicochemical characteristics of the ion exchangers used for the research (Purolite, 2019)
Tab. 2. Charakterystyka fizykochemiczna jonitów zastosowanych w badaniach (Purolite, 2019)

Resin Purolite	Type functional group		Matrix	The range of particle size [mm]
	Name	Formula		
S 910	Amidoxime	$-C(NH_2)NOH$	Macroporous crosslinked polymer	0.3–1.2
S 930	Iminodiacetic	$R-CH_2-N-(CH_2COOH)_2$	Macroporous styrene-divinylbenzene	0.425–1.2
S 940	Aminophosphonic	$RCH_2NHCH_2PO_3$		0.43–0.85
S 950	Aminophosphonic	$RCH_2NHCH_2PO_3$		0.3–1.2
C 160	Sulfonic	$R-SO_3^-$		0.3–1.2

$$X = \frac{c_o - c_e}{c_o} \cdot 100\% \qquad (1)$$

where: c_o and c_e – initial and equilibrium concentration of Cu^{2+} ions in solutions [mg/L].

In the next stage of research, regeneration possibility of used resins with 50 ml of 10% hydrochloric acid solution was studied. Reagent selection and regeneration conditions were in line with manufacturer's instructions (regeneration time - 30 minutes) (Purolite 2019).

In order to determine surface morphology of studied ion exchangers, photos were recorded using Scanning Electron Microscope (SEM) from FEI Quanta 200 FEG company. These analyses were extended with microchemical studies. They were performed using an EDS detector. This tests were carried out in high vacuum mode. Samples were coated with carbon before analysis. Acceleration voltage was 20 kV.

Results and Discussion

Photos of surface morphology of tested ion exchangers were recorded for materials after the ion exchange process. Examples of SEM images and EDS spectra of examined materials are shown in Figure 1.

A S 910 and S 940 resins are characterized by a porous surface (Figure 1 a, g), while S 930, S 950 and C 160 have a more smooth surface with numerous cracks and grooves (Figure 1 d, j, m). Microstructural investigations performed for studied materials after sorption process clearly indicate that Cu^{2+} ion removal process occurred in accordance with ion exchange mechanism, which was confirmed by recorded SEM images (Figure 1). No microprecipitations were observed on the surface of tested ion exchangers.

Determined degree of solutions purification from Cu^{2+} ions with use of synthetic ion exchange resins as a function of initial concentration is shown graphically in Figure 2.

For all tested ion exchangers the highest degree of purification was observed at low concentrations (Figure 2). All ion exchangers, except for S 910, purified solutions from Cu^{2+} ions with efficiency greater than 90% up to a concentration of 100 mg/L. In case of S 930 and S 940 chelating resins their efficiency was close to 100%. For the concentration above 100 mg/L, efficiency of tested ion exchangers decreased significantly. The lowest decrease in degree of Cu^{2+} ions separation was observed for the C 160 cation ion exchanger. In this case, for the highest concentration (1000 mg/L) purification level reached 43.7%. A S 910 chelate resin turned out to be the least effective (for a concentration of 1000 mg/L) – degree of copper separation was only 16.1%.

Observed differences in efficiency of purification of aqueous solutions from Cu^{2+} ions by tested resins resulted from both different structure of ion exchangers, as well as from differences in functional groups. Ion exchangers: S 930 with the iminodiacetic groups, S 940 containing aminophosphonic groups and C 160 with sulfonic groups proved to be the most effective in ion exchange process. Slightly lower solutions purification level from copper(II) ions was observed for S 950 chelating resin, which possesses the same functional groups as S 940 ion exchanger but shows a greater diversity of particles size. A S 910 ion exchanger, which contained amidoxime groups was the least efficient.

The results of regeneration are presented in Figure 3.

Among all tested resins, the highest efficiency of regeneration process was achieved for ion exchanger C 160 (80.5%) and S 910 (64.5%). Recovery of copper after regeneration for remaining three chelating resins (S 930, S 940 and S 950) is significantly smaller and reaches about 54%. Cation exchanger C 160 regenerates much better than chelating resins, which is probably due to their different structure and differences in mechanism of ion exchange process. In case of chelating resins, stability of formed complexes is a function of solution pH. Therefore, smaller efficiency values of regeneration process are observed for ion exchangers S 930, S 940 and S 950 in comparison with resin S 910. Ion exchanger S 910 forms stable complexes with copper only at pH > 3. Other remaining resins have lower minimum pH values below which removal of Cu2+ ions from purified solution is no longer possible (Purolite, 2019). In addition, reducing volume of 10% HCl (50 ml) compared to volume of solution submitted to sorption process (100 ml), allowed to concentrate solution and reduce consumption of regenerating reagent.

Summary

Based on obtained results, it was found that studied ion exchangers removed effectively copper(II) ions from aqueous solutions, especially in low concentration range. This process took place in accordance with ion exchange mechanism. On the surface of tested resins, no microprecipitations were observed. All ion exchangers, except of S 910, purified solutions from Cu^{2+} ions with efficiency greater than 90% up to a concentration of 100 mg/L. In case of S 930 and S 940 chelating resins, their efficiency was close to 100%. For higher concentrations, efficiency of tested ion exchangers decreased significantly. The lowest decrease in degree of Cu^{2+} emission was observed for C 160 cation exchanger with sulfone groups. The lowest efficiency was found in S 910 chelate resin containing amidoxime groups. Existing differences in affinity of

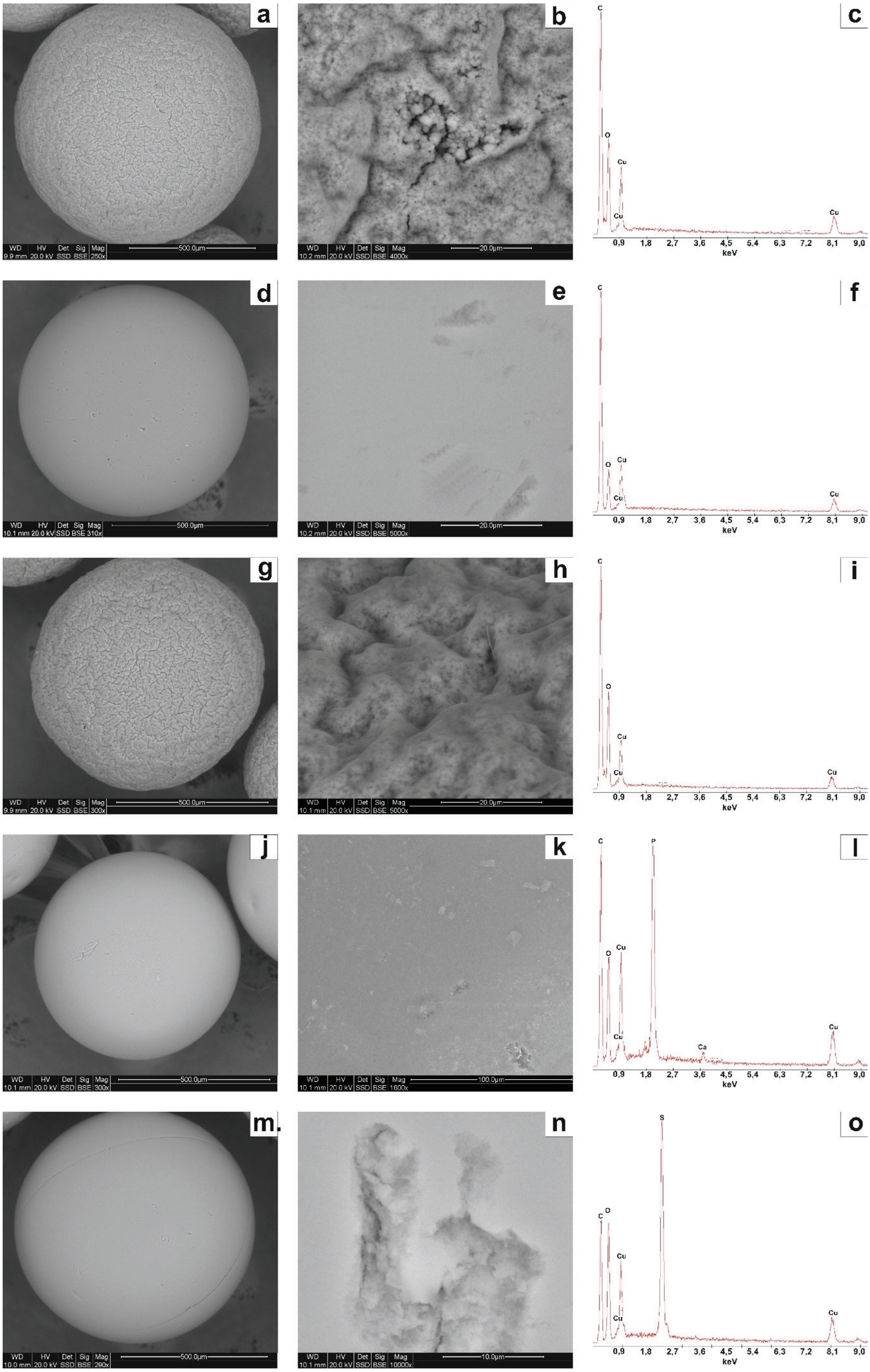

Fig. 1. Example SEM images and EDS spectra obtained for samples of Purolite synthetic ion exchangers: S 910 (a, b, c); S 930 (d, e, f); S 940 (g, h, i); S 950 (j, k, l); C 160 (m, n, o) after Cu^{2+} ions exchange process

Fig. 1. Przykładowe zdjęcia SEM oraz widma EDS uzyskane dla próbek syntetycznych jonitów firmy Purolite: S 910 (a, b, c); S 930 (d, e, f); S 940 (g, h, i); S 950 (j, k, l); C 160 (m, n, o) po procesie wymiany jonowej jonów Cu^{2+}

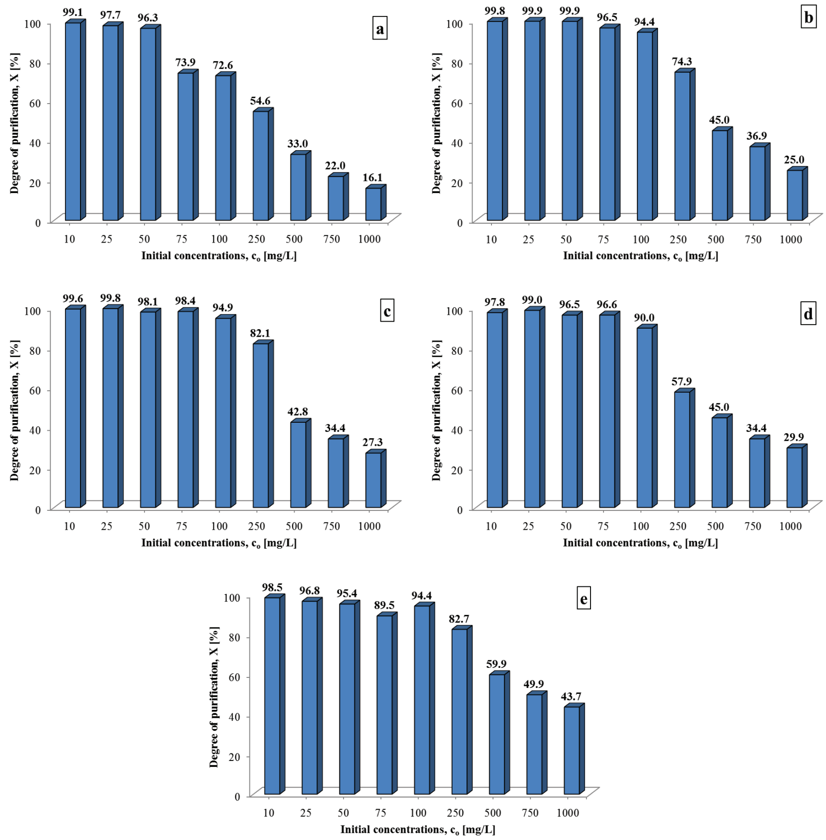

Fig. 2. Impact of initial concentration on Cu^{2+} ion exchange process on resins S 910 (a); S 930 (b); S 940 (c); S 950 (d); C 160 (e)

Fig. 2. Wpływ stężenia wyjściowego na proces wymiany jonowej jonów Cu^{2+} na jonicie: S 910 (a); S 930 (b); S 940 (c); S 950 (d); C 160 (e)

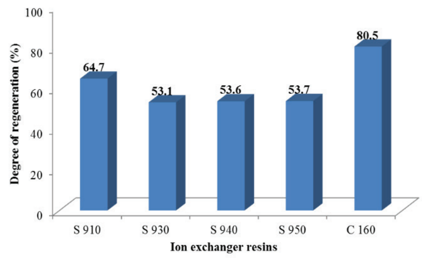

Fig. 3. Regeneration of tested ion exchangers using 10% HCl

Fig. 3. Regeneracja badanych jonitów przy użyciu 10% HCl

tested resins towards Cu^{2+} ions may be caused by a different chemical and physical structure or by size of their particles. Probably transformations of Cu^{2+} ions into complex forms will increase efficiency of their removal by tested chelating ion exchangers. This will be the subject of further research. Results obtained after the regeneration process confirmed, that studied resins can be regenerated using 10% hydrochloric acid solution. Efficiency of regeneration varies from 53.1% (for S 930 resin) to 80.5% (for C 160 resin).

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Usuwanie i odzysk miedzi z roztworów wodnych przy użyciu wybranych syntetycznych żywic jonowymiennych (część I)

W pracy przedstawiono wyniki badań dotyczące usuwania jonów Cu^{2+} z roztworów wodnych metodą wymiany jonowej w zakresie stężeń 10–1000 mg/L. W tym celu zastosowano żywice jonowymienne firmy Purolite: S 910, S 930, S 940, S 950 i C 160. Otrzymane wyniki zinterpretowano w oparciu o stopień oczyszczenia roztworu i badania mikrostrukturalne. Zbadano również możliwość regeneracji użytych jonitów za pomocą 10% roztworu kwasu solnego.

Na podstawie otrzymanych wyników stwierdzono, że badane jonity skutecznie usuwały jony miedzi(II) z roztworów wodnych, szczególnie w niskich stężeniach. Badania mikrostrukturalne wykonane dla badanych materiałów po procesie sorpcji wyraźnie wskazują, że proces usuwania jonów Cu^{2+} zachodził zgodnie z mechanizmem wymiany jonowej, co potwierdzają zarejestrowane obrazy SEM. Na powierzchni badanych jonitów nie zaobserwowano mikrostrąceń.

Wszystkie wymieniacze jonowe z wyjątkiem S 910 oczyszczały roztwory z jonów Cu^{2+} z wydajnością większą niż 90% do stężenia 100 mg/L. W przypadku jonitów S 930 i S 940 ich skuteczność było bliska 100%. W przypadku większych stężeń wydajność badanych jonitów znacząco malała. Najmniejszy spadek stopnia wydzielenia jonów miedzi(II) zaobserwowano dla kationitu C 160 zawierającego grupy sulfonowe. Najmniej skuteczny okazał się jonit chelatujący S 910 z grupami amidoksymowymi. Wszystkie badane jonity można regenerować za pomocą 10% roztworu kwasu solnego. Wydajność tego procesu waha się od 53,1% do 80,5% w zależności od użytej żywicy jonowymiennej.

Słowa kluczowe: *jony miedzi, wymiana jonowa, jonity, badania mikrostrukturalne*

Cooper Removal and Recovery from Aqueous Solutions by Using Selected Synthetic Ion Exchange Resins (Part II)

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Abstract

In paper the possibility of Cu^{2+} ions removing from aqueous solutions on selected synthetic ion exchange resins (Purolite S 910, S 930, S 940, S 950, C 160) was studied. These processes were described by the Langmuir and Freundlich adsorption models.
It was found that the process of Cu^{2+} ions removing on S 910 and S 930 ion exchangers were the best described by linear equation form of Langmuir isotherm. The fit quality of the Freundlich isotherm is the best for S 940, C 160 and S 950 ion exchangers, which is confirmed by the obtained values of correlation coefficients R.
The highest value of the maximum sorption capacity (about 69 mg/g) was obtained for C 160 cation exchange resin with sulfonic groups. For others ion exchange resins the monolayer capacity was decreasing in following order S 940 > S 930 > S 950 > S 910. The S 940 and S 930 ion exchangers were characterized by the highest affinity for Cu^{2+} ions. The amidoxime polyacrylic chelating resin S 910 was the least efficient. The differences in the affinity of the studied resins towards to Cu^{2+} ions can be explained by their different chemical or physical structure and particles size.
In case of the studied ion exchange resins, the 1/n parameter values of the Freundlich isotherm were in range of 0.21–0.32. Therefore, it can be concluded that energy heterogeneity of the studied sorption system and intensity of Cu^{2+} ion removal on above ion exchangers are moderate. The K parameter value of the Freundlich equation was also highest for ion exchangers S 930 and S 940.

Keywords: *copper, ion exchange resins, Langmuir isotherm, Freundlich isotherm*

Introduction

Nowadays, human activity generates significant amounts of waste. This includes also wastewater, which pose a significant threat to living organisms. Among the substances emitted into the natural environment there are also copper compounds.

Copper is a toxic metal, but it is also a micronutrient necessary for proper functioning of living organisms. The basic function of copper in human body is its participation in

oxidation-reduction processes. This element is in enzymes active centres which are involved in cell metabolic processes. Its deficiency causes a significant reduction in copper-dependent enzymes, which leads to inhibition of cells life processes (Ogórek et al. 2017).

However, copper excess is toxic to living organisms. One of its main consequences is formation of reactive oxygen forms, causing development of oxidative stress. In cell, this process can damage proteins and lipids thus cell structures and genetic material. Its excess in diet is mainly associated with changes in liver, followed by damage to kidneys, brain tissue, coronary vessels and cardiac muscle (Piontek et al. 2014; Ogórek et al. 2017). Copper is one of the factors responsible for appearance and progression of Alzheimer's and Parkinson's diseases. Disorders of copper metabolism in body also lead to Menkes' and Wilson's diseases (Hu et al. 2017).

Copper is a valuable element, widely used in many industries. It has the highest electrical and thermal conductivity of all base metals, therefore it is widely used in electrical industry as well as in production of alloys (brass, bronze, alloys with aluminium, manganese and beryllium). It is also used for wood impregnation and for production of insecticides and fungicides (Al-Saydeh et al. 2017). Therefore, in untreated industrial and municipal sewage, copper compounds concentration is usually at a high level. Considerable copper environmental pollution is also found near mines and smelters of this metal (Seńczuk 2017).

The current requirements for plants which discharge sewage into the municipal and industrial sewage system or watercourses determine that concentration of copper ions cannot exceed 0.1 mg/L for wastewater from the ceramic industry and 0.5 mg/L for other types of wastewater (Dz. U. 2014.1800). Exceeding of these acceptable standards affects surface water quality and poses a special threat to living aquatic organisms in these ecosystems. This is also important for the raw water intake and production of drinking water with suitable quality, for which copper ions concentration cannot exceed 2 mg/L (Dz. U. 2017.2294).

For the copper ions removal from aqueous solutions, methods such as: precipitation (Lundström et al. 2016), electrochemical processes (Jack et al. 2014; Rincón and La Motta 2014; Li et al. 2017) and membrane processes (Ahmad and Ooi 2010; Tran et al. 2012), adsorption (Prakash and Arungalai Vendan 2016; Shahamirifard et al. 2016; Dil et al. 2017) and ion exchange (Lin and Juang 2007; Bulai et al. 2009; Kołodyńska 2009; Gurnule and Dhote 2012; Rudnicki et al. 2014; Al-Saydeha et al. 2017) are commonly used. Choice of water and wastewater treatment methods always depends on the number of parameters, including: kind and composition

Tab. 1. Physicochemical characteristics of studied Purolite ion exchangers: S 910, S 930, S 940, S 950 and C 160 (Purolite 2019)
Tab. 1. Charakterystyka fizykochemiczna badanych jonitów firmy Purolite: S 910, S 930, S 940, S 950 and C 160 (Purolite 2019)

Resin Purolite	Type functional group		Matrix	The range of particle size [mm]
	Name	Formula		
S 910	Amidoxime	$-C(NH_2)NOH$	Macroporous crosslinked polymer	0.3–1.2
S 930	Iminodiacetic	$R-CH_2-N-(CH_2COOH)_2$	Macroporous styrene-divinylbenzene	0.425–1.2
S 940	Aminophosphonic	$RCH_2NHCH_2PO_3$		0.43–0.85
S 950	Aminophosphonic	$RCH_2NHCH_2PO_3$		0.3–1.2
C 160	Sulfonic	$R-SO_3^-$		0.3–1.2

Tab. 2. Characteristics of adsorption isotherms (Atkins 2012; Bożęcka et al. 2017)
Tab. 2. Charakterystyka izoterm adsorpcji (Atkins 2012; Bożęcka et al. 2017)

Isotherm	Langmuir	Freundlich
Equation	$Q = \frac{q_{max} \cdot b \cdot c_e}{(1 + b \cdot c_e)}$ (2)	$Q = K \cdot c_e^{1/n}$ (3)
Linear form	$\frac{1}{Q} = \frac{1}{q_{max \cdot b}} \cdot \left(\frac{1}{c_e} + b\right)$ (4)	$logQ = logK + \frac{1}{n} \cdot logc_e$ (5)
where:	Q – amount of the metal ions per gram of the sorbent [mg/g]; c_e – the equilibrium concentrations of Cu^{2+} ions [mg/L]; a and b – Langmuir coefficients; K and n – Freundlich coefficients	

of wastewater as well as form and concentration of removed pollutants. The method's effectiveness and economic reasons are also important.

Among previously mentioned methods, ion exchange has a significant role in modern technologies of metal ions removal from wastewater. In initial phase of technology development for synthetic ion exchangers production, their use was mainly related to the need of water treatment. Gradually, ion exchange resins were also used to treat industrial wastewater, from which it was possible to recover not only water, but also other components, e.g. precious metals. However, used conventional ion exchangers were characterized by limited ion exchange capacity. Therefore, work has been begun to improve their selectivity (Greluk and Hubicki 2011).

The much greater selective sorption ability of one ion in the presence of other was obtained for chelating resins. They are characterized by presence of active functional groups capable to react with metal ions contained in solution with which they form cyclic chelate complexes. The sorption abilities of these ion exchangers depend on type of functional groups and on physicochemical properties of polymer matrix (Bożęcka and Sanak-Rydlewska 2018).

High selectivity of chelating ion exchangers on selected metal ions allows their use in industrial conditions, when concentrations of adsorbed ions are even very low compared to concentrations of accompanying ions. This is an important advantage compared to traditional liquid-liquid or liquid-solid extraction methods where it is necessary to use environmentally harmful solvents (Bożęcka and Sanak-Rydlewska 2018).

The aim of this study was to determine and compare ion exchange properties of selected synthetic ion exchange resins towards Cu^{2+} ions. This kind of experimental and theoretical studies are valuable in search of new, more effective sorption materials used to remove and recovery valuable metals, including copper. Therefore, it is planned to continue this problem.

Materials and methods

The Purolite S 910, S 930, S 940, S 950 chelating ion exchangers and C 160 cation exchanger were subject of the research. Their physicochemical characteristics are presented in Table 1. The main stage in resins preparation for the research was swelling them in deionized water for 24 hours.

The Cu^{2+} ions sorption experiments were performed in 250 mL Erlenmeyer flasks. The 0.5 g sample of ion exchanger and 100 mL of studied solutions were introduced into each flask. Copper solutions were prepared from hydrated copper(II) nitrate(V) [$Cu(NO_3)_2 \cdot 3H_2O$] by ACROS ORGANICS. The Cu^{2+} ions concentrations were in the range of 10–1000 mg/L. Solutions with ion exchangers were shaken for 60 min by using laboratory shaker with a constant speed equal to 180 rpm. After this time system reached equilibrium. The pH up to value 4.0 was regulated by addition of nitric acid solution.

Tab. 3. Langmuir and Freundlich isotherms coefficients for studied Purolite ion exchangers: S 910, S 930, S 940, S 950 and C 160

Tab. 3. Współczynniki izoterm Langmuira i Freundlicha wyznaczone dla badanych jonitów firmy Purolite: S 910, S 930, S 940, S 950 and C 160

Resin Purolite	Langmuir isotherm				Freundlich isotherm			
	q_{max} [mg/g]	b [L/mg]	R_L	R	K [L/mg]	n	$1/n$	R
S 910	35.60	0.0253	0.0380	0.9973	7.62	4.2858	0.2333	0.9201
S 930	48.33	0.1141	0.0087	0.9863	13.92	4.7403	0.2110	0.9762
S 940	50.08	0.1197	0.0083	0.9922	13.35	4.6925	0.2131	0.9981
S 950	46.32	0.0623	0.0158	0.9333	8.88	3.5270	0.2835	0.9866
C 160	68.96	0.0667	0.0148	0.9836	11.27	3.1029	0.3223	0.9964

Before measurements, all samples were filtered to remove solid particles. Concentration of Cu^{2+} ions was determined by using UV-VIS Cadas 200 spectrometer from Dr. Lange. The analysis were carried out in an ammonia-citrate medium at pH 8.0–9.5. Absorbance of copper solutions was measured at 600 nm wavelength.

The sorption capacity was calculated using Formula 1:

$$Q = \frac{V(c_o - c_e)}{m} \quad (1)$$

where: Q is the amount of adsorbed Cu^{2+} ions per gram of ion exchanger in equilibrium [mg/g], V – is the volume of the solution [L], co and ce are the initial and equilibrium concentrations of Cu^{2+} ions [mg/L], m is the quantity of dry mass of the ion exchanger [g].

The removal of Cu^{2+} ions on selected ion exchangers was described by two most popular adsorption isotherm models (Langmuir and Freundlich). Despite the increasing number of recent achievements in modelling adsorption processes, these isotherms are still often used for both micro- and macroporous materials (Bulai et al. 2009; Greluk and Hubicki 2011; Edebali and Pehlivan 2016; Yuanfeng et al. 2016). The equations of these two isotherms and their linear forms were shown in Table 2.

For the Langmuir equation a dimensionless division factor, RL, was determined in accordance with Formula (6) (Bożęcka et al. 2017):

$$R_L = \frac{1}{(1 + b \cdot C_o)} \quad (6)$$

where: Co is the highest initial concentration of adsorbate in solution [mg/L]. It is related to the shape and determines the intensity of the adsorption process according to the following dependences:

- $R_L > 1$ – adsorption occurs poorly (unfavourable character);
- $R_L = 1$ – the linear course depends on the adsorbate concentration;
- $0 < R_L < 1$ – intensive course (favourable character)
- $R_L = 0$ – the process is irreversible.

Discussion of the results

For mathematical description of experimental data, often used empirical dependencies of Langmuir and Freundlich isotherms were applied. Parameter values of these isotherms for all studied experimental systems were given in Table 3.

Data analysis showed that the process of Cu^{2+} ions removing on S 910 and S 930 ion exchangers was the best described by using linear equation of Langmuir isotherm. For other resins, isotherms fit to experimental data is also quite good, which is confirmed by obtained values of correlation coefficients R.

The Langmuir model assumes that surface of adsorbent is homogeneous. When localized adsorption occurs the molecule cannot move freely across the surface. Lateral interactions between the adsorbed molecules are irrelevant. Therefore, it is a monolayer adsorption (Atkins 2012; Bożęcka et al. 2017). Langmuir's theory works well when total number of active sites is saturated, as shown by course of obtained adsorption isotherms (Figure 1).

The linear form of the Langmuir isotherm was used to determine the capacity of obtained monolayer, i.e. amount of adsorbate covering adsorbent surface with a monomolecular layer. The state of maximum adsorption, corresponding to occupancy of all active centres is determined by q_{max} parameter of the isotherm. The highest value of this parameter, equal to 68.96 mg/g, was obtained for C 160 cation exchanger with sulfonic groups. The monolayer capacity values determined for other chelating ion exchangers (S 910, S 950, S 930, S 940) differed from each other and were 35.60 mg/g; 46.32 mg/g; 48.33 mg/g; 50.08 mg/g; respectively (Table 3).

Based on intersection point of linear form of Langmuir isotherm with axis of ordinates, values of b constants were determined, which defining affinity of studied ion exchange resins to Cu^{2+} ions. The higher value of b parameter the greater affinity and the more steep course of Langmuir isotherm. For most of the studied ion exchange resins, obtained b parameter values of the Langmuir equation were quite high (Table 3). The highest value was obtained for S 940 ion exchanger (b = 0.1197 L/mg). A very similar result was obtained for S 930 chelating resin (b = 0.1141 L/mg). For other ion exchangers

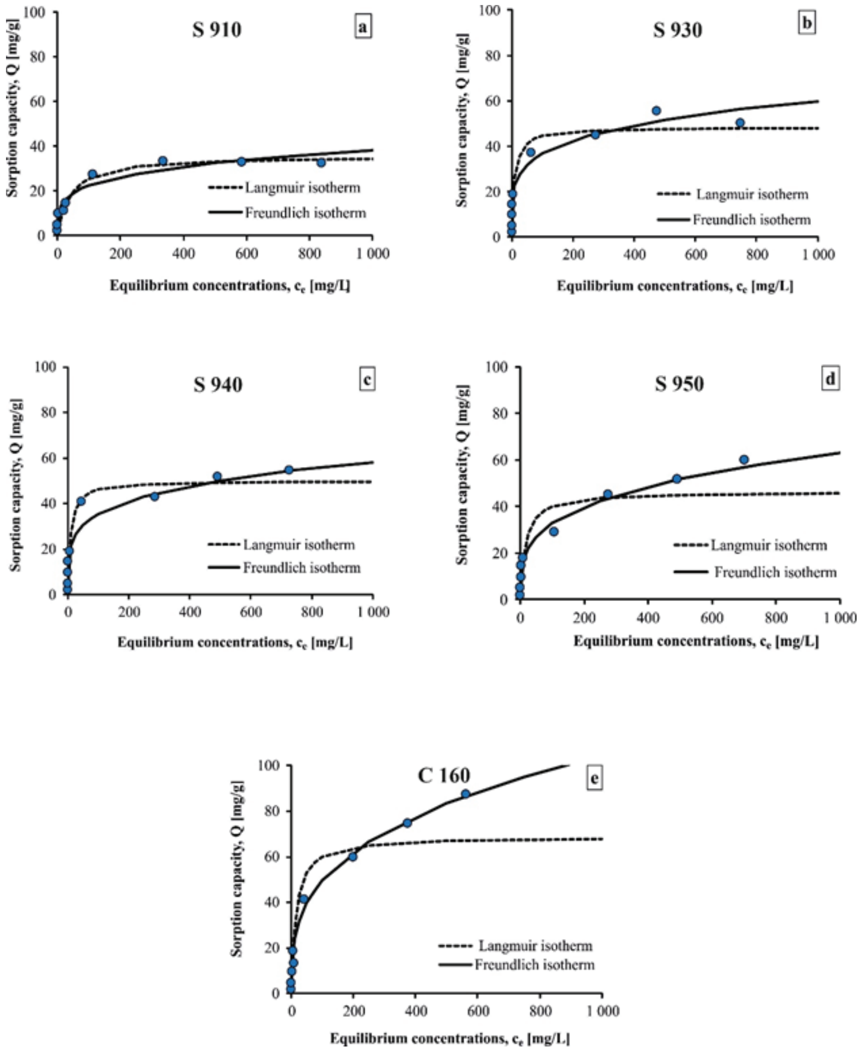

Fig. 1. Langmuir and Freundlicha isotherms for Cu^{2+} ions sorption on S 910 (a), S 930 (b), S 940 (c), S 950 (d) and C 160 (e) ion exchangers
Rys. 1. Izotermy Langmuira i Freundlicha dla jonów Cu^{2+} na wymieniaczach jonowych S 910 (a), S 930 (b), S 940 (c), S 950 (d) i C 160 (e)

(C 160; S 950 and S 910) b parameter values were lower and reached respectively 0.0667 L/mg; 0.0623 L/mg and 0.0253 L/mg. Generally a good sorbent should have high values of both q_{max} and b constants.

Dimensionless division factor R_L was calculated in order to determine degree of resins suitability for Cu^{2+} ion removal process. Its values are in the range $0 < R_L < 1$, thus confirming that course of the studied ion exchange processes is favourable.

The Freundlich isotherm is an experimental equation, which well describes adsorption at energetically heterogeneous surface and microporous adsorbents. Freundlich theory assumes, that upon complete covering of adsorbate surface by adsorbent particles, their number cannot be greater than number of surface active sites. This equation well describes reversible adsorption from diluted solutions (Atkins 2012; Bożęcka et al. 2017).

Data presented in Table 3 show that fit quality of the Freundlich isotherm to experimental data is also good, as evidenced by the obtained value of correlation coefficients R. Freundlich model describes the best removal process of Cu^{2+} ions for ion exchangers S 940 (R = 0.9981); C 160 (R = 0.9964) and S 950 (R = 0.9866).

The graph of log Q = *f (log* c_e*)* is a straight line, which easily allowed to determine K and 1/n constants from Freundlich equation and to describe the experimental systems by using these parameters (Figure 1 and Table 3). The K constant determines sorption capacity of studied ion exchangers at equilibrium concentration of Cu^{2+} ions in solution. Parameter 1/n is a measure of surface heterogeneity. The more value of this constant is closer to zero, the more adsorbent surface is energetically inhomogeneous (Atkins 2012; Bożęcka et al. 2017).

The analysis of data shows that in the case of studied ion exchange resins, values of 1/n constant are in the range of 0.21–0.32 (Table 3). Therefore, it can be concluded that there is a moderate energetic inhomogeneity of studied sorption system. Exponent 1/n also allows to determine the intensity of the removal of Cu^{2+} ions from the aqueous phase by using studied ion exchangers. When the 1/n = 1, the isotherm is linear, which confirms that the enthalpy of process is constant throughout all range of concentrations. When 1/n < 1, the isotherm has a growing concave course, from which it can be concluded that a larger number of molecules at surface increases enthalpy and thereby further enhances adsorption (Greluk and Hubicki 2011). In analysed cases, parameter values indicate a moderate intensity of Cu^{2+} ion removal on studied ion exchangers (1/n < 1) (Table 3).

Summary

In this paper possibility of Cu^{2+} ions removing from aqueous solutions by using selected ion exchange resins produced by Purolite (S 910, S 930, S 940, S 950, C 160) was studied. The studied processes were described by the Langmuir and Freundlich adsorption models.

It was found that the process of Cu^{2+} ions removing on S 910 and S 930 ion exchangers were the best described by using linear equation of Langmuir isotherm. Fit quality of the Freundlich isotherm is the best for S 940, C 160 and S 950 ion exchangers. For other resins, isotherms fit to experimental data is also quite good, which is confirmed by obtained values of correlation coefficients R.

The highest value of maximum sorption capacity (about 69 mg/g) was obtained for C 160 cation exchanger with sulfonic groups. For others ion exchange resins monolayer capacity was decreasing in following order S 940 > S 930 > S 950 > S 910.

For most of studied ion exchange resins, obtained values of b parameter of the Langmuir equation were quite high. Ion exchangers: S 940 containing aminophosphonic groups and S 930 with the iminodiacetic groups were characterized by the highest affinity to Cu^{2+} ions. The amidoxime polyacrylic chelating resin S 910 was the least efficient. Differences in affinity of studied resins towards Cu^{2+} ions can be explained by their different chemical and physical structure and particles size.

In case of studied ion exchange resins, the 1/n parameter values of the Freundlich isotherm were in range of 0.21–0.32. Therefore, it can be concluded that there is moderate energetic inhomogeneity of studied sorption system. This parameter also indicates a moderate intensity of Cu^{2+} ions removal process on above ion exchangers (1/n < 1). The K parameter value of the Freundlich equation was also the highest for ion exchangers S 930 and S 940.

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Usuwanie i odzysk miedzi z roztworów wodnych przy użyciu wybranych syntetycznych żywic jonowymiennych (część 2)

Wykorzystanie modeli izoterm adsorpcji do opisu procesów usuwania jonów Cu^{2+} z roztworów wodnych na wybranych syntetycznych żywicach jonowymiennych

W pracy zbadano możliwość usuwania jonów Cu^{2+} z roztworów wodnych za pomocą syntetycznych żywic jonowymiennych firmy Purolite. Do badań wytypowano jonity chelatujące S 910, S 930, S 940, S 950 oraz kationit C 160. Badane procesy opisano za pomocą modelu adsorpcji Langmuira i Freundlicha.

Stwierdzono, że liniowa forma równania izotermy Langmuira najlepiej opisuje proces usuwania jonów Cu^{2+} na jonicie S 910 i S 930. Jakość dopasowania izotermy Freundlicha jest najlepsza w przypadku jonitów S 940; C 160 i S 950 o czym świadczą uzyskane wartości współczynników korelacji R. Największą wartość maksymalnej pojemności sorpcyjnej (ok. 69 mg/g) uzyskano dla kationitu C 160 z grupami sulfonowymi. Pojemność monowarstwy wyznaczona dla pozostałych jonitów chelatujących malała w szeregu S 940 > S 930 > S 950 > S 910. Największym powinowactwem do jonów Cu^{2+} cechował się jonit S 940 i S 930. Najmniej skuteczna okazała się amidoksymowa poliakrylowa żywica chelatująca S 910. Zaistniałe różnice w powinowactwie badanych żywic względem jonów Cu^{2+} można tłumaczyć ich odmienną budową chemiczną, strukturą fizyczną oraz wielkością cząstek.

W przypadku badanych żywic jonowymiennych, wartości stałej 1/n izotermy Freundlicha znajdowały się w zakresie 0,21–0,32. Można zatem stwierdzić, że niejednorodność energetyczna badanego układu sorpcyjnego i intensywność procesu usuwania jonów Cu^{2+} na ww. jonitach jest umiarkowana. Wartość parametru K równania Freundlicha była najwyższa również dla jonitów S 930 i S 940.

Słowa kluczowe: *miedź, żywice jonowymienne, izoterma Langmuira, izoterma Freundlicha*

The Possibilities of Utilising Postoptimal Analysis for the Decision-Making on the Trends and Concentration of Coal Sales

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Abstract

When developing optimal coal production and sales plans for coal mines, one is often faced with the necessity to modify them, which implies the rationality of such plans. This is achieved through postoptimal analysis, which allows coal mines' production plans, formally optimal, to be modified. The article presents the possibilities of utilising postoptimal analysis developed as part of a method for the rationalisation of production decisions with regard to the management of a coal company. The algorithms resulting from this analysis, accompanied by examples of their practical application, illustrate the possibility of presenting the economic effects of adjustments, if any, quantitatively, which also includes adapting the coal production and sales plans to actual demand, both in terms of quantity and quality. The provided examples of adjustments to the optimal plan concern the "producer-recipient" relationship and the concentration of coal sales.

Keywords: *optimization, post-optimal analysis, Simplex algorithm*

General description of the proposed approach

The developed production-rationalisation approach is a combination of the results of optimising coal production and sales programmes (using the SIMPLEX algorithm) with the algorithmically developed multi-aspect post-optimal analysis. The optimisation model developed and adapted to the conditions of a group of mines (companies) is as follows [1, 2, 3, 4, 5, 6, 7, 8]:

Objective function (quality coefficient):

$$F = \sum_{i=1}^{r_j} \sum_{j=1}^{p} \sum_{k=1}^{m_{ij}} (c_{ijk} - kz_{ijk}) \cdot x_{ijk} - \sum_{j=1}^{p} Ks_j \rightarrow \max \qquad (1)$$

Constraints:

$$\sum_{i=1}^{r_j} \sum_{j=1}^{p} \sum_{k=1}^{m_{ij}} x_{ijk_n} \leq Z_k \quad \text{dla każdego } k, \qquad (2)$$

$$\sum_{i=1}^{r_j} \sum_{n=1}^{m_{ij}} x_{ijk_n} \cdot b_{ijk_n} \leq Qs_j \quad \text{dla każdego } j, \qquad (3)$$

$$\sum_{i=1}^{r_j} \beta_{ij} = 1 \quad \text{dla każdego } j, \qquad (4)$$

$$x_{ijk} \geq 0 \,, \qquad (5)$$

where:

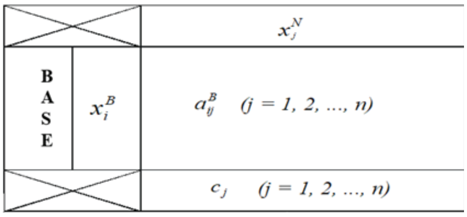
c_{ijk} – price of the *ij*-type of coal accepted by the *k* demand group;
kz_{ijk} – unit variable cost of the *i* type of coal in the conditions of the *j* mine;
Ks_j – total fixed cost of production in the conditions of the *j* mine;
x_{ijk} – net production of the *ij*-type of coal accepted by the k_n demand group;
Z_k – demand of the *k* group of recipients;
Qs_j – total aggregate gross production of the *j* mine;
i – coal type index, $i = 1, 2, \dots, r_j$,
j – mine index; $j = 1, 2, \dots, p$,
k_n – demand group index; $k = 1, 2, \dots, m_{ij}$, where m_{ij} means the size of the k_n set for *ij* type of coal;
b_{ij} – gross/net conversion factor;
β_{ij} – the share of the production of a given type of coal in the total gross production of the mine.

What is important is that in order to accurately reflect the phenomenon of underutilisation of the production capacities typical in market and competition conditions, in each case the criterion function must take into account the division of total costs into fixed and variable costs. Given the interests of any mining company operating in the current market conditions, the most appropriate and viable optimisation is one based on the profit criterion, as it allows the company to refrain from fully meeting the demand unless it is profitable. This can be formally factored in in the optimisation task by placing inequality constraints (2).

The above model leads to a solution in the form of an annual optimal production plan for the company. Although formally optimal (in terms of the linear quality coefficient), the resulting solution does not necessarily have to be the most advantageous from the point of view of the company's interests. At this point, it is necessary to analyse the effects of the desirable optimal-plan adjustments that would make it possible to rationally revise the plan given the prevailing conditions. Adjustments to the optimal plan are made as part of the post-optimal analysis, which constitutes a multi-faceted tool allowing for the fulfilment of the practical conditions mentioned in [3] that are relevant from the decision-maker's point of view. The author confined himself to presenting the algorithm of the adjustment procedure (related to the subject of this publication) along with the numerical example of how the procedure can be used in practice.

The proposed scope of postoptimal analysis

The postoptimal analysis discussed in this publication includes the exploration of how changes to decision variables



Rys. 1. Ogólna postać tablicy SIMPLEX; Źródło: opracowanie własne
Fig. 1. The general form of the SIMPLEX table; Source: Own elaboration

impact on the effect of optimisation, based on the results of the SIMPLEX algorithm. This in practice entails the possibility of accounting for additional important factors, such as the relationships between the producer and the recipient.

The postoptimal analysis therefore allows one to determine which coal production and sales programme will be rational in specific conditions.

The analysis is based on the data obtained from the SIMPLEX algorithm (specifically the SIMPLEX final table) and the values of underlying variables.

The SIMPLEX table offers a complete set of accounting equations and coefficients of goal function sensitivity to changes in the decision variables. The basic form of the SIMPLEX table is shown in Fig. 1.

The key to the figure is as follows:
a_{ij}^B – constraint coefficients forming the A matrix;
x^B, x^N – vectors of basic and nonbasic decision variables, respectively;
c – vector of objective-function coefficients (of shadow prices).

The formal starting point for the post-optimal analysis is, therefore, the optimal solution, which – in relation to the basic and nonbasic variables and the quality coefficient – is represented by the following equations [4, 5, 6, 7, 9]:

$$x^B = \left[A^B\right]^{-1} \cdot B - \left[A^B\right]^{-1} \cdot A^N \cdot x^N \qquad (6)$$

$$J = c^{BT} \cdot \left[A^B\right]^{-1} \cdot B - [[c^{BT} \cdot \left[A^B\right]^{-1} \cdot A^N]^T - c^N]^T \cdot x^N \qquad (7)$$

where:
A^B, A^N – submatrixes of the A matrix (A – matrix of the constraint coefficients);
B – vector of the right-hand sides of the equation;
c^B, c^N – subvectors of objective-function coefficients;
J – objective function (quality coefficient).

The post-optimal analysis will directly use the formulas obtained after substitutions and reductions [1, 3, 4, 5, 6]:

$$x^B = x^{BO} = x^{BO} - A^O \cdot x^N \qquad (8)$$

and

$$J = J^O - c^{OT} \cdot x^N \qquad (9)$$

where:
x^{BO} – vector of the optimal values of basic variables;
c^O – shadow prices of nonbasic variables, ≥ 0 for maximisation of the quality coefficient and negative for minimisation;
A^O – matrix of optimal-solution coefficients;
J^O – optimal value of the quality coefficient.

The post-optimal analysis can be used to change selected decision variables while maintaining the feasibility of the solution, i.e. maintaining the positive values of all variables and taking into account their mutual relations expressed with the formula (8). As indicated by the relationship (9), the shadow prices can be used to estimate the economic effects of departing from the optimal solution as a result of an increase in nonbasic variables [1, 3, 5]. What is also important is that the adjustments of production plans can be made without having to solve the problem (start the optimisation procedure) again from the beginning, substantially reducing the calculation time.

The algorithm for incorporating producer-recipient relationships

If some of the non-underlying variables have zero shadow prices, they can be modified without any losses to the quality indicator [equation (9)]. Such ambiguities in the optimisation solution are often encountered while planning coal production. This provides the decision-maker with a certain degree of freedom when it comes to establishing the final structure of coal production and sales (e.g. by taking into account the existing producer-recipient relationships and concentration of sales directions). Should the adjustment generate losses, postoptimal analysis will make it possible to assess their validity by comparing them with the benefits resulting from the modification of the plan.

An indisputable benefit for a coal mine which is linked to a specific recipient lies in the fact that the mine acquires a regular customer for its product (e.g. through long-term contracts) and can negotiate favourable coal prices (e.g. the need to adjust the quality of production to the recipient's requirements). The strategic recipients of the mining industry are power plants and CHP plants. Such a solution is beneficial for the recipient also due to there being fewer coal acquisition "channels", which lowers the related costs of transport. At the same time, a need may arise to restrict sales to other customers or even forgo some of them (this is true in the case of modifying the obtained solution for an optimal coal production and sales plan, while retaining its optimality). In such a case, regaining "lost" customers may prove difficult or even impossible. For this reason, when cooperating with only several customers, the coal mine should reconsider whether this strategy is profitable. An undoubtedly adverse effect of this decision occurs if the recipient associated with the mine is forced to reduce its demand or goes into liquidation. The situations described above are obviously extreme cases that were only mentioned to make the reader aware of the problem.

From a computational point of view, this strategy boils down to finding, according to the equation:

Tab. 1. Optymalny plan produkcji po korekcie „powiązanie producent–odbiorca"; Źródło: opracowanie własne

Tab. 1. An optimal production plan following the adjustment of the "producer-recipient relationship"; Source: Own elaboration

Company „Alpha"				
Max. Extraction: 15,949,350 ton		Profit: 316,267,643 zł		
Sold: 11,423,865 ton		Company reserves: 1,854,588 ton		
Mine „A"				
Max. Extraction: 1,454,750 ton		Profit: 4,806,243 zł		
Sold: 597,902 ton		Mine reserves: 0 ton		
Name of consumer group	Coal size grade	adjusted amount of sales [ton]	The basic amount of sales [ton]	Difference + increase − decrease [ton]
Dust kettles	fine coal I	264,765	264,765	0
Dust kettles	fine coal II	317,135	317,135	0
Grates 4	slurry	16,002	16,002	0
Dumping coal	cobble	160,023	160,023	0
Dumping coal	nut coal	21,821	21,821	0
Dumping coal	fine coal IIA	675,004	675,004	0
Mine „B"				
Max. Extraction: 793,500 ton		Loss: −4,352,243 zł		
Sold: 121,880 ton		Mine reserves: 400,338 ton		
Name of consumer group	Coal size grade	adjusted amount of sales [ton]	The basic amount of sales [ton]	Difference + increase − decrease [ton]
Grates 3	fine coal II	121,880	113,486	8,394
Dumping coal	coaking coal	271,282	252,598	18,685
Mine „C"				
Max. Extraction: 1,110,900 ton		Profit: 4,8,896,429 zł		
Sold: 989,348 ton		Mine reserves: 121,552 ton		
Name of consumer group	Coal size grade	adjusted amount of sales [ton]	The basic amount of sales [ton]	Difference + increase − decrease [ton]
Export 5	coaking coal	123,542	123,542	0
Coking plants 3	coaking coal	865,806	865,806	0
Mine „D"				
Max. Extraction: 3,174,000 ton		Profit: 53,348,590 zł		
Sold: 1,653,633 ton		Mine reserves: 1,501,900 ton		
Name of consumer group	Coal size grade	adjusted amount of sales [ton]	The basic amount of sales [ton]	Difference + increase − decrease [ton]
Export 2	coaking coal	302,606	292,713	9,893
Export 3	coaking coal	220,455	220,455	0
Indv. consumers 2	cobble	36,934	36,934	0
Indv. consumers 3	fine coal IIA	637,566	637,566	0
Grates 3	fine coal II	0	8,394	-8,394
Coking plants 1	coaking coal	408,682	418,575	-9,893
Chamber grates 1	fine coal IIA	47,390	47,390	0
Dumping coal	fine coal I	18,467	18,467	0
Mine „E"				
Max. Extraction: 2,988,850 ton		Profit: 73,490,006 zł		
Sold: 2,934,441 ton		Mine reserves: 9,893 ton		
Name of consumer group	Coal size grade	adjusted amount of sales [ton]	The basic amount of sales [ton]	Difference + increase − decrease [ton]
Export 1	coaking coal	22,984	22,984	0
Export 2	coaking coal	0	9,893	-9,893
Export 8	nut coal	38,855	38,855	0
Indv. consumers 2	cobble	215,197	215,197	0
Dust kettles	fine coal I	206,231	206,231	0
Dust kettles	fine coal IIA	1,545,235	1,545,235	0

Dust kettles	fine coal II	863,778	863,778	0
Grates 4	slurry	13,752	13,752	0
Chamber grates 2	slurry	28,409	36,803	-8,394
Dumping coal	slurry	44,516	36,122	8,394
Mine „F"				
Max. Extraction: 3,385,600 ton			Profit: 105,742,684 zł	
Sold: 3,069,123 ton			Mine reserves: 0 ton	
Name of consumer group	Coal size grade	adjusted amount of sales [ton]	The basic amount of sales [ton]	Difference + increase – decrease [ton]
Export 7	cobble	225,012	225,012	0
Coking plants 2	coaking coal	68,243	78,136	-9,893
Export 8	nut coal II	46,885	46,885	0
Indv. consumers 2	cobble	18,507	18,507	0
Coking plants 1	coaking coal	241,457	231,563	9,894
Dust kettles	fine coal I	243,520	243,520	0
Dust kettles	fine coal IIA	23,675	23,675	0
Dust kettles	fine coal II	2,201,825	2,201,825	0
Dumping coal	coaking coal	228,073	228,073	0
Dumping coal	nut coal	13,995	13,995	0
Dumping coal	slurry	74,409	74,409	0
Mine „G"				
Max. Extraction: 3,041,750 ton			Profit: 34,335,366 zł	
Sold: 1,915,250ton			Mine reserves: 520 ton	
Name of consumer group	Coal size grade	adjusted amount of sales [ton]	The basic amount of sales [ton]	Difference + increase – decrease [ton]
Indv. consumers 2	cobble	53,039	53,039	0
Export 9	fine coal IIA	933,003	932,482	521
Export 9	fine coal II	206,112	206,632	-520
Indv. consumers 3	fine coal IIA	677,516	677,516	0
Dust kettles	fine coal IIA	0	521	-521
Dust kettles	fine coal II	12,155	12,155	0
Chamber grates 2	fine coal II	33,426	33,426	0
Grates 4	slurry	53,315	53,315	0
Dumping coal	nut coal	15,194	15,194	0
Dumping coal	coaking coal	1,057,470	1,057,470	0

$$x_i^B + a_{ik}^o \cdot x_k^N \geq 0 \quad (10)$$

such a nonbase variable that links the mines to a specific recipient accepting the type of coal offered.

The balance relation between the nonbasic variable and basic variables based on the coefficients of a selected SIMPLEX tableau column is as follows:

$$x_i^B = \overline{x}_i^B + a_{ik}^O \cdot x_k^N \quad (11)$$

where: $\overline{x}_i^B$ – a new adjusted value of the basic variable.

After adjusting the defined variable value x_j^N, the new basic variables will take the following form:

$$\overline{x}_i^B = x_i^B - a_{ik}^O \cdot x_k^N \quad (12)$$

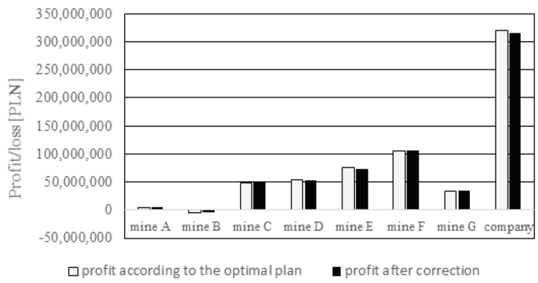
The calculation procedure for the proposed strategy is as follows [3]:
1. From the system of equations (12), the one is chosen for which the quotient:

$$\frac{x_i^B}{a_{ik}^O} > 0 \quad (13)$$

is the smallest and positive. It is the maximum value by which it is possible to increase the nonbasic variable without exceeding the constraints of the model.

2. If the change is satisfactory to the decision maker, the required adjustment to the i basic variable is made by increasing the k nonbasic variable by the value $\frac{x_i^B}{a_{ik}^O}$. This yields a minimum decrease in the value of the quality coefficient. In the case of thus determined value of the nonbasic variable, the remaining values of the basic variables are calculated according to the formula (12), and the calculation procedure is completed.

Following the steps in points 1 and 2 of the strategy in question, one can find the maximum value of the non-underlying variable (production volume), which does not affect the restrictions of the task and causes a minimal change to the quality indicator. It is by this volume, or the volume assumed by the decision-maker, that the underlying vari-



Rys. 2. Zysk/strata spółki i kopalń według planu optymalnego i po korekcie powiązania producent–odbiorca; Źródło: opracowanie własne
Fig. 2. Profit/loss of the company and coal mines according to the optimal plan and after adjusting the producer-recipient relationship; Source: Own elaboration

able (sales) which captures the link between the coal mine and the recipient, is increased, and the other underlying variables are adjusted. The condition to be met in order for a decision-maker to create an exclusive link between a specific recipient and a specific mine is that the mine is able to satisfy that decision-maker's needs in both quantitative and qualitative terms. Once this condition is met, the calculation procedure presented above will essentially consist of a search through all non-underlying variables linked to a given coal mine and mines which sell coal to the same recipient, and the elimination of their sales. Any resulting losses must be then set by the decision-maker against benefits brought about by the said strategy.

Assessing the effects of the assumed adjustment of the producer-recipient relationship

On analysing the optimal production and sales plan of company *Alfa* (Table 1, column 4), one will notice small sales figures in the following mines:

- coal mine "D" – 8,394 tonnes for the recipient "Grates 3";
- coal mine "E" – 9,893 tonnes for the recipient "Export 2";
- coal mine "F" – 521 tonnes for the recipient "Dust kettles".

Supplying such small amounts of coal to the recipient is not profitable for the sole reason of transport costs. For example, coal mine "B" could increase its production by 8,394 tonnes, because the "Grates 3" group is also a recipient of its coal.

The minimum optimal sales flow was assumed to amount to 12,000 tonnes. For this flow volume, the company's optimal production and sales plan was adjusted in accordance with the above-presented algorithm. The results of the adjustment are shown in Table 1. Figure 2 shows profit/loss trends in the respective coal mines and the company.

The adjustment resulted in the following changes when compared to the optimal plan [3]:

1) In coal mine "B" – increase in sales to the recipient "Grates 3" by 8,394 tonnes, resulting in the removal of this recipient from the sales plan of coal mine "D". In consequence, the sales volume grew by 7.4%, reducing the loss of coal mine "B" by 10%; the amount of unused reserves dropped by 6.3%.

2) In coal mine "D", following the removal of the recipient "Grates 3", the sales volume recorded a 0.5% decrease, causing a profit reduction of 2.18%. The coal mine's reserves increased by the amount of coal sold to the recipient removed from the plan.

3) The production plans of coal mines "A" and "C" remained unchanged.

4) As regards coal mine "E", its sales dropped by 0.62%, resulting in profit lower by 3.48%.

5) The recipient of coal was replaced in the production plans of coal mine "F", which resulted in a slight (by PLN 466) increase in profit.

6) In coal mine "G", the low volume of sales (521 tonnes) for the recipient "Dust kettles" was cancelled in favour of the recipient 'Export 9'. This is also the amount by which the sales of fine coal II assortment dropped for this recipient.

7) The company's profit resulting from this adjustment dropped by 1.07%; sales dropped by 0.7%; production reserves recorded a 0.4% decrease.

Summary

1. The proposed method allows the analysis and evaluation of additional practical aspects deemed relevant, which change over time and which were not included in the general model of optimisation.

2. The presented examples of practical uses of the method illustrate the possibility of depicting the economic effects of adjustments in quantitative terms – this includes adapting coal production and sales plans to actual changes in both the level and structure of demand.

3. The coal production and sales programmes, which meet the adopted optimisation criterion in adjusted (through post-optimal analysis) conditions, are deemed rational in the decision-making scenario in question.

4. The presented method facilitates the adaptation of production decisions to relevant, both internal and external, additional conditions, as well as their changes, while fully accounting for the effects of alternative decisions under consideration.

The paper presents results of research conducted in AGH University of Science and Technology no. 16.16.100.215

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Możliwości wykorzystania analizy postoptymalnej do podejmowania decyzji o kierunkach i koncentracji zbytu węgla

Przy opracowywaniu optymalnych programów produkcji i sprzedaży węgla dla kopalń występuje niejednokrotnie konieczność ich modyfikacji, co implikuje racjonalność planów produkcji i sprzedaży węgla. Realizuje się to dzięki analizie postoptymalnej, pozwalającej na modyfikację formalnie optymalnych planów produkcyjnych kopalń. W artykule zaprezentowano możliwości analizy postoptymalnej opracowanej w ramach metody racjonalizacji decyzji produkcyjnych dla potrzeb zarządzania spółką węglową. Opracowane w ramach tej analizy algorytmy poparte przykładami praktycznego ich wykorzystania ilustrują możliwości ilościowego ujmowania skutków ekonomicznych ewentualnych korekt, w tym dostosowania planów produkcji i sprzedaży węgla do realnych zmian zapotrzebowania, zarówno w sensie ilościowym jak i jakościowym. Podane przykłady korekt planu optymalnego dotyczą powiązania producent-odbiorca oraz koncentracji zbytu węgla.

Słowa kluczowe: *optymalizacja, analiza postoptymalna, algorytm Simpleks*

Projektowanie obudowy wyrobisk specjalnych z uwzględnieniem obciążeń użytkowych

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Abstract

Obudowa, obok zabezpieczenia wyrobiska przed ciśnieniem deformującego się górotworu, pełni również funkcję konstrukcji nośnej dla wyposażenia wyrobiska. Dla realizacji procesu technologicznego w kopalni podziemnej wykonuje się często wyrobiska specjalne, charakteryzujące się, poza znacznymi wymiarami przekroju poprzecznego, dodatkowymi obciążeniami obudowy pochodzącymi od podwieszonych na niej elementów. Podjęty problem został przedstawiony na przykładzie wyrobisk komorowych pełniących funkcję stacji przeładunkowych. Realizacja zadań transportowych w tych wyrobiskach wymagała zabudowy większej liczby tras kolejki podwieszanej. Do rozwiązania zadania wykorzystano metody numeryczne uwzględniające obciążenie ze strony górotworu oraz obciążenie statyczne i dynamiczne, pochodzące od zainstalowanych i przemieszczających się urządzeń transportowych. W artykule przedstawiono również założenia do postępowania przy projektowaniu wyrobisk specjalnego przeznaczenia.

Słowa kluczowe: *wyrobiska górnicze, stateczność wyrobisk, obudowa wyrobisk górniczych, dobór obudowy*

1. Wstęp

Prowadzenie podziemnej eksploatacji górniczej wymaga wykonania i utrzymywania wielu wyrobisk korytarzowych i komorowych. Roboty górnicze w otaczającym je górotworze powodują zachwianie równowagi panujących w nim naprężeń i odkształceń, co w konsekwencji prowadzi do przemieszczeń masywu w stronę wybranej przestrzeni i obciążenia obudowy wyrobisk. Względy technologiczne często wymagają wykonywania wyrobisk o dużych wymiarach przekroju poprzecznego, co jest powodem rosnących obciążeń obudowy oraz zwiększenia rozpiętości elementów obudowy wpływającej na niekorzystny rozkład i wielkość sił wewnętrznych i naprężeń. Z drugiej strony mechanizacja robót górniczych powoduje, że obudowa staje się konstrukcja nośną dla wyposażenia wyrobiska, co powoduje dodatkowe jej obciążenie i zwiększa wymagania w zakresie jej nośności.

Z tego punktu widzenia stwierdza się, że utrzymanie stateczności wyrobisk wymaga prowadzenia specjalnych działań zmierzających do wzrostu podporności obudowy, szczególnie w rejonach występowania największych jej obciążeń ze strony deformującego się górotworu i obciążeń użytkowych.

2. Podstawy teoretyczne obliczeń statycznych obudowy wyrobisk górniczych

Obudowa wyrobisk korytarzowych obciążona jest siłami lub ciśnieniem powstałymi wskutek występowania wielu różnych czynników takich jak lokalizacja wyrobiska, właściwości ośrodka, procesy naprężeniowo – deformacyjne zachodzące w górotworze, parametry techniczne wyrobiska, konstrukcja obudowy czy wyposażenie wyrobiska i sposób jego użytkowania itp. [1,5,7] (rys. 5.2).

Obciążenia działające na obudowę można podzielić na [12,13,14,15]:

- oddziaływanie stałe – oddziaływanie, które prawdopodobnie występuje w sposób ciągły przez okres odniesienia i którego zmiany wartości w czasie są małe w porównaniu z wartością średnią lub zmienia się tylko w jednym kierunku, zmierzając do jakiejś wartości granicznej.
- oddziaływanie zmienne – oddziaływanie, którego zmiany wartości w czasie nie są pomijalne w porównaniu z wartością średnią i nie są monotoniczne.

Do obciążeń stałych zalicza się ciężar własny stałych elementów konstrukcji obudowy i wyposażenia wyrobiska, ciężar skał zawartych w strefie odprężonej, plastycznej lub zniszczenia oraz ciśnienie hydrostatyczne wody.

Obciążenie zmienne to głównie obciążenie technologiczne oraz środowiskowe. Te pierwsze zależne są od funkcji i sposobu użytkowania wyrobiska, zaś drugie zależne od środowiska, w którym wyrobisko jest wykonane.

W praktyce mogą występować jeszcze obciążenia wyjątkowe, tj. obciążenia, których wystąpienie ze znaczną wartością jest mało prawdopodobne w rozpatrywanej konstrukcji i w danym okresie odniesienia.

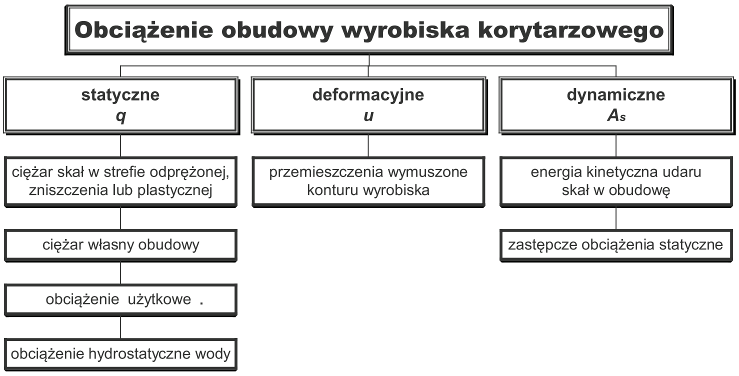
Przy sprawdzaniu stanów granicznych nośności konstrukcji obudowy zwykle stosuje się kombinację podstawową obciążenia, która ma postać:

$$q_p = \sum_{i=1}^{m} \gamma_{fi} \cdot G_{ki} + \sum_{i=1}^{m} \psi_{oi} \cdot \gamma_{fi} \cdot Q_{ki} \, , kN/m, \qquad (1)$$

gdzie: G_{ki}, Q_{ki} – wartości charakterystyczne obciążeń stałych; G_{ki}, Q_{ki} – wartości charakterystyczne obciążeń zmiennych; γ_{fi} – współczynnik obciążenia; ψ_{oi} – współczynniki jednoczesności obciążeń zmiennych.

Jeżeli mogą wystąpić obciążenia wyjątkowe, to stosuje się kombinację wyjątkową, która przyjmuje postać:

$$q_w = \sum_{1}^{m} \gamma_{fi} \cdot G_{ki} + 0{,}8 \cdot \sum_{1}^{n} \gamma_{fi} \cdot Q_{ki} + F_a \, , kN/m, \qquad (2)$$



Rys. 1. Rodzaje obciążenia obudowy wyrobisk korytarzowych i komorowych [1,5,7]
Fig. 1. Load types of mine galleries [1,5,7]

gdzie: F_a – obciążenie wyjątkowe, kN/m; G_{ki}, Q_{ki}, γ_{fi}, ψ_{oi} – ja we wzorze (1).

Wymiarowanie stalowej obudowy odrzwiowej podatnej zaleca się wykonywać etapami.

W etapie I wymiarowanie stalowej obudowy odrzwiowej prowadzi się w stanie usztywnionym metodą stanów granicznych stosując model ciała sztywno – plastycznego ze wzmocnieniem. Uproszczoną zależność, określającą wielkość naprężeń dopuszczalnych w stanie granicznym nośności dla modelu ciała sprężysto – plastycznego ze wzmocnieniem przedstawia wzór [2,4,5]:

$$\sigma_{dop} = \frac{R_e \cdot (m_s + n_1)}{\gamma_s \cdot m_1}, MPa, \tag{3}$$

gdzie: σ_{dop} – dopuszczalna wartość naprężeń w obudowie, MPa; R_e – granica plastyczności stali przy rozciąganiu i ściskaniu, MPa; m – współczynnik Schaefera; n_1 – współczynnik zależny od granicy plastyczności i wytrzymałości stali na rozciąganie; γ_s – współczynnik materiałowy zależny od granicy plastyczności stali; m_1 – współczynnik warunków pracy obudowy uzależniony od funkcji i przewidywanego okresu istnienia wyrobiska.

Etap II obejmuje dobór parametrów konstrukcyjnych złącza w oparciu o określoną wymaganą jego nośność:

$$N_z = 0{,}8 \cdot N \cdot d_1,\ kN, \tag{4}$$

gdzie: N_z – wartość nośności złącza odrzwi obudowy, kN; N – wartość siły osiowej w miejscu złącza odrzwi dla prognozowanego całkowitego obciążenia obliczeniowego przypadającego na 1 mb wyrobiska, kN; d_1 – odległość między odrzwiami obudowy ŁP obliczona ze wzoru (1), [m].

Etap III obejmuje sprawdzenie posadowienia odrzwi obudowy w oparciu o przybliżony warunek:

$$A_{min} = \frac{0{,}5 \cdot q_c \cdot S_w}{R_c}, m^2, \tag{5}$$

gdzie: A_{min} – wymagana wielkość powierzchni posadowienia łuku ociosowego odrzwi, m²; q_c – obciążenie obliczeniowe odrzwi obudowy, MN/m; S_w – szerokość wyrobiska w świetle obudowy, m; R_c – wytrzymałość obliczeniowa na ściskanie skał spągowych, MPa.

Wartości sił wewnętrznych i naprężeń w odrzwiach obudowy oblicza się za pomocą modelowania numerycznego metodą elementów skończonych. Obliczenia obudowy najczęściej przeprowadza się przy założeniu, że odrzwia tworzą konstrukcje belkowe, przez które rozumie się matematyczne modele obliczeniowe wykonywane w postaci odpowiednio ukształtowanych odcinków prostych (prętów) połączonych ze sobą, a wykonanych z typowych profili górniczych.

3. Przykład planowanej przebudowy odcinka przekopu w celu uzyskania gabarytów przekroju poprzecznego dla stworzenia stacji przeładunkowej materiałów z kołowej kolei podziemnej na samojezdną, spalinową kolej podwieszaną

3.1. Ogólna charakterystyka przebudowywanego wyrobiska

Planowane do przebudowy wyrobisko wykorzystywane jest jako arteria wentylacyjna i transportowa. W ramach wyposażenia zabudowane są w nim 2 torowiska kolei podziemnej o rozstawie torów 900 mm oraz przejście dla załogi. Na łukach stropnicowych podwieszone są rurociągi oraz kable energetyczne mediów kopalnianych, a także trasa (odcinkowo 2 ciągi tras) kolejki podwieszanej typu KSP (rys. 2a). Na łukach ociosowych podwieszone jest okablowanie oświetlenia i łączności dołowej (rys. 2b).

Przebudowę odcinka przekopu planowano wykonać z obudowy ŁP10/V32 na obudowę o rozmiarach 7,2 m × 5,2 m. Wybór podyktowany był koniecznością zmiany funkcji przebudowanego odcinka wyrobiska na stację przeładunkową materiałów z kolei podziemnej kołowej na kolej spalinową, podwieszaną, samojezdną. Na przebudowanym odcinku zaplanowano zabudowę podwójnego toru zarówno kolei podziemnej kołowej jak i kolei spalinowej podwieszanej.

Ze względu na zabudowę kolei podwieszanej na obudowie, w obliczeniach konieczne było uwzględnienie obciążenia obudowy pochodzące zarówno od górotworu jak i maksymalnego ciężaru elementów transportowanych koleją podwieszaną.

Z uwagi na projektowany, długi okres istnienia ww. stacji przeładunkowej zaproponowano zastosowanie jako opinki betonitów układanych na długości łuku stropnicowego oraz siatki węzłowej ciężkiej na łukach ociosowych. Zalecono posadowienie obudowy na stopach podporowych o powierzchni min. 400 cm².

3.2. Warunki geologiczno-górnicze w otoczeniu analizowanego odcinka wyrobiska

Planowany do przebudowy odcinek wyrobiska zlokalizowany jest w górotworze karbońskim w pakiecie skał iłowcowo-piaskowcowych warstw górnorudzkich. Według

a)


b)


Rys. 2. Widok planowanego do przebudowy wyrobiska. a) z podwójną trasą kolejki podwieszanej; b) z pojedynczą trasą kolejki podwieszanej
Fig. 2. View of mine gallery planned to reconstruction: a) with double overhead rail along the route; with single overhead rail along the route

wykonanych badań penetrometrycznych wytrzymałości skał z rejonu planowanych robót kształtują się następująco:

- iłowiec – Rc = 37,3 ÷ 24,7 MPa, przy zmienności 35%,
- piaskowiec – Rc = 42,6 MPa, przy zmienności 19%,
- węgiel pokładu 404/5 – Rc = 11,2 MPa, przy zmienności 26%,
- węgiel pokładu 405/1 - Rc = 13,4 MPa, przy zmienności 26%.

Zgodnie z wykonanymi badaniami penetrometrycznymi średnia wytrzymałość na wytrzymanie skał w stropie wyrobiska wynosi 37,97 MPa, przy współczynniku zmienności 31% .

Na wybiegu planowanego do przebudowy odcinka przekopu nie stwierdzono zaburzeń tektonicznych.

Przekop zaliczony jest do 1-go stopnia zagrożenia wodnego. Według uzyskanych danych jedynie w rejonie skrzyżowań istnieje możliwość zmiany własności fizykomechanicznych skał z uwagi na wzrost ich zawilgocenia.

W otoczeniu przekopu na analizowanym odcinku nie prowadzono robót górniczych ani nad ani pod poziomem wyrobiska. Brak jest też oddziaływujących krawędzi eksploatacji i wyrobisk równoległych do przekopu.

W rejonie projektowanej stacji w trakcie prowadzenia eksploatacji górniczej wystąpiły wstrząsy wysokoenergetyczne. Maksymalną energię wstrząsu określono na wielkość 9×E6 J, a incydentalnie E7 J. Dalsza eksploatacja górnicza projektowana jest w dużej odległości od analizowanego wyrobiska.

W miejscu planowanej przebudowy przekop zaliczony jest do następujących zagrożeń naturalnych: I stopień zagrożenia wodnego, klasa B zagrożenia pyłowego, nie występują zagrożenia metanowe i tąpaniami.

3.3. Obciążenie obudowy analizowanego odcinka wyrobiska

Przeprowadzone obliczenia obciążenia ze strony górotworu obudowy odcinka przebudowywanego przekopu w celu uzyskania gabarytów dla stworzenia stacji przeładunkowej materiałów z kołowej kolei podziemnej na samojezdną, spalinową kolej podwieszaną wynoszą 181 kN/m.

Oprócz obciążenia ze strony górotworu obudowa odcinka przekopu, w celu uzyskania wymaganych gabarytów przekroju poprzecznego, spełniać będzie funkcję konstrukcji nośnej dla:

- dwóch torów jezdnych kolejki podwieszanej, po których jeździć będą lokomotywy spalinowe o długości ok. 9 m i masie własnej ok. 5000 kg wraz z zestawem transportowym o długości ok. 18 m i masie własnej ok. 3000 kg; w sumie zestaw transportowy wraz z lokomotywą będzie miał długość ok. 27 m, a jego sumaryczna masa będzie wynosić ok. 8000 kg; zestaw podnosił będzie elementy o maksymalnej masie 18 000 kg (sekcja obudowy zmechanizowanej),
- rurociągów,
- kabli teletechnicznych.

Schemat układu transportowego przyjęty do obliczeń przedstawiono na rys. 3.

Do obliczeń przyjęto najmniej korzystny układ obciążeń technologicznych obudowy, w którym lokomotywa spalinowa będzie transportować pojedynczy element (np. sekcję obudowy zmechanizowanej) o maksymalnej masie własnej 18 000 kg, podwieszony na belce transportowej w układzie „duo". W obliczeniach uwzględniono również masę własną wszystkich elementów układu transportowego [6,10,12].

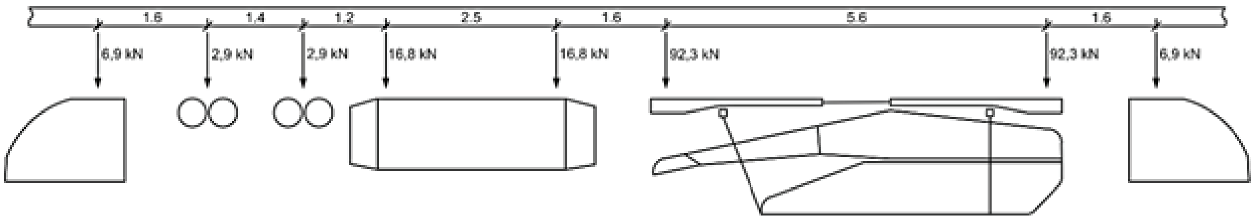
3.4. Obliczenia statyczne obudowy wyrobiska

Wielkość oddziaływania górotworu na obudowę projektowanego wyrobiska przyjęto dla kombinacji najmniej korzystnych warunków geologiczno-górniczych i obciążeń technologicznych. Dla tak przyjętego modelu określono maksymalne wielkości naprężeń w elementach obudowy przy wykorzystaniu metody elementów skończonych.

Na rys. 4 w postaci geometrycznej wizualizacji przedstawiono przykładowy model numeryczny obudowy przyjęty do obliczeń.

Obliczenia przeprowadzono przyjmując następujące założenia [2,3,8,9,11]:

- obudowa w analizowanym wyrobisku wzdłuż wybiegu obciążona jest obciążeniem statycznym wynoszącym 181 kN/m,
- obciążenie odrzwi jest rozłożone równomiernie na całej szerokości obudowy,
- w obliczeniach uwzględniono dodatkowe obciążenie obudowy wynikające z obciążenia technologicznego (rys. 3),
- do obliczeń przyjęto najmniej korzystny układ obciążeń technologicznych obudowy, przy założeniu że wystąpi on równocześnie na obydwu torach jezdnych kolejki podwieszanej,
- z uwagi na funkcję i planowane wyposażenie wyro-



Rys. 3. Układ transportowy przyjęty do obliczeń obciążeń technologicznych obudowy przedmiotowego wyrobiska
Fig. 3. The transport system adopted for calculating the technological loads of the gallery

biska w prowadzonej analizie posłużono się modelem przestrzennym obudowy,

- odrzwia obudowy wykonane są z profilu V32,
- rozstaw odrzwi obudowy wynosi 0,75 m,
- odrzwia wykonane są ze stali o podwyższonych parametrach wytrzymałościowych (np. S480W lub równoważnej), tj.: Re = 480 MPa i Rm = 650 MPa,
- śruby w strzemionach złącz obudowy podatnej dokręcone są z momentem 450 Nm,
- do stabilizacji poprzecznej odrzwi zastosowano rozpory stalowe dwustronnego działania rozmieszczone na obwodzie wyrobiska w odstępie nie większym niż 1,2 m,
- łuki ociosowe posadowione są na stopach podporowych o powierzchni min. 400 cm², ograniczających możliwość przemieszczenia pionowego punktów posadowienia obudowy,
- stalową obudowę odrzwiową wzmocniono wzdłuż całego wybiegu dwoma rzędami podciągów wykonanych z kształtownika V32, przykotwionych kotwami stalowmi o długości 5,8 m i nośności min. 350 kN,
- obliczenia naprężeń granicznych σ_{dop} przeprowadzono przy przyjęciu współczynnika bezpieczeństwa m_1 = 1,5.

Dla tak opracowanego modelu numerycznego obliczono wartości sił wewnętrznych (rys. 5 ÷ 6) oraz naprężeń zredukowanych (rys. 7) w elementach obudowy przy użyciu programu Autodesk Robot Structural Analysis Professional 2016 [10,16].

Z przeprowadzonych obliczeń wynika, że stopień wyczerpania nośności najbardziej wytężonego przekroju elementów konstrukcyjnych obudowy po jej wzmocnieniu dwiema parami kotew stalowych wynosi:

- odrzwia obudowy k = 0,83
- podciągi k = 0,59
- kotwy k = 0,72

Podsumowując wykonane obliczenia można stwierdzić, że projektowana obudowa wyrobiska po wzmocnieniu dwoma rzędami podciągów przykotwionych kotwami o nośności min. 350 kN spełnia kryterium bezpieczeństwa.

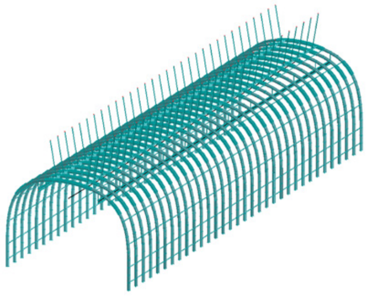
4. Podsumowanie

Przeprowadzone obliczenia symulacyjne i analiza ich wyników nasuwa jednoznaczny wniosek, że w obliczeniach statycznych obudowy wyrobisk podziemnych należy uwzględniać nie tylko obciążenie ze strony górotworu, ale również obciążenia użytkowe.

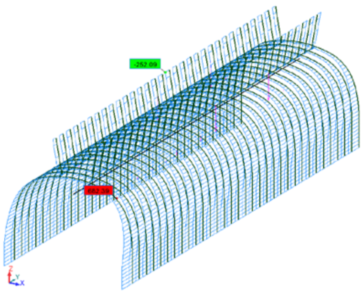
Analiza wyników wielowariantowych obliczeń numerycznych wykazała, że:

- największym obciążeniem użytkowym odrzwi obudowy najczęściej jest ciężar podwieszanej lokomotywy transportującej sekcję obudowy zmechanizowanej. Wzrost wartości obciążenia w odrzwiach osiągać może wówczas nawet 80% wartości obciążenia ze strony górotworu i z reguły przekracza wartość 40 kN,
- podwieszanie przenośnikiem zgrzebłowym lub kolejką podwieszaną do transportu ludzi powoduje wzrost obciążenia odrzwi na poziomie od 6% do 47% wartości obciążenia ze strony górotworem i często przekracza wartość 40 kN,
- dodatkowe obciążenie wentylatorem lutniowym i chłodnicą powietrza powoduje wzrost obciążenia odrzwi na poziomie poziomie od 1% do 15%. W tym przypadku z reguły obciążenie odrzwi nie przekracza wartości 40 kN,
- przeprowadzona analiza jednoczesności występowania obciążeń technologicznych wykazała, że przy występowaniu dwóch obciążeń technologicznych jednocześnie, wartości sił wewnętrznych wzrastają jeszcze bardziej i modele obliczeniowe powinny to uwzględniać.,
- przeprowadzona analiza współpracy sąsiadujących ze sobą odrzwi obciążanych przejazdem kolejki podwieszanej wykazała, że odrzwia sąsiednie, bez podwieszonej szyny jezdnej, praktycznie w ogóle nie biorą udziału w przenoszeniu sił i ugięć. Wartości sił wewnętrznych i ugięć w stosunku do odrzwi obciążanych kształtują się w nich na poziomie od 0% do 4%. Brak współpracy wynika z tego, że obudowa odrzwiowa w kierunku podłużnym łączona jest rozporami o stosunkowo małej sztywności. Obudowa odrzwiowa nie posiada cech rusztu, który w obydwu prostopadłych do siebie kierunkach ma zbliżone sztywności elementów obudowy.

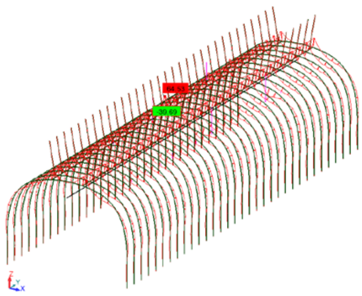
Dla zwiększenia stopnia bezpieczeństwa obudowy wyrobiska na etapie jej doboru, obciążenie ze strony wyposażenia podwieszanego na obudowie powinno być uwzględniane obok obciążenia liniowego ze strony górotworu jako dodatkowa siła skupiona działająca w miejscu zabudowy elementu obciążającego obudowę. W oparciu o tak przeprowadzoną analizę statyczną konstrukcji obudowy będzie można sformułować szczegółowe warunki dotyczące współpracy obudowy z wyposażeniem wyrobiska jak np. zwiększenie liczby punktów podwieszenia szyny jezdnej dla umożliwie-



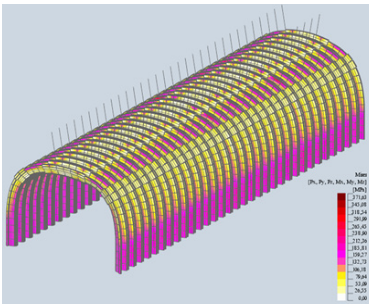
Rys. 4. Geometryczna wizualizacja modelu numerycznego obudowy stacji przeładunkowej przyjętej do obliczeń
Fig. 4. Geometric visualization of the numerical model of the transshipment station lining adopted for calculations



Rys. 5. Kształtowanie się wielkości sił osiowych w elementach obudowy
Fig. 5. The magnitude of axial forces in the lining components



Rys. 6. Kształtowanie się wielkości momentów zginających w elementach obudowy
Fig. 6. The magnitude of bending moments in the lining components



Rys. 7. Kształtowanie się wielkości naprężeń zredukowanych w elementach obudowy
Fig. 7. The magnitude of the von Mises stress in the lining components

nia transportu elementów o dużej masie, czy też zwiększenie nośności obudowy (zmniejszenie odległości pomiędzy odrzwiami, zwiększenie nośności odrzwi poprzez zastosowanie cięższego profilu, wyższego gatunku stali lub zwiększenie nośności złącz) obciążonej elementami wyposażenia wyrobiska.

Podsumowując należy stwierdzić, że problem obliczeń statycznych obudowy jest złożony i wymaga dostosowania do warunków rzeczywistych. Szczególnie w przypadku coraz szerszego stosowania w kopalniach transportu kolejkami podwieszanymi, występowania coraz trudniejszych warunków geologiczno-górniczych oraz wymagań ekonomicznych.

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Designing the Lining of Special Galleries with Consideration of Imposed Loads

The lining, in addition to securing mine galleries against the pressure of deforming rock mass, often acts as a supporting structure for the gallery equipment. In order to implement the technological process in an underground mine, special galleries are also created. Apart from significant cross-section dimensions, these special galleries are characterised by additional lining loads resulting from the equipment suspended on it. The problem under consideration was presented on the example of chamber workings used as loading stations. The implementation of transportation tasks in these workings required the construction of more suspended railway routes. To solve this task, numerical methods were used, taking into account the load from the rock mass, as well as the static and dynamic load from the installed and moving transport equipment. Additionally, this paper presents the procedural principles for designing special purpose galleries.

Keywords: *mining excavations, excavation stability, mining excavation support, selection of the support*

Crisis Management in Mining Companies in the Event of an Epidemic Threat

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Abstract

The emergence of the epidemic in Poland at the beginning of 2020 was reflected in the economic activity, including the operation of mining enterprises. Many of them were forced to take immediate measures to protect the health and life of employees and their families, as well as maintain financial stability in connection with the economic slowdown that took place in the initial period of the epidemic. Preventive measures taken by the management contributed to limiting the spread of the coronavirus among mine workers. The article presents the characteristics of the crisis caused by the epidemiological situation due to the SARS-Cov-2 virus, the challenges faced by mining enterprises during the pandemic, the directions of actions aimed at stopping the spread of the coronavirus among employees, and the epidemiological situation in one of the hard coal mining companies.

Keywords: *mining companies, epidemic, crisis, crisis management*

Introduction

The occurrence of an epidemic threat in a given country means that the government needs to introduce many restrictions, which not only limit the current activity of the society but also severely affect the operation of many enterprises, including those belonging to the mining sector. Pursuant to the Act of December 5th, 2008 on preventing and combating infections and infectious diseases in humans, an epidemic threat is defined as a legal situation introduced in a given area in connection with the risk of an epidemic in order to undertake preventive measures specified in the Act [1]. Closure of borders, economic slowdown, suspension of investments and other activities by certain companies, or a drop in demand for the raw material produced are just some of the difficulties that mining companies must face during an epidemic. In addition to the problems related to the functioning and implementation of the planned investments, mining companies need to deal with the most important problem at the moment, namely ensuring the sense of safety for their employees and their relatives. Due to the inability to completely cease the work of underground mining plants for the duration of a pandemic, it is necessary to systematically implement, for example, those tasks that are necessary to ensure the continuity of their operation. Failure to act, even for a very short time, to use preventive measures or to maintain mining excavations may result in huge material losses, and in extreme cases, contribute to the necessity to close a given plant. This means that enterprises conducting underground mining activities, as one of the few, cannot completely suspend their operation and, despite the occurrence of a threat, must continue carrying out their tasks. Therefore, developing a strategy for mining enterprises to deal with an epidemic crisis is quite difficult and complex. This is because their management boards need to develop such rules and procedures that, on the one hand, will ensure economic security and continuity in the implementation of planned investments [15, 13, 14], in the first place, those aimed at maintaining workings, and on the other hand, guarantee the sense of peace and safety for all employees performing their tasks during an epidemic.

The following article attempts to describe the operation of mining enterprises in the event of a crisis related to an epidemic in the territory of the Republic of Poland.

The concept of crisis and a crisis situation in an enterprise

Crisis is a term derived from the Greek word – "krisis" – which in translation means a choice, a decision-making process, a struggle, and also a fight in which activities are carried out under time pressure [2]. It can also be understood as a condition that threatens a company's survival and the achievement of its goals. It is emphasized that the crisis is an undetectable situation. In general it means an unstable situation that requires reform [16]. In addition, it limits the time available for taking remedial actions and surprises decision-makers with its occurrence, thus putting strong pressure on them [3]. However, it should be remembered that this concept is a well-known term for entrepreneurs. Crisis is closely related to a crisis situation, which, unlike a crisis, concerns a state that results from the formation of certain unfavorable phenomena over time. It is crucial to emphasize that it does not pose a direct threat to the existence of an organization but leads to an unsatisfactory assessment of its activities from the point of view of changes taking place in the environment and/or in relation to the model conditions [4].

So far, mining companies have struggled with many crises, the background of which was immensely diverse. A decline in demand for coal, changes in crude oil prices, increasingly difficult geological and mining conditions, coal imports, restrictions related to gas emissions and instability and uncertainty of economic, socio-environmental and political conditions [5, 9, 10, 11, 12] are just some of the reasons that led to the emergence of a crisis in mining companies, and have always required the management board to take immediate action to mitigate their effects [5]. Therefore, the concept of crisis and a crisis situation in a mining enterprise has become the subject

Tab. 1. Challenges faced by mining companies during the coronavirus epidemic. Source: own elaboration
Tab. 1. Wyzwania postawione spółkom górniczym w czasie epidemii koronawirusa. Źródło: opracowanie własne

ECONOMIC	ORGANIZATIONAL	HEALTH-RELATED
- decline in demand for the manufactured raw material resulting from the suspension of many investments, - decline in the company's stock market value, - the need to find additional capital for the purchase of protective measures for employees, - loss of strategic recipients, - loss of financial liquidity, - the need to limit funds for own investments, - reduction of employee wages	- the need to introduce a temporary ban on entering the mine area for external stakeholders, - adapting workplaces to the guidelines issued by state institutions concerned with limiting the spread of the virus, - providing an appropriate amount of protective and disinfecting agents to mines, as well as organizing teams to supervise the process of room and workstation disinfection, - reorganization of working time, - limiting contact between employees to the necessary minimum, - introducing remote work for those positions that do not require being on the premises of the plant, - organizing underground transport in accordance with the guidelines regarding the number of people, - preparing teams and rooms in the plant in case it is necessary to gather the crew	- employees' fear of illness, - problems with access to protective measures or their insufficient amount in the initial phase, - preparing a procedure in the event of an accident in the workplace, - organizing medical points where employees can seek advice

of many scientific papers [6, 13, 14]. When talking about a crisis, it is also worth paying attention to the concept of crisis management, i.e. all those activities aimed at controlling and overcoming the situation, as well as trying to develop certain actions to be implemented once it occurs [13].

An epidemic as a complex crisis for mining enterprises

The outbreak of the coronavirus epidemic in March 2020 presented all enterprises with a very difficult task. An epidemic means the occurrence of more cases with a given disease in a given area and in a given time than statistically expected [7]. If this situation takes place in more countries in the world, it can be called a pandemic. As already mentioned, the crisis itself is not an issue that companies have not dealt with before. In most cases, they have even managed to develop action plans in the event of their occurrence. Nevertheless, in the case of previous crises, they usually had to deal with only one problem requiring intervention. This time, however, management boards were forced to take immediate action on three planes simultaneously: economic, organizational, healt-related.

The announcement of the occurrence of an epidemic in a given country by the government is connected with the introduction of a number of measures aimed at stopping the epidemic development as much as possible and controlling its course. For almost all enterprises, this means the occurrence of a number of difficulties related to the current operation. Companies concerned with activities that do not allow then to continue them remotely, or those that do not have assets enabling them to suspend their operation and survive in this period, as a result of long-term limitations, are not able to cope with their effects. This often means the loss of many jobs, and in extreme cases, leads to their liquidation.

In the case of companies extracting hard coal using an underground method, the problem is much more complex. Firstly, mines that comprise mining enterprises, despite their resources allowing them to survive during a crisis, must maintain the continuity of works. It is related to the specificity of their functioning. On a daily basis, apart from mining, mines must simultaneously carry out a number of preventive works. These include inspection of excavations, rock mass, ventilation of excavations, control of the amount of water from the rock mass, fires, etc. It is related to the presence of employees on the premises of the plant. Therefore, as mentioned in the introduction, mining enterprises, at the time of the emergence of an epidemic, are forced to prevent the economic and organizational effects of the emerging crisis and must take measures to stop the spread of this epidemic among employees while in the workplace. In the case of economic and organizational difficulties that may lead to a crisis, the following can be distinguished: a decrease in demand for the produced raw material, stock market collapses, an increase in the costs of existing investments, difficulties related to restrictions on functioning in the existing reality, and reorganization of work. In addition, there are challenges related to the pathogen itself: fear among employees and absence. These and other problems contributing to the deepening of the crisis that arose as a result of the epidemic are presented in Table 1.

It is worth emphasizing that, so far, both the difficulties and the effects of the crises reported have been related mainly to either economic or organizational problems. The outbreak of the coronavirus epidemic forced employers to simultaneously take measures to protect the health and life of employees on a very large scale. Therefore, the simultaneous overlapping of so many aspects that must be mastered in a very short time allows for defining the present crisis as a complex crisis.

Recommendations on the operation of industrial plants issued by the Chief Sanitary Inspectorate (GIS) in connection with the spread of SARS-Cov-2 virus in the territory of the Republic of Poland [8]

Due to the fact that in the last few decades, there have been no epidemics on a scale as large as the coronavirus epidemic, no actions were taken to develop procedures for the operation of enterprises during biological threats. As a result of the pandemic in March 2020, the GIS issued recommendations on the operation of industrial plants for the duration

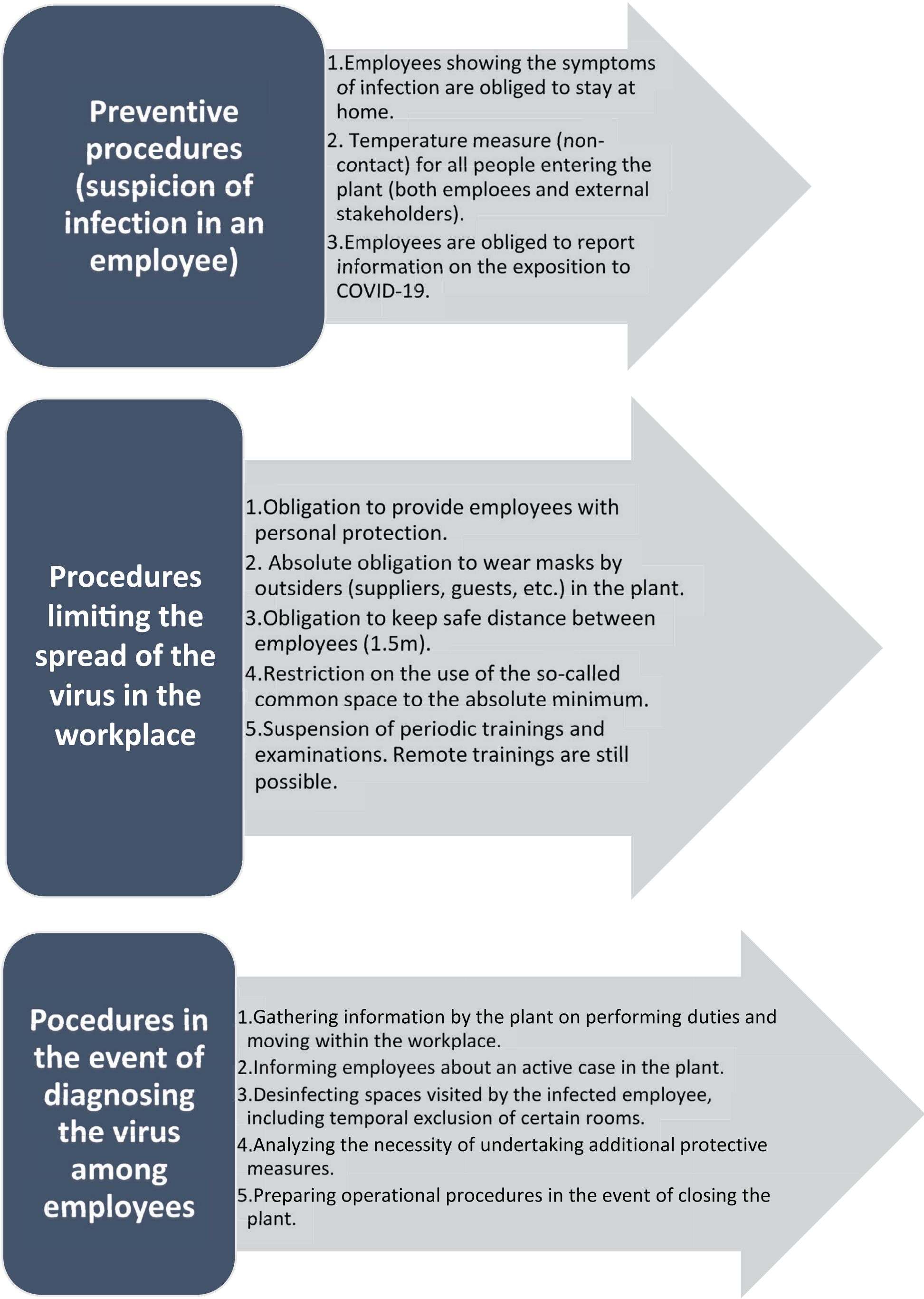

Fig. 1. GIS recommendations on preventing the spread of the coronavirus for industrial plants. Source: [8]
Rys. 1. Wytyczne GIS dla zakładów przemysłowych. Źródło: [8]

of the epidemic threat. They have been divided into 3 groups: prevention, restriction and procedure in the event of a threat. This makes entrepreneurs not only to develop methods to control cases among employees but also to provide them with protective measures. All GIS guidelines and recommendations are presented in Figure 1.

In addition to the recommendations on the operation of enterprises during the epidemic, the GIS has published additional guidelines to help limit the spread of the epidemic and they include [8]:

1. To prevent the spread of the pathogen:
- implementation of procedures aimed at collecting information (every day) on the health condition of employees, contacts with infected individuals or those at the risk of infection.

2. To limit the spread of the pathogen:
- restriction on contacts between employees,
- work in small teams isolated from the rest,
- limiting contacts between employees from individual shifts through the reorganization of work,
- different times of starting and ending work as well as adjusting breakfast breaks to reduce clusters of employees,
- remote work for employees whose duties can be successfully performed from home,

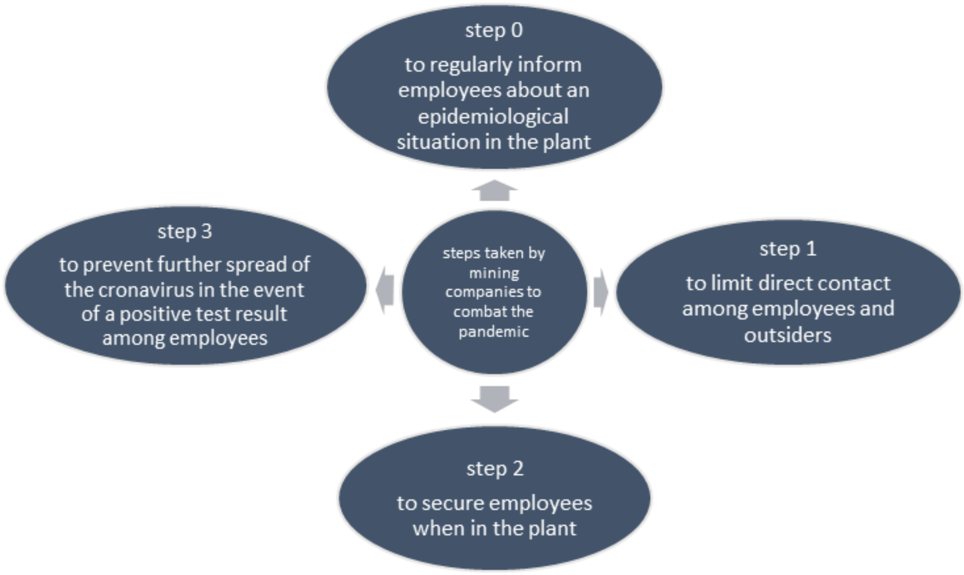

Fig. 2. Steps taken by mining companies to combat the threat of the coronavirus. Source: own elaboration
Rys. 2. Kroki podjęte przez spółki górnicze w walce z zagrożeniem koronawirusem. Źródło: opracowanie własne

- limiting the number of employees in social rooms,
- suspending contacts with external stakeholders (remote meetings are recommended),
- if it is necessary to meet a larger group of people, such as employee briefings, it is recommended to conduct them outdoors. In the case of meetings held indoors, the best possible ventilation of the rooms should be maintained by opening windows and doors;
- preventive decontamination procedures throughout the plant.

3. When an employee tests positive:
- Depending on the possibility, it is recommended that employees work remotely or refrain from work for a period of two weeks in the case of those who have contact with an infected co-worker. If necessary, reserve personnel should be mobilized. In the absence of symptoms for a period of 2 weeks, employees may return to work.

Operation of mining companies during the epidemic

The new reality caused by the outbreak of the coronavirus epidemic has forced the management boards of mining companies to take immediate action to limit the spread of the epidemic among employees. When compared to the crises that mining enterprises had struggled with before, these tasks were much more complex, for instance, due to the need to deal with difficulties in the economic, organizational and epidemic fields at the same time. The previous crises required mainly one aspect to be resolved. In the case of economic problems, mining companies, after years of experience, have developed many plans on how to survive this type of breakdown. This time, the crisis related to the epidemic itself turned out to be the most difficult to deal with.

In order to ensure the safety of their employees and their relatives, the management boards took immediate measures to prevent the development of the epidemic in the mining plants. In the first place, a decision was made to introduce remote work for all positions in the mining industry, the tasks of which could be carried out without the need to stay in the mine. These activities allowed for a significant reduction in the number of people present on the premises of the plant, thus reducing the risk of further spread of the pathogen. Additionally, contacts with external stakeholders were limited to emergencies only. In other cases, they were conducted remotely. However, the most difficult task that had to be performed was securing those employees whose work did not allow for remote continuation. In this case, the immediate procedure used was to measure the temperature of all employees entering the plant and to limit contact between these employees. It should be remembered, however, that limiting contact between employees who carry out mining or repair works underground is extremely hard and, in some cases, even impossible to achieve. In this case, mining companies focused on introducing the need to constantly use personal protective equipment, such as masks and gloves. Additionally, a procedure to be followed in the event of an incident in the mines, belonging to individual companies, was specified. The exact steps taken by the companies to prevent the spread of the coronavirus in the mines are shown and described in Figure 2.

Regular information provided to employees about the epidemic situation in their workplace is a crucial step that was applied in the fight against the epidemic. It allows companies both to avoid chaos and implement subsequent steps to increase the sense of safety among employees.

In the case of the first step, aimed at limiting direct contact between employees and external stakeholders, mining companies decided to implement the following procedures:
- To introduce remote work in office positions both in individual plants and management boards.
- To reduce the number of employees (some employees, in the initial phase of the epidemic, used their outstanding leave).
- To introduce distance between employees: in the case of surface workers (necessary office workers) and un-

Tab. 2. The epidemiological situation in hard coal mines of PGG S.A. (as of September 3rd, 2020)
Tab. 2. Sytuacja epidemiologiczna w kopalniach węgla kamiennego PGG S.A. (stan na dzień 03.09.20 r.)

PGG S.A.	Employment status (as of sept. 3rd, 2020)	Number of infected employees (growing till Sept. 3rd, 2020)	Number of healthy employees (as of sept. 3rd, 2020)
KWK Murcki - Staszic	3849	345 *(9%)*	3504 *(91%)*
KWK Mysłowice – Wesoła	3252	8 *(0,25%)*	3244 *(99,75%)*
KWK Wujek	1350	62 *(5%)*	1288 *(95%)*
KWK ROW – Ruch Chwałowice	2796	322 *(12%)*	2474 *(88%)*
KWK ROW – Ruch Jankowice	3086	703 *(23%)*	2383 *(77%)*
KWK ROW – Ruch Marcel	2902	311 *(11%)*	2591 *(89%)*
KWK ROW – Ruch Rydułtowy	2738	32 *(1%)*	2706 *(99%)*
KWK Piast-Ziemowit - Ruch Piast	3452	24 *(1%)*	3428 *(99%)*
KWK Piast-Ziemowit - Ziemowit	3634	44 *(1%)*	3590 *(99%)*
KWK Ruda – Ruch Halemba	2305	27 *(1%)*	2278 *(99%)*
KWK Ruda – Ruch Pokój	1155	33 *(3%)*	1122 *(97%)*
KWK Ruda – Ruch Bielszowice	2774	657 *(24%)*	2117 *(76%)*
KWK Bolesław Śmiały	1719	94 *(5%)*	1625 *(95%)*
KWK Sośnica	2006	460 *(23%)*	1546 *(77%)*

derground workers (workshops), keeping a distance of 1.5 m from individual positions (unfortunately, not all positions can maintain the recommended distance).

- To change working hours (introduction of a 3-shift work system of 6 hours each, with two-hour breaks enabling the disinfection of rooms and limiting employees' contact from individual shifts).
- In the case of external stakeholders, the preferred contact via mobile devices or postponing the visit to the site to another date. This type of contact is also dedicated to employees from various shifts and from different departments to reduce the possibility of spreading the virus.
- To limit the number of crew in underground transport (trains) and in mine cages, as well as to prevent the formation of clusters of workers waiting for transport.
- To organize additional entries/exits from workplaces in order to reduce the number of people gathering at the same time.
- To organize meetings and divide duties in small groups, in large rooms with open windows (in the case of favorable weather conditions conducted in the fresh air).
- To maintain safe distance between employees while waiting to enter the plant, before congresses, during meetings, when using a bathhouse, when contacting workmates, and during work.
- To suspend business trips, conferences, and to cancel courses and other events for the duration of the epidemic.

The second step is to protect employees from contact with the virus and to recognize people suspected of being infected by:

- measuring the temperature of employees before entering the plant,
- wearing masks by all employees from the moment they enter the mine,
- disinfecting rooms that employees use most often, or where the risk of infection is greater: bathhouses, cloakrooms, corridors, rooms where employees gather, some offices, lamp rooms, underground stations;
- disinfecting the company's means of transport, both underground and surface: trains, buses;
- arranging hand disinfection points on the premises of the plant and disinfecting gates in front of the entrance to the mine cage,
- introducing a ban on taking snuff,
- avoiding touching objects, handrail buttons, etc., and using protective gloves.

The third step is to prevent possible further contamination among crew members when the virus emerges:

- To organize the crew's work in a way that limits contact between employees: work in permanent groups and on specific shifts.
- To introduce an obligation to undergo a two-week quarantine in the case of return from abroad, contact with an infected person and at the request of the employer.
- To prevent employees with symptoms of infection from working.
- To test employees for the presence of the coronavirus in the event of an active case among them,
- To allow only employees who have a negative test result to work when a larger number of positive cases occur.
- To arrange isolation tents in front of the mines, with the possibility to obtain medical advice, and isolation rooms in the mine for employees with symptoms.
- To introduce an obligation to inform superiors about all disturbing symptoms and contacts with the potentially infected.
- To be compliant with hygiene rules (frequent washing of hands, covering the face when sneezing or coughing, and keeping distance from others).

The epidemiological situation in Polska Grupa Górnicza S.A. (as of September 3rd, 2020)

Despite the implementation of measures and procedures aimed at preventing the spread of SARS-Cov-2 virus among employees, as well as the discipline to comply with these recommendations, it was not possible to completely limit the

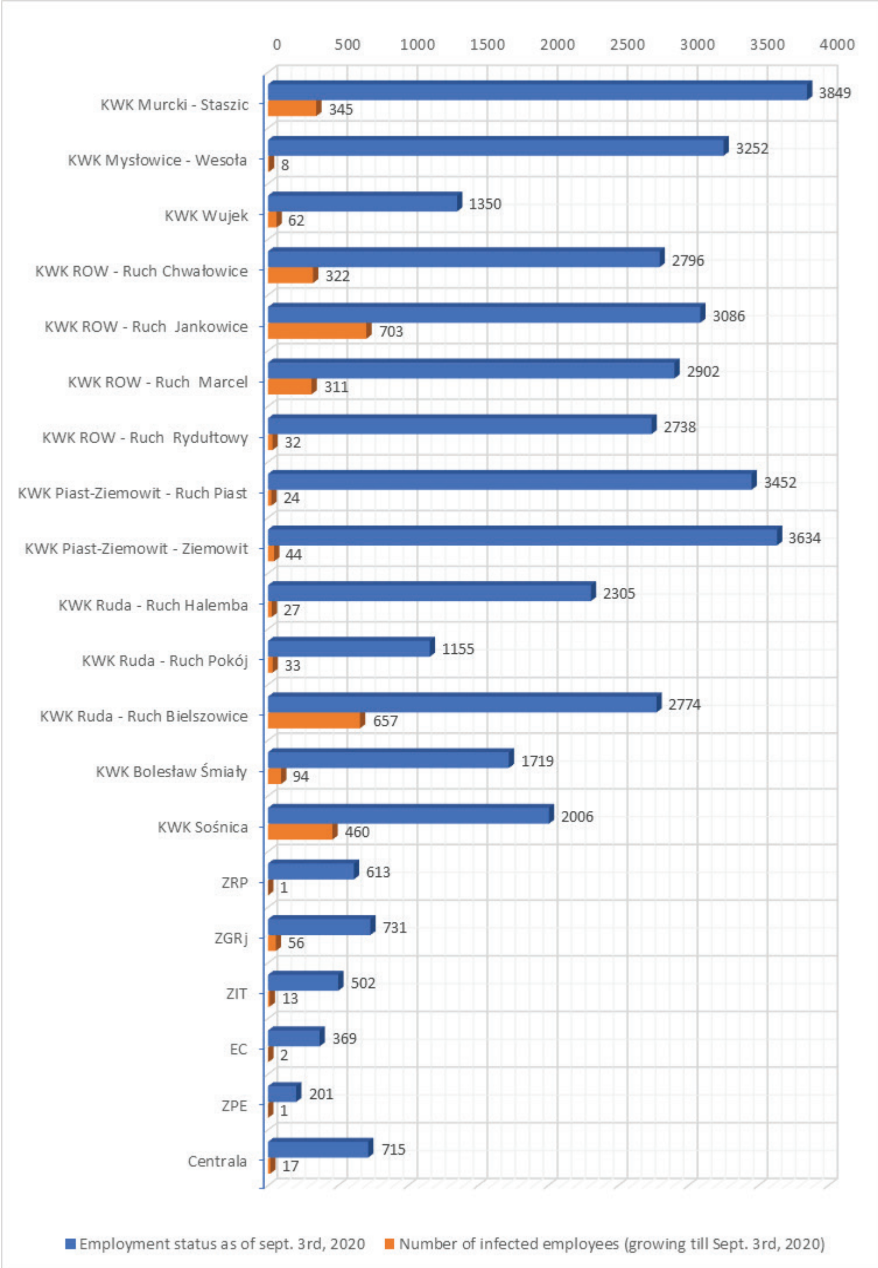

Fig. 3. Comparison of the number of employees of PGG units to the number of inidividuals with a positive test result for the coronavirus. Source: own elaboration
Rys. 3. Zestawienie liczby pracowników jednostek PGG do ilości osób u których stwierdzono pozytywny wynik testu na koronawirusa. Źródło: opracowanie własne

infiltration of the virus into the mining plants. This is due to the fact that some of the employees have close relatives who work in the health service, and initially it was hospitals and other medical centers that posed a threat in the spread of the virus. In addition, loosening the restrictions in the second half of April 2020 contributed to the increase in disease incidence, and thus increased the risk of virus transmission to the mines. It is worth adding that the vast majority of people working in mining are young, and thus the initial symptoms were difficult to detect, or no symptoms were present. Only the screening tests allowed for more accurate depiction of the epidemiological situation of the mining sector employees [17]. In the case of Polska Grupa Górnicza S.A., 3,212 infections were confirmed among all employees (the total number of PGG S.A. employees is 40,149). The exact number of employees who tested positive is presented in Table 2 and in a diagram (Fig.3.). These data refer to cases reported until Sept. 3rd, 2020.

Tabele 2 present a comparison of the number of employees of the mines belonging to Polska Grupa Górnicza SA who tested positive for SARS-Cov-2 virus to the number of healthy individuals in the period from the occurrence of the pandemic to September 3rd, 2020. The comparison is presented both in numbers and percentages. The mines where the percentage of infected individuals was greater than 10% included those belonging to KWK ROW: Chwałowice, Jankowice, Marcel; the Sośnica mine and KWK Ruda - Ruch Bielszowice . In the case of the remaining mines, the percentage ratio of the infected to non-infected ranged from 1 to 10%. The smallest percentage, only 0.25% of infected individuals in relation to the total number of people employed, was found in KWK Mysłowice - Wesoła. Figure 3 presents a comparison of the number of indiciduals who tested positive for SARS-Cov-2 virus, including employees from mines and other bodies belonging to Polska Grupa Górnicza S. A., as well as the number of employees in individual units and plants.

The total number of employees of the mining plants belonging to Polska Grupa Górnicza S. A., who tested positive for SARS-Cov-2, was 3,122 by Sept 3rd, 2020 and accounted for 8% of all employees. The number of people who were not employees of the mining plants but were employed in Polska Grupa Górnicza S. A., and who also tested positive for coronavirus, was 90, which is less than 1% of all employees of the company. As already mentioned, the total number of people with a positive test result was 3,212 as of Sept. 3rd, 2020, which is slightly over 8% of all employees.

Conclusion

The outbreak of the coronavirus epidemic influenced the way hard coal mines operate throughout the region. In addition, along with the epidemic threat, mining companies were forced to deal with the effects of the worldwide crisis caused by the pandemic overnight.

Over the years, in the event of economic problems, coal mining companies have managed to develop procedures to help survive this type of crisis and to collect additional funds in the event of problems with maintaining financial liquidity.

The biggest issue faced by the management boards was to ensure the safety of employees and their families, as well as to prevent the rapid spread of the coronavirus. For this purpose, a number of measures were applied to limit the spread of the pathogen, including remote work, personal protective measures, distance among employees, or contact via mobile devices.

The analysis of the incidence data among employees of Polska Grupa Górnicza S.A showed that the total number of positive cases as of Sept 3rd, 2020 was 3,212 and accounted for 8% of all employees.

The vast majority of people with positive test results involved employees of the mining plants belonging to Polska Grupa Górnicza S.A. This number amounted to 3,122 cases. The largest number of cases in relation to the number of people employed was reported for KWK ROW - Ruch Jankowice, and it amounted to 703.

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Zarządzanie kryzysowe w przedsiębiorstwach górniczych w sytuacji zagrożenia epidemicznego

Wprowadzenie stanu epidemii na terenie Polski na początku 2020 roku miało swoje odzwierciedlenie w działalności gospodarczej, w tym działalności przedsiębiorstw górniczych. Wiele z nich zostało zmuszonych do podjęcia natychmiastowych działań mających na celu zapewnienie ochrony zdrowia i życia pracowników oraz ich rodzin, a także utrzymania stabilności finansowej w związku ze spowolnieniem gospodarczym jakie miało miejsce w początkowym okresie epidemii. Działania profilaktyczne, podjęte przez zarządy spółek górniczych, przyczyniły się do ograniczenia rozprzestrzeniania się koronawirusa wśród pracowników kopalń. W artykule przedstawiono charakterystykę kryzysu wywołanego sytuacją epidemiologiczną spowodowaną wirusem SARS-Cov-2, wyzwania, jakim musiały sprostać przedsiębiorstwa górnicze w czasie pandemii, oraz kierunki działań spółek górniczych mających na celu zahamowanie rozprzestrzeniania się koronawirusa wśród pracowników, a także sytuację epidemiologiczną w jednej ze spółek górniczych wydobywających węgiel kamienny.

Słowa kluczowe: *przedsiębiorstwa górnicze, epidemia, kryzys, zarządzanie kryzysowe*

The Adopted Weight of Asbestos-Containing Products Versus Results of Stocktaking in the Area of Poland

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Abstract

The performance of detailed stocktaking of asbestos-containing products including the assessment of their quality is the basic action carried out in the process of cleaning the area from asbestos. The asbestos removal in Poland from the area of individual municipalities is carried out based on the Programme of Country Cleaning from Asbestos for the years 2009–2023. This document determines tasks necessary to perform by 2032 and the basis of actions consists of carrying out detailed stocktaking in field conditions. The results of stocktaking on a current basis are registered in the Asbestos Database kept by the Ministry of Economic Development, Labour and Technology (and before Ministry of Development) (http://www.bazaazbestowa.gov.pl). Values obtained during stocktaking in field conditions in units of area [m²] were converted according to 3 different weight conversion factors, used over the years, i.e. 11, 14, and 15 kg per 1 m². Potential accumulation and thereby generation of asbestos-containing waste may be estimated also based on the indices of generation by residents. Because of conditions in the urban and rural areas it is necessary to estimate separately waste generation indices for those areas. Moreover, individual voivodeships feature a specific nature and each of them should be considered on an individual basis. At present more than 480 million m² of asbestos-containing products were registered in the territory of Poland, which makes 7.2 million Mg, Those figures were obtained applying the conversion factor of area to weight equal to 15 kg. The greatest accumulation is observed in the Mazovian and Lublin voivodeships. On the entire country scale the deficit of landfilling capacity is now approx. 2,664,974 m³. The change of asbestos cement panel weight and the related change of conversion factor for the waste quantity from the area to weight does not affect the estimation of demand for additional landfill capacities. It should be clearly emphasised, that the amount of accumulated asbestos-containing waste, and hence the waste generation, should be provided in units of area [m²]. Values given in units of weight depend on the applied conversion factor.

Keywords: *waste, asbestos, stocktaking, generation index, landfills capacity, Asbestos Database*

Introduction

The performance of detailed stocktaking of asbestos-containing products including the assessment of their condition, i.e. quality, is the basic action carried out in the process of cleaning any area from asbestos. The asbestos removal in Poland from the area of individual municipalities is carried out based on the Programme of Country Cleaning from Asbestos for the years 2009–2023 (Programme of Asbestos Removal... 2002, Programme of Country Cleaning... 2009). This document determines tasks necessary to perform by 2032 and the basis of actions consists of carrying out detailed stocktaking in field conditions.

The results of stocktaking on a current basis are registered in the Asbestos Database kept by the Ministry of Economic Development, Labour and Technology (http://www.bazaazbestowa.gov.pl). This database is one of tools for monitoring the performance of tasks resulting from the programme and is a source of information in the field of this process execution pace and actions planning (Klojzy-Karczmarczyk et al. 2016, Klojzy-Karczmarczyk and Staszczak 2018, Wilk et al. 2015). The main elements related to asbestos-containing products occurrence in Poland are objects and sites, where such products are used. The corrugated asbestos cement sheets or 'diamond type panels situated on building roofs and façades as well as asbestos cement pipes are the most frequently existing elements. Each asbestos-containing product during the removal from a specific building becomes automatically group 17 hazardous waste. Such classification results from the provisions of the Act on Prohibition of Asbestos-Containing Products Use of 19 June 1997 (i.e. Dz.U. of 2020, item 1680 with amendments). A widespread and long-lasting process of asbestos removal from the territory of the whole country was started. The main environmental hazard consists in elements of damaged structure, in particular when they are not properly removed (e.g. Jawecki 2008; Szeszenia-Dąbrowska 2007; Szeszenia-Dąbrowska and Sobala 2010; Szeszenia-Dąbrowska et al. 2015, Klojzy-Karczmarczyk et al. 2016; Małuszyńska and Małuszyński 2016; Klojzy-Karczmarczyk and Staszczak 2018).

More than 7 million Mg of asbestos-containing products have been registered now and not disposal yet (as of 2019 end). The weight of asbestos-containing waste, specified in the Asbestos Database, is based on the determination of the area of built-in asbestos-containing products in field conditions. The adopted weight of asbestos-containing panel was changing over the years. It was not related to a change of those products conditions, but resulted from the analysis of data from various environments. Undoubtedly, a change of the adopted weight (in Mg) for 1 m² of panels affects the specified weight

Tab. 1. The amount of asbestos-containing products in accordance with the results of stocktaking carried out in the area of Poland and the forecast asbestos-containing waste generation based on indices estimated by the authorsown elaboration

Tab. 1. Ilość wyrobów zawierających azbest zgodnie z wynikami inwentaryzacji przeprowadzonej na obszarze Polski oraz prognozowane wytwarzanie odpadów zawierających azbest na podstawie wskaźników szacowanych przez autorów

No	Voivodeship	Registered stock of asbestos-containing products (and not dispose yet) based on the Asbestos Database *		Forecast generation of asbestos-containing waste **	
		weight [Mg]	area [m²]	weight [Mg]	area [m²]
1	Lower Silesian	138,960	9,263,992	340,340	22,689,364
2	Kuyavian-Pomeranian	496,867	33,124,442	301,373	20,091,545
3	Lublin	1,128,952	75,263,480	386,382	25,758,818
4	Lubuskie	71,396	4,759,729	130,702	8,713,455
5	Łódź	732,811	48,854,091	333,660	22,244,000
6	Lesser Poland	346,586	23,105,703	598,497	39,899,818
7	Mazovian	1,405,483	93,698,861	700,758	46,717,182
8	Opole	75,108	5,007,167	161,875	10,791,636
9	Podkarpackie	299,491	19,966,053	419,681	27,978,727
10	Podlaskie	516,942	34,462,826	166,525	11,101,636
11	Pomeranian	224,924	14,994,942	305,422	20,361,455
12	Silesian	252,063	16,804,169	426,965	28,464,364
13	Świętokrzyskie	469,063	31,270,900	233,611	15,574,091
14	Warmian-Masurian	201,750	13,449,995	208,564	13,904,273
15	Greater Poland	684,253	45,616,864	552,657	36,843,818
16	West Pomeranian	146,920	9,794,659	200,805	13,387,000
	POLAND	**7,191,568**	**479,437,873**	**5,467,818**	**364,521,182**

* – The registered stock of asbestos-containing products based on the Asbestos Database, as on 6 November 2019 (http://www.bazaazbestowa.gov.pl), assuming 1m² = 0.015 Mg (15 kg)

** – Forecast generation of asbestos-containing waste estimated based on indices presented in the paper by B. Klojzy-Karczmarczyk et al. (2016) with the weight converted according to the assumption of 1m² = 0.015 Mg (15 kg)

of those products or waste in general. In 2018, the authors in a previous paper (Klojzy-Karczmarczyk and Staszczak 2018) provided the total weight of registered products lower by nearly 2 million Mg. However, it is necessary to emphasise, that during processing the data in previous years a definitely lower weight of 1 m2 of asbestos-containing materials was adopted. The paper shows the changes of the weight adopted for 1 m2 of asbestos-containing panels over the years and proves the impact of such a change on the results obtained during the stocktaking in the area of Polish municipalities.

The stocktaking and generation of asbestos-containing waste

The performance of detailed stocktaking, including the assessment of the quality condition of asbestos-containing products is the basic action carried out in the process of country cleaning from asbestos. The results of stocktaking carried out on site in municipalities are on a current basis presented in the Asbestos Database kept by the Ministry of Economic Development, Labour and Technology (formerly Ministry of Development, Ministry of Entrepreneurship and Technology, and beforehand by the Ministry of Development and Ministry of Economy) (http://www.bazaazbestowa.gov.pl). The data gathered in the Asbestos Database allow to obtain a real and not presumed amount of materials accumulated in the area of Poland. At present (as on 6 November 2019) the amount of asbestos-containing products registered during the stocktaking (and not disposed yet) is 7,191,568 Mg (Table 1). This stocktaking is still incomplete and requires continuation but it is more and more precision. Not all municipalities carried out detailed stocktaking in their area yet. Certain municipalities performed it fragmentarily or entered only the products, which they intended to remove in a specific year based on residents declaration. However, it should be emphasised, that the share of municipalities having a programme of asbestos-containing products removal from their own area, and hence detailed stocktaking, exceeds already 60%. Instead, the total number of municipalities covered by full or only partial stocktaking is estimated at more than 95%. So the figures given in Table 1 will be increased once full stocktaking is completed throughout the country, but at the same time decreased by landfilled values. The 2018 paper (Klojzy-Karczmarczyk and Staszczak 2018) provided the registered amount of approx. 5,392,718 Mg (as on 21 August 2018). An increase over a year is significant, but it does not result from the increase in the amount of registered products in the area of consecutive municipalities in Poland. Such an increase results from the applied conversion factor from the amount given in units of area to the amount given in units of weight.

The programme of asbestos and asbestos-containing products removing from the territory of Poland (Programme of Asbestos Removal... 2002) specifies that the weight of 1 square metre of an asbestos cement panel is 11 kg (0.011 Mg). While in accordance with the data gathered by the paper authors from various asbestos-containing waste landfills, the weight of 1 m² of asbestos cement panel is on average 14 kg (0.014 Mg). This very value was taken in the 2011 paper to estimate indices for generation and calculation of waste weight potentially generated by one resident (Klojzy-Karczmarczyk and Makoudi 2011). In turn, in accordance with the Asbestos Database, from 1 July 2019 the weight of 1 m² of asbestos cement panel is 15 kg (0.015 Mg). Till 30 June 2019 the conversion factor used in the database was 11 kg (0.011 Mg) per 1 m², in accordance with the 2002 programme. The weight of 11 kg per 1 m² was adopted during the results processing

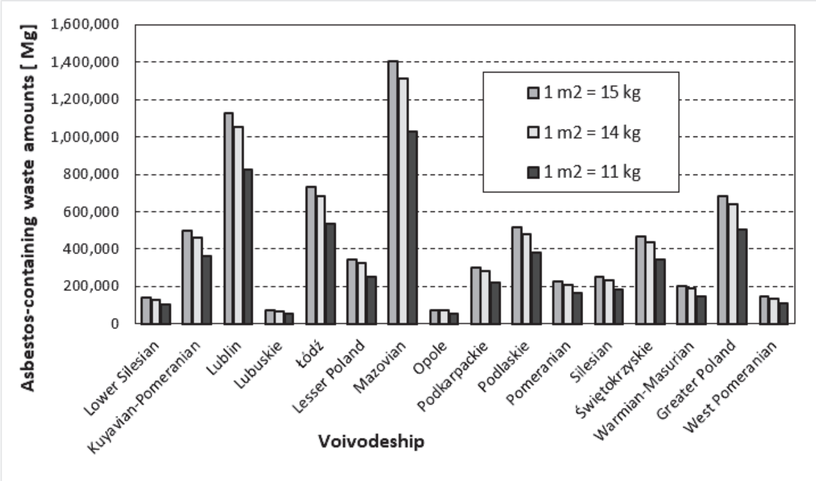

Fig. 1. The amount of asbestos-containing waste registered during the stocktaking in [Mg] assuming three different conversion factors of product [m²] to weight [kg] (based on http://www.bazaazbestowa.gov.pl)
Rys. 1. Wielkość zinwentaryzowanych wyrobów zawierających azbest w [Mg] przy założeniu trzech różnych przeliczników [m²] wyrobu na masę [kg] (na podstawie http://www.bazaazbestowa.gov.pl)

and estimating the indices in the 2015 and 2016 papers (Klojzy-Karczmarczyk at al. 2015; 2016).

The estimation of possible generation of asbestos-containing waste based on indices of generation by residents is a separate issue in the process of analysis. This parameter value varies over time and results from delivering newer and newer stocktaking data, which at the same time feed the Asbestos Database. The paper authors participated in numerous stocktaking operations, which results allowed to produce indices for asbestos-containing waste generation by residents. Because of conditions in the urban and rural areas it is necessary to estimate separately waste generation indices for those areas (Klojzy-Karczmarczyk and Makoudi 2011, Klojzy-Karczmarczyk et al. 2016). Those indices were also used in this paper, but they were corrected due to a change of estimated weight of 1 m² of asbestos cement panel. In July 2019 the hitherto conversion factor from a square metre to kilogrammes was changed in the Asbestos Database. The previous value was 11 kg, while from July 2019 this value is 15 kg. Therefore indices calculated in 2016 were recalculated. The generation index provided in m2 did not change, but the total weight of products forecast to generate was changed. Also the stocktaking results gathered in the Asbestos Database so far and converted to weight were automatically recalculated taking into account the weight of asbestos cement panel equal to 15 kg. Table 1 specifies the registered amount of asbestos-containing products with forecast generation of asbestos-containing waste in Poland estimated based on indices in a voivodeship arrangement. In the calculations the waste generation index (based on products accumulation) was taken for rural areas as 21 m²/per capita (0.315 Mg/per capita). Instead, the estimated index for waste generation in urban areas is 1.8 m²/per capita (0.027 Mg/per capita).

On the entire country scale the amount of material registered in the stocktaking is definitely higher than that forecast based on indices. The analysis carried out in the voivodeship arrangement shows those figure depending on the area. In the Warmian-Masurian voivodeship the amount registered in the stocktaking corresponds to the forecast one. In 8 voivodeships (Lower Silesian, Lubuskie, Lesser Poland, Opole, Podkarpackie, Pomeranian, Silesian, West Pomeranian) the forecast amount is higher than the registered one. In the other voivodeships the forecast amounts are lower than those registered in stocktaking. Voivodeships with high accumulation of asbestos-containing products comprise mainly the area of central and eastern Poland. However, in the process of index estimation, this area – due to the sequence of tasks performance – was represented only by single municipalities. To determine an index reliable for the entire area of Poland in each voivodeship it is necessary to carry out stocktaking in the same or similar number of municipalities with different types of development. The asbestos-containing waste generation index per 1 resident is definitely lower in urban than in rural municipalities, which results from the nature of development.

The amount of asbestos-containing products registered in the Asbestos Database is presented below (Fig. 1). Values obtained during stocktaking in field conditions in units of area [m²] were converted according to 3 different weight conversion factors, used over the years, i.e. 11, 14, and 15 kg per 1 m². The presented graphs show that in the Mazovian and Lublin voivodeships there are now more than million Mg of asbestos-containing products, which should be disposed by 2032. The results, specified in Mg, reflect the problem irrespective of the applied conversion factor of the registered area to weight, although the values applied now taking into account those used in the Asbestos Database give obviously the highest values.

The ensuring of capacity for asbestos-containing waste landfilling

There are many methods for effective and safe disposal of asbestos-containing waste (e.g. Makoudi 2007; Pawluk 2010; Wilk et al. 2015). The basic method consists in landfilling the asbestos-containing waste in places especially designed for this purpose. In the area of Poland there is a number of landfills or landfill sections designed and adapted to landfill such waste. There are also plans to expand such facilities or to build new ones. In almost every voivodeship there is a landfill for asbestos-containing waste or another landfill with a separate

Tab. 2. Available capacity of landfills for asbestos-containing products disposal by voivodeships
Tab. 2. Dostępna pojemność składowisk do unieszkodliwiania wyrobów zawierających azbest z podziałem na województwa

No	voivodship	Number of generally accessible landfills*	Free capacity of generally accessible landfills [m^3]*
1	Lower Silesian	2	3,800
2	Kuyavian-Pomeranian	2	65,250
3	Lublin	3	171,198
4	Lubuskie	1	38,806
5	Łódź	2	8,957
6	Lesser Poland	3	40,207
7	Mazovian	1	33,918
8	Opole	-	-
9	Podkarpackie	4	9,101
10	Podlaskie	2	144,233
11	Pomeranian	4	202,939
12	Silesian	4	323,186
13	Świętokrzyskie	1	1,460,000
14	Warmian-Masurian	1	12,193
15	Greater Poland	1	53,000
16	West Pomeranian	2	95,325
total	**POLAND**	**33**	**2,662,113**

* – based on the Asbestos Database, as on 6 November 2019 (http://www.bazaazbestowa.gov.pl)

section for asbestos-containing waste landfilling. The Opole voivodeship is an exception, where there is no such landfill at all. Perhaps this results from the fact that the Opole voivodeship belongs to those with the smallest amounts of asbestos-containing products, which ultimately will become waste. Moreover, in the neighbouring Silesian voivodeship there are as many as 4 plants for this hazardous waste landfilling.

Overall, in the territory of Poland there are 33 landfills, where asbestos-containing products can be subject to disposal. The biggest number, 4 facilities, are situated in Podkarpackie, Pomeranian, and Silesian voivodeships, while 3 facilities in each of Lublin and Lesser Poland voivodeships. The specification of free capacity to landfill asbestos-containing waste (Table 2) shows that in many voivodeships there is a situation, that the amount of landfill capacity slowly becomes scarce. Acc. to the data registered in the Asbestos Database in total the free landfilling capacity (as on 6 November 2019) amounts to 2,662,113 m^3, where in the Lower Silesia only 3,800 m^3 left to fill, in the Łódź voivodeship 8,957m^3 left, while in the Podkarpackie voivodeship (despite 4 operating landfills) only 9,101 m^3 left. Taking into account the fact that the data in the database cannot be updated on a current basis, the size of landfill sections left to fill for asbestos containing waste may be even smaller. So it is necessity to build new landfills or to transport asbestos-containing waste to other voivodeships. In the 2018 paper (Klojzy-Karczmarczyk and Staszczak 2018) the available landfilling capacity was shown as 2,679,409 m^3 (as on 21 August 2018). The decrease in the free landfilling capacity on a year scale is not significant and results from the volume of landfilled waste. At the same time also sections for landfilling were expanded. The change of waste conversion factor from the area to weight does not affect the estimated landfilling capacity.

Conclusions

In 1998 a broad and long-lasting process of asbestos removal from the territory of the entire country was started in Poland, which at the same time resulted in the generation of group 17 hazardous waste. The grounds to analyse results of stocktaking of built-in asbestos-containing products and monitoring of the removal process and determination of demand for the next landfills or landfill sections consist of the data and information gathered in the Asbestos Database (http://www.bazaazbestowa.gov.pl) as well as of the data obtained during the own work by the authors.

At present more than 480 million m^2 of asbestos-containing products were registered in the territory of Poland, which makes 7.2 million Mg. More than 1 million Mg exist only in the Mazovian and Lublin voivodeships. In 2018 the amount registered in the stocktaking was 490 million m^2 and the weight of registered products amounted to 5.4 million Mg, Such an increase in weight over 1 year results only from the applied conversion factor of area to weight. At the same time a part of asbestos-containing materials was removed from the area of real estates and disposed and the process of removal is visible via reduction of the area of accumulated materials expressed in m^2.

The paper presents the amount of asbestos-containing products registered in the Asbestos Database of the Ministry of Economic Development, Labour and Technology (and before Ministry of Development). Values obtained during stocktaking in field conditions in units of area [m^2] were converted according to 3 different weight conversion factors, used over the years, i.e. 11, 14, and 15 kg per 1 m^2. Potential accumulation and thereby generation of asbestos-containing waste may be estimated also based on the indices of generation by residents. Because of conditions in the urban and rural areas it is necessary to estimate separately waste generation indices for those areas. Moreover, individual voivodeships feature a specific nature and each of them should be considered on an individual basis.

On the entire country scale the deficit of landfilling capacity is now approx. 2,664,974 m^3. After the carried out planned expansion of the landfilling base the shortages will decrease to 1,420,004 m^3. The change of asbestos cement panel weight and the related change of conversion factor for the waste quantity from the area to weight does not affect the estimation of demand for landfills. The decrease in the free landfilling capacity in the years 2018-2019 is not significant and results from the volume of landfilled waste. On a year scale the total available landfilling capacity went down by 17,296 m³.

Taking into account the results of carried out analysis in the field of asbestos-containing products stocktaking and estimating the available waste landfilling capacity it is necessary to emphasise that these values should be referred to a unit of area or a unit of volume. Indices of those products accumulation and thereby generation indices given in units of area [m2] remain topical. While the indices given in units of weight lose their importance and depend on the applied conversion factor. The only deviation from this observation consists in the fact of possible specification of accumulated products (waste) in weight units measured in real terms.

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Przyjmowana waga wyrobów zawierających azbest a wyniki inwentaryzacji na obszarze Polski

Podstawowym działaniem, realizowanym w procesie oczyszczania obszaru z azbestu, jest przeprowadzenie szczegółowej inwentaryzacji wyrobów zawierających azbest wraz z oceną ich jakości. Usuwanie azbestu w Polsce, z terenu poszczególnych gmin, realizowane jest na podstawie Programu oczyszczania kraju z azbestu na lata 2009–2032. Dokument ten określa zadania niezbędne do realizacji do 2032 roku, a podstawą działań jest przeprowadzenie szczegółowej inwentaryzacji w warunkach terenowych. Wyniki procesu inwentaryzacji są na bieżąco zamieszczane w Bazie Azbestowej prowadzonej przez Ministerstwo Rozwoju, Pracy i Technologii (wcześniej Ministerstwo Rozwoju) (http://www.bazaazbestowa.gov.pl). Wartości pozyskane w trakcie inwentaryzacji w warunkach terenowych w jednostkach powierzchni [m²] przeliczono zgodnie z 3 różnymi przelicznikami wagowymi, stosowanymi na przestrzeni lat, czyli 11, 14 oraz 15 kg na 1 m². Potencjalne nagromadzenie a tym samym wytwarzanie odpadów zawierających azbest może być też szacowane na podstawie wskaźników wytwarzania przez mieszkańców. Ze względu na uwarunkowania obszarów miejskich oraz wiejskich, konieczne jest oddzielne szacowanie wskaźników wytwarzania odpadów dla tych obszarów. Poza tym poszczególne województwa wykazują specyficzny charakter i każde z nich należy traktować indywidualnie. Na chwilę obecną, na terytorium Polski, zinwentaryzowanych zostało ponad 480 mln m² wyrobów zawierających azbest, co stanowi 7,2 mln Mg. Wielkości te pozyskano stosując przelicznik powierzchni na masę na poziomie 15 kg. Największe nagromadzenie obserwowane jest w województwie mazowieckim oraz lubelskim. W skali całego kraju istnieje obecnie niedobór miejsca do składowania na poziomie 2 664 974 m³. Zmiana masy płyty azbestowo-cementowej i związana z tym zmiana przelicznika ilości odpadów z powierzchni na masę nie ma wpływu na szacowanie zapotrzebowania na dodatkowe pojemności składowiska. Należy wyraźnie zauważyć, że ilość nagromadzonych wyrobów zawierających azbest a tym samym wytwarzanie odpadów podawane powinno być w jednostkach powierzchni [m²]. Wartości podawane w jednostkach masy są uzależnione od zastosowanego przelicznika.

Słowa kluczowe: *odpady, azbest, inwentaryzacja, wskaźnik wytwarzania, pojemność składowania, Baza Azbestowa*

Pro-Social Activities within the CSR by the Jastrzębska Spółka Węglowa SA – a Case Study

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Abstract

Nowadays, companies are facing a number of challenges. In the current era of changes in the structure of energy mixes and "moving away from coal", mining companies are looking for various forms of improving their image in the environment. At the same time, the need to develop the so-called Corporate Social Responsibility (CSR) activities prompt the search for various forms of cooperation with the society. The following article presents activities within the CSR area undertaken by the Jastrzębska Spółka Węglowa SA, which was positively assessed by both the business world and society. As an example, a beekeeping educational center has been created to serve both residents and mining families.

Keywords: *coal mining, CSR, bee*

Introduction

The economy plays an increasingly important role in the modern world. It determines life aspirations and models among societies. Also, it has become a creator of values and trends, as well as the needs of consumers, repeatedly leading the society into the trap of both materialism and consumerism. The dominant view is that the economy is to blame for many problems of the modern world (poverty, consumption of natural resources, pathologies, or environmental degradation). The society began to demand that companies should become responsible for their negative impact on the environment, which is where the idea of Corporate Social Responsibility (CSR) came from. As a result of globalization processes, the approach and understanding of the CSR has changed as rapidly as the business and its environment. The CSR has been dynamically evolving for decades. The modern understanding of the idea in question assumes that it is not a temporary fashion, but a tool to achieve a competitive advantage on the market. It is both a strategy and philosophy of managing a modern organization.

Corporate Social Responsibility (CSR) – main assumptions

A concept that is increasingly implemented in the management of companies is corporate social responsibility. Generally it consists in combining activities aimed at building a competitive advantage of enterprises. The main reason for changing the approach to CSR is the change in the understanding of added value. Currently, the added value does not have a purely financial dimension, it is treated as an element realized through both material and non-material factors. Therefore, undertaking initiatives beneficial to the company's environment and the environment definitely positively influences building and consolidating their image [1].

The concept of the CSR is now the basis for the proper management of an organization. The high degree of complexity and variability of the environment in which companies operate is the key factor that managers must face. The management style is changing due to the society's expectations related to business. Professional management requires managers to properly recognize changes in the environment and react to them. Today, organizations face an increasing number of challenges, incorporating them into their business practice. They include in particular (Fig. 1) [2, 3]:

- environmental challenges - climate change, resource dwindling;
- social challenges - marginalization of specific social groups, violation of human rights;
- economic challenges.

All of them make the CSR a permanent part of the strategies of companies and influences their development, innovation and competitive advantage.

Currently, the CSR, when properly used, allows organizations to positively stand out from the competition and shows that a given companies has a conscious impact on its environment. Without the broadly understood CSR, an organization would be solely focused on profit maximization and assessed only on the basis of financial data. The concept of the CSR is now becoming the basis of proper company management and the way to its further development.

It is important to include the expectations of various interest groups in the process of creating values and to take into account rapid changes observed in the business environment. The CSR is a long-term, well-thought-out and well-developed strategy based on the consistent building of good relations both with the company's employees and its environment. Such a strategy can bring tangible profits to all interest groups involved in the process.

Activities carried out as part of the CSR are undertaken voluntarily by organizations and addressed to specific recip-

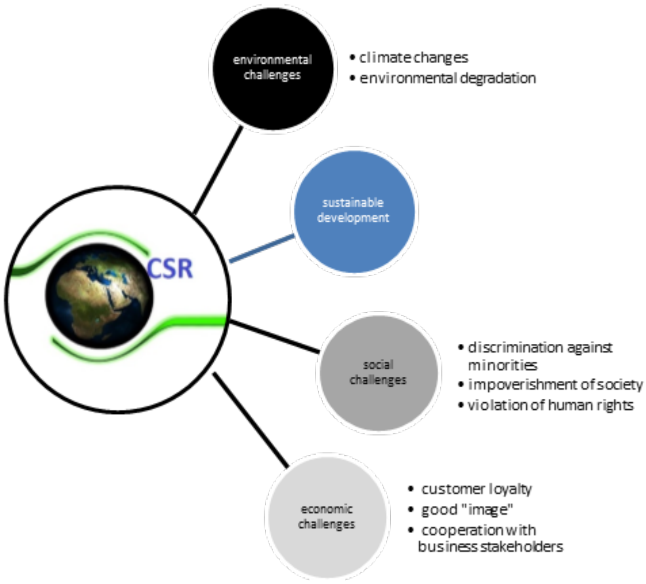

Fig. 1. Challenges faced by organizations in the modern business world [based on 2]
Rys. 1. Wyzwania stojące przed organizacjami we współczesnym świecie biznesu [na podstawie 2]

ients. Each organization works with specific groups of stakeholders. The article will present the CSR activities undertaken by a coal mining company to raise the social awareness of its employees, their families and the entire environment in terms of environmental threats and degradation of the bee population. Such activities, seemingly inconsistent with the profile of the industry, allow large employers to engage in promoting significant ideas and influence specific behaviors of people. Such programs are more and more often included in the CSR activities of large corporations.

Bees – problem of the modern world

Almost 90% of flowering plants worldwide require a greater or lesser proportion of pollinators to produce seeds. In Europe, relatively many wind-pollinated species can be distinguished. However, several plant species growing in the temperate zone are animal-pollinated [4]. In addition to flowering plants, there are also crops, trees and shrubs. The "work" of pollinators has its economic dimension. It is estimated that the share of animals pollinating flowers to the global economy is between € 153 and € 265 billion per year (depending on the research method) [5]. Poland has been reported to show the annual share of pollinators in the agricultural production value of at least 3-4 billions PLN [6].

The most important of all pollinators are, obviously, bees. They are naturally best adapted to the pollination of flowering plants. They often come into very close relationships with insect-pollinating plants. This is due to the joint evolution of bees and plants for at least 100 million years, which provides them with mutual benefits. Bees, during their various stages of development, feed on nectar and pollen of plants. On the other hand, due to bees, plants can have a "faithful" pollinator [7].

The progressive degradation of the natural environment leads to the thinning or even extinction of many plant and animal species. Unfortunately, bees are also in this group, as they are becoming less and less resistant to harmful and aggressive pesticides, viruses and environmental pollution. Scientists have not been able to pinpoint a clear cause of this phenomenon (called CCD – Colony Collapsed Disorder) [8].

The progressive warming of the climate may turn out to be a significant threat to the protection of pollinating insects [9]. Mild winters cause a shift in plant vegetation periods in relation to the insect development cycle. Numerous periods of droughts caused by low rainfall (e.g. rainfall 56–91% lower than the long-term average) significantly limit pollen production [10]. The intensification of agriculture and changes in the spatial structure of villages and cities are also perceived as one of the factors responsible for bee extinction. The liquidation of wastelands, flowering meadows, and intensive mowing of home gardens mean that these insects lack food (pollen and nectar) [11].

Massive bee extinctions were first observed in the United States in the 1960s [12]. Despite preventive measures taken, this process has continued and even intensified. Between 2006–2007 in North America, 1/3 of the population of all bees died out. Since 2008, the process of mass extinction of these insects has reached Europe. There have already been winters, after which the population of Polish bees decreased by 30% [13]. After all, bees are the basic insects that pollinate plants and, consequently, determine the production of 1/3 of the world's food. Therefore, it is essential for the safety of people and the bee ecosystem to protect and care for them as well as eliminate threats. Moreover, it is necessary to develop the bee population also in non-obvious locations. There are too few shelters and space for building nests or laying eggs by either solitary bees or bumblebees. Thus, an interesting idea is to deliberately locate bee colonies in a highly urbanized area, namely, the city centers [14]. According to some breeders, city honey can be even healthier, because the bees' greatest enemy are plant protection products, quite commonly used in the countryside.

As part of the CSR, more and more companies are implementing activities for the benefit of the natural environment to support the process of bee population growth by establishing apiaries in their factories or office buildings. An example of this type of activity is the initiative of the president of ERGO Hestia. On the roof of the company's headquarters, on

Tab. 1. The structure of apiaries by voivodships in Poland in 2019 [17]

Tab. 1. Struktura pasiek według województw w Polsce w 2019 roku [17]

voivodship	Number of bee colonies								Total numer of beekeepers
	Up to 5	from 6 to 10	from 11 to 20	from 21 to 50	from 51 to 80	from 81 to 150	from 151 to 300	over 301	
Małopolskie	2255	2816	2142	1505	279	74	18	5	9094
Lubelskie	706	1681	2214	2101	576	130	31	7	7446
Podkarpackie	944	1947	2239	1734	453	90	27	2	7436
Śląskie	2676	2291	1512	802	114	24	5	1	7425
Mazowieckie	1184	1871	1888	1440	279	70	18	0	6750
Dolnośląskie	772	1338	1570	1494	351	97	13	1	5636
Wielkopolskie	1059	1354	1379	1223	359	89	26	5	5494
Łódzkie	881	1272	1272	814	131	21	5	1	4397
Warmińsko – mazurskie	282	645	936	1449	617	186	45	16	4176
Kujawsko – pomorskie	557	797	937	896	201	52	11	1	3452
Zachodniopomorskie	365	649	850	1042	314	85	13	1	3319
Świętokrzyskie	445	869	889	739	223	59	6	1	3231
Opolskie	599	720	673	460	136	30	6	2	2626
Pomorskie	431	590	683	656	163	33	17	5	2578
Lubuskie	309	505	620	608	173	33	4	4	2256
Podlaskie	247	478	566	562	102	24	5	0	1984

the border between Sopot and Gdańsk, almost 60,000 Krainka bees have been permanently located. They are non-aggressive towards people and, therefore, very willingly used in the urban environment. The company also supports the local ecosystem by planting honey plants. More than 20 species of such plants have been planted in the Hestia Park, which from early spring to late autumn are a source of food for bees. In 2016, the company was able to reward its customers with honey from its own apiary for the first time. As many as 60,000 bees live on the roof of the office building. Ultimately, there will be 600,000 of them. Another interesting example is the "Wild Bees Mine" program, which the Limestone Mine Górażdże, in cooperation with the Nature and Man Association, is implementing in their plant. It is devoted to the protection of wild bees and pollinating insects, and one of its elements is the construction of "hotels for bees" in the mine. In Paris, London or Berlin, there are 4-5 thousand hives. It is estimated that Warsaw has several hundred of them for the time being, but their number is growing every year. Interestingly, "urban beekeeping arose as a response to the fact that the environment in the countryside is now more polluted with chemicals and sprays than 100 years ago. It turned out that bees are doing quite well in the city and this trend has been developing since the 1980s. It has been observed that city bees bring even more honey, are healthier and do not get sick, because they are not poisoned by spraying - says Kamil Baj from Newseria Biznes, beekeeper, founder of beekeeping" [15].

Companies involved in this type of projects began to notice and understand that the full success of a modern organization goes far beyond satisfactory financial results, and that the largest companies have adequate potential to solve both economic and social problems. According to the research of the French-Polish Chamber of Commerce, over 80 percent of respondents were reported to consider it an important element of companies' strategies and economic life [16]. Conducting appropriate courses and creating educational centers can significantly affect the amount of honey production and the bee population.

As shown in Table 1, the number of small and medium-sized apiaries in the Śląskie Voivodeship is significant when compared to the rest of the country. Therefore, building educational centers to promote such activities aims to develop such a structure and increase the bee population in the region. At the same time, when looking at the number of bee colonies in the Śląskie Voivodeship in 2019 per 1 square km (Fig. 2) versus the whole country, it can be seen that the popularity of beekeeping in this area is greater than in other regions. As part of promoting the idea of beekeeping in this region, small apiaries dominate in the Śląskie Voivodeship (Fig. 3), often of an amateur nature (Fig. 4) [17].

Therefore, the article presents the implementation of the project "Save the Bees - They Can Live among Us" in the Jastrzębska Spółka Weglowa SA Company (JSW Capital Group) as an example of the CSR activities. Such activities not only take up an important ecological subject, but are also accepted and positively received by the society.

JSW SA – case study

Corporations feel responsible for the natural environment and invest in city apiaries. Following the ecological trend from the countries of Western Europe , the largest producer of coking coal in the EU – the JSW Capital Group, also gives priority to initiatives related to nature protection and its resources. Hence the concept of implementing the project "Save the Bees - They Can Live among Us", related to the establishment of an apiary as a component of the development of the revitalization, reclamation and rational management of the JSW Capital Group's mining areas. It should be emphasized that this initiative is of a pilot nature due to its unique location - in the area adjacent to the active mine Borynia-Zofiówka, Borynia Section in Jastrzębie Zdrój. By implementing the concept of ecological development of industrial areas, the JSW SA decided to introduce a program for the protection of beneficial insects and the production of honey from the Jastrzębie apiary corresponding to the educational program "Bees" developed by the JSW SA CSR team. As part of these activities, after the completion of the investment part and the opening of the apiary with an educational path for the youngest in August 2019, local schools in October 2019 participated in the City Game, called hare and hands, in Jastrzębie-Zdrój. Students looked for illustrated boards with tasks under the teacher's supervision. The entire route was about 3 kilometers long, and the checkpoints were

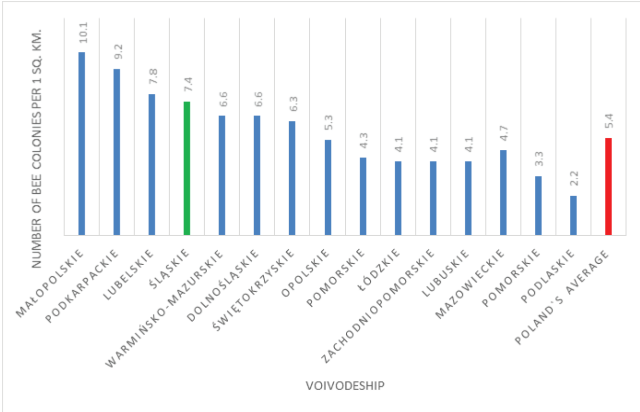

Fig. 2. Number of bee colonies per 1 sq km by voivodeships in Poland in 2019 [17]
Rys. 2. Liczba rodzin pszczelich na 1 km2 w województwach w Polsce w 2019 roku [17]. 1. Struktura pasiek według województw w Polsce w 2019 roku [17]

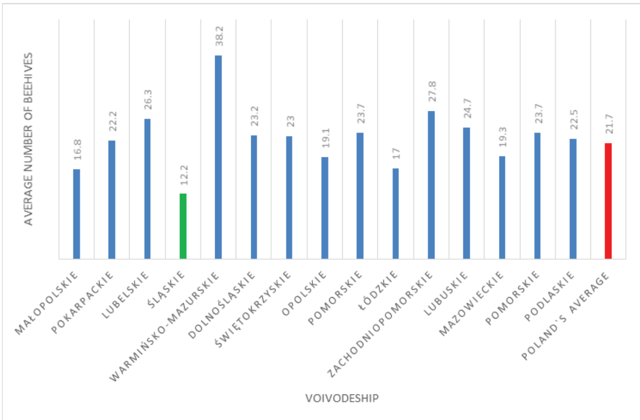

Fig. 3. The average number of beehives by voivodeships in Poland in 2019 [17]
Rys. 3. Średnia liczba uli według województw w Polsce w 2019 roku [17]

hidden in interesting corners of the city. This allowed young people to learn not only about bees but also about the history and geography of the nearest area. It is worth adding that as part of this activity, children and young people could write an article on the protection of bees and take part in a thematic competition announced by National Geographic Kids.

In accordance with the adopted assumption, the Apiary "Save the Bees" has become a local education center, and the accompanying activities support this process. During lectures in the apiary, young people have the opportunity to learn about the construction of a hive, the use of bee products, hive habits, and the hierarchy of a bee colony. In the Jastrzębie apiary, students will find an exhibition of posters from the book "Bees" by Wojciech Grajkowski, illustrated by Piotr Socha and published by the Dwie Siostry Publishing House, which has been awarded many times both in Poland and abroad. As many as 200 children visited the apiary over the course of two months, i.e. September and October. The JSW Group plans to develop this pilot project for other plants of the Capital Group, aimed at increasing the number of bees and fighting the problem of their increased mortality. It is worth noting that millions of hard-working honeybees in cities provide not only delicious honey to citizens but also a thriving park environment and greenery. This initiative was one of the projects that were noticed by the Experts of the Responsible Business Forum in the 18th edition of the Report "Responsible Business in Poland. Good Practice". According to experts from the European Environment Agency (EEA), Poland has nearly 1/10 of all hives in the European Union. In this respect, only Spain and Romania are ahead of it. It is worth noting that "one of the great things about city bees is that they are not exposed to pesticides. They can go out to parks where it is clean, pollinate the flowers and produce honey that is not only good for humans, but keeps bee colonies"[18]. Moreover, honeybees are the most valuable pollinators of crops in the world. However, in recent years, a decline in the number of honeybees has been observed globally. The way they live means they fly out and collect pollen from plants and pollinate them. In today's world, it also means restoring pesticides that kill them or make them sick. According to the EEA, city bees are not exposed to pesticides, and thus apiaries set up by corporations help entire bee populations to pollinate our world and produce some of the purest honeys in urban spaces. In addition, EUR 265 billion is the global economic benefit of pollination (amount based on pollination-dependent crop values, estimated by the Greenpeace).

Conclusion

The operation of large corporations in the CSR area should not only focus on wide-ranging pro-social or pro-eco-

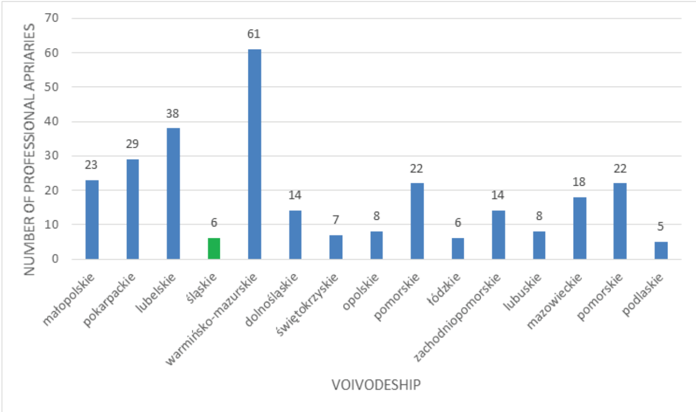

Fig. 4. Number of professional apiaries by voivodeships in Poland in 2019 [17]
Rys. 4. Liczba pasiek zawodowych według województw w Polsce w 2019 r. [17]

logical activities. The described example of the apiary and educational center shows how to build future generations and their pro-ecological behavior. Such activities are the real contribution of corporations to shaping the natural environment. Obviously, such a small apiary will not meet the needs of pollinating insects. However, the main goal of this activity is not only to promote the idea of beekeeping but also to change behavior and attitudes among both children and adolescents. The involvement of children and, consequently, their parents in pro-ecological activities is the main goal of the created educational center. Support in setting up small apiaries and arranging educational lessons for schools also build a different, better perception of an company, so far assessed through the prism of the coal. Activities aimed directly at the social environment may exclusively contribute to the improvement of the media image built around hard coal mining plants in Poland.

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Działania prospołeczne w ramach CSR Jastrzębskiej Spółki Węglowej – Case Study

Współczesne przedsiębiorstwa stoją obecnie przed szeregiem wyzwań. W obecnej dobie zmian w strukturze mixów energetycznych oraz "odchodzenia od węgla" przedsiębiorstwa górnicze poszukują różnych form poprawy swojego wizerunku w otoczeniu. Równocześnie potrzeba rozwoju działań CSR (społecznej odpowiedzialności biznesu) wpływa na poszukiwanie różnych aktywności współpracy z otoczeniem społecznym. W artykule opisane zostało działanie z obszaru CSR Jastrzębskiej Spółki Węglowej, które uzyskało bardzo pozytywną ocenę, zarówno ze strony świata biznesu, jak i ze strony społecznej. Stworzono pszczelarskie centrum edukacyjne służące mieszkańcom i rodzinom górniczym.

Słowa kluczowe: *górnictwo węgla kamiennego, CSR, pszczoła*

Ocena parametrów wytrzymałościowych obudowy szybów w oparciu o wyniki badań prób rdzeniowych pobranych przy użyciu innowacyjnego zestawu wiercącego

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Abstrakt

Ocena stanu technicznego obudowy szybów i szybików, zgodnie z obowiązującym w Polsce od listopada 2016 r. przepisami, wymaga wykonywania badań obmurza zarówno metodami nieniszczącymi jak i niszczącymi. Szczególne trudności sprawia pobieranie materiału do badań niszczących z uwagi na brak urządzeń przystosowanych do wykonywania w szybach odwiertów rdzeniowych. Aby umożliwić bezpieczne i precyzyjne pobieranie prób do badań wytrzymałościowych w specyficznych warunkach szybów górniczych opracowano innowacyjny zestaw wiercący o napędzie pneumatycznym. Dla potwierdzenia skuteczności opracowanego urządzenia wykonano próby ruchowe w warunkach dołowych. Pobrane z obmurza rdzenie oceniono pod kątem jakości i precyzji wykonania. Następnie, w oparciu o wyniki badań niszczących popranych prób rdzeniowych, określono możliwości ich wykorzystania do oceny parametrów wytrzymałościowych obudowy szybów.

Keywords: *szyby górnicze, wiertnica, stan techniczny obudowy, próby rdzeniowe*

Wstęp

Obowiązujące w Polsce od listopada 2016 r. przepisy, dotyczące prowadzenia ruchu podziemnych zakładów górniczych nakładają na rzeczoznawców ds. ruchu zakładu górniczego nowe obowiązki w zakresie badania stanu technicznego obudowy szybów i szybików. Obligatoryjne stało się wykonywanie badań obmurza zarówno metodami nieniszczącymi jak i niszczącymi [9].

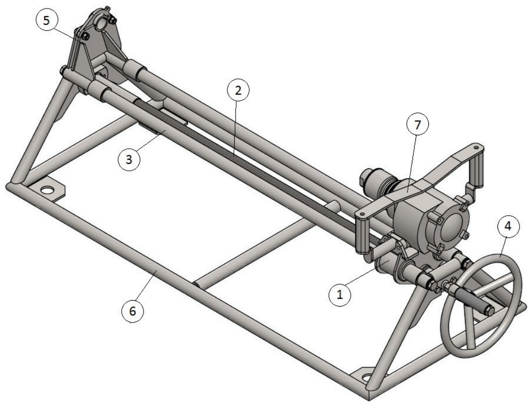
Metody nieniszczące umożliwiają ocenę parametrów wytrzymałościowych materiałów wbudowanych w konstrukcje obudów szybowych w oparciu o zależność matematyczną, wiążącą ich wytrzymałość na ściskanie z mierzoną wielkością fizyczną (np. twardość materiału, prędkość rozchodzenia się fal ultradźwiękowych itp.). W badaniach tego typu wykorzystuje się zwykle sklerometry lub betonoskopy ultradźwiękowe. Konieczność weryfikacji wyników badań nieniszczących w odniesieniu do badań niszczących, przeprowadzonych na próbkach pobranych z obmurza szybu, wymaga najczęściej wykonania odwiertów rdzeniowych. Szyby górnicze są zwykle zawilgocone i zaliczane do pomieszczeń zagrożonych wybuchem, co w większości przypadków eliminuje możliwość stosowania popularnych w budownictwie powierzchniowym wiertnic zasilanych silnikami elektrycznymi. Stąd też zaistniała konieczność opracowania urządzenia pozwalającego na bezpieczne i precyzyjne wykonywanie odwiertów rdzeniowych w specyficznych warunkach szybów górniczych. W tym celu zaprojektowano i zlecono wykonanie lawety umożliwiającej montaż i prowadzenie dowolnej górniczej wiertarki ręcznej przy zapewnieniu wszelkich wymogów bezpieczeństwa pracy w wyrobiskach górniczych. Aby potwierdzić skuteczność opracowanego urządzenia należało wykonać próby ruchowe w warunkach dołowych, ocenić jakość rdzeni wiertniczych i określić możliwość skorelowania parametrów wytrzymałościowych konstrukcji obudowy szybu, uzyskanych z prób niszczących, w odniesieniu do badań sklerometrycznych wykonanych w miejscu pobrania rdzeni.

Zestaw wiercący do pobierania prób rdzeniowych

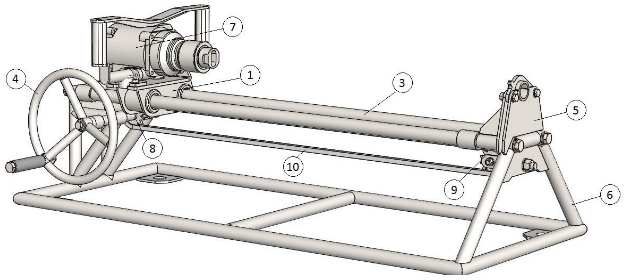
Opracowany zestaw wiercący do pobierania prób rdzeniowych składa się z dwóch zasadniczych części:

- pneumatycznej wiertarki ręcznej PWR II firmy MOJ S.A.,
- lawety umożliwiającej zamocowanie oraz precyzyjne prowadzenie wiertarki ręcznej wykonanej wg projektu autorów niniejszej pracy.

Górnicza pneumatyczna wiertarka ręczna PWR II przeznaczona jest do wiercenia otworów w skałach miękkich i średniotwardych. Jedną z głównych zalet urządzenia jest możliwość stosowania w pomieszczeniach ze stopniem „c" niebezpieczeństwa wybuchu metanu oraz klasy B zagrożenia wybuchem pyłu węglowego. W związku z powyższym oraz z uwagi na prostą konstrukcję, niewielką wagę i gabaryty urządzenia zdecydowano o jego przystosowaniu do prowadzenia wierceń w obiektach budowlanych, a w szczególności w obmurzu szybów górniczych. Wiertarka zasilana jest sprężonym powietrzem przepływającym przez smarownicę i współpracuje z różnymi typami żerdzi do obrotowych wierceń bezrdzeniowych. Dzięki odpowiedniej modyfikacji żerdzi uzyskano możliwość prowadzenia wierceń rdzeniowych z płuczką wodną. Aby umożliwić precyzyjne prowadzenie wiertarki ręcznej opracowano specjalną lawetę umożliwia-



Rys. 1. Laweta z śrubowym mechanizmem posuwu: 1) suport, 2) śruba napędowa, 3) prowadnice, 4) pokrętło, 5) centralizator, 6) rama, 7) wiertarka
Fig. 1. Drill guide with screw drive: 1) support, 2) screw drive, 3) guide, 4) knob, 5) centralizer, 6) frame, 7) drill



Rys. 2. Laweta z łańcuchowym mechanizmem posuwu: 1) suport, 3) prowadnice, 4) pokrętło, 5) cen-tralizator, 6) rama, 7) wiertarka, 8) zębatka napędowa, 9) zębatka bierna, 10) łańcuch napędowy
Fig. 2. Drill guide with chain drive: 1) support, 3) guide, 4) knob, 5) centralizer, 6) frame, 7) drill, 8) drive sprocket, 9) passive sprocket, 10) chain drive

jącą stabilizację urządzenia i płynny posuw podczas prowadzenia robót wiertniczych, a w szczególności pobierania prób rdzeniowych. W tym celu przewidziano zastosowanie ręcznie napędzanego, śrubowego lub łańcuchowego mechanizmu posuwu, dzięki czemu wiercenie odbywa się bez wysiłku, a operator w pełni kontroluje proces wiercenia. Do podstawowych zalet zaprojektowanego urządzenia można zaliczyć wydajność wiercenia, bezpieczeństwo i komfort pracy operatora, jakość i powtarzalność wykonanych odwiertów oraz mniejsze zużycie żerdzi wiertniczych.

Lawetę do prowadzenia górniczych wiertarek ręcznych zaprojektowano w dwóch rozwiązaniach, tj. z napędem śrubowym i napędem łańcuchowym. Na rysunku 1 przedstawiono lawetę z napędem śrubowym, natomiast na rysunku 2 lawetę z napędem łańcuchowym.

Próby ruchowe zestawu wiercącego do pobierania prób rdzeniowych

W celu potwierdzenia przydatności praktycznej zaprojektowanego urządzenia zlecono wykonanie prototypu lawety z napędem śrubowym firmie Archon Sp. z o.o., na której zamocowano pneumatyczną wiertarkę ręczną PWR II. Następnie urządzenie wyposażono w zestaw ciśnieniowy do wiertnic, umożliwiający prowadzenie płuczki wodnej, wąż ciśnieniowy do podawania sprężonego powietrza oraz diamentową koronkę rdzeniową o średnicy 62 mm do wiercenia w elementach żelbetowych, betonowych i murowych.

Dla tak przygotowanego urządzenia wykonano próby ruchowe w dwóch szybach jednej z kopalń należących do PGG SA, wyposażonych w klatki do jazdy ludzi.

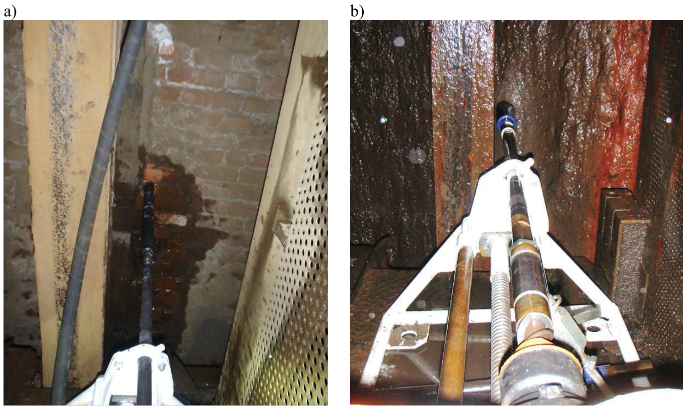
Po zamontowaniu zestawu wiercącego na piętrze klatki (rys. 3) i podłączeniu przewodu ze sprężonym powietrzem przystąpiono do pobierania prób rdzeniowych. W tym celu opuszczano klatkę poniżej zrębu/poziomu i w wybranych miejscach prowadzono wiercenia w obmurzu (rys. 4). Po pobraniu próby rdzeniowej otwór każdorazowo likwidowano spoiwem mineralnym. Po zakończeniu wiercenia w miejscach pobrania prób rdzeniowych wykonywano serię badań sklerometrycznych.

W celu wykonania badań obudowy metodą inwazyjną i nieinwazyjną wybrano miejsca umożliwiające łatwy dostęp do obmurza i pozwalające na wykonanie testów zarówno na elementach z cegły jak i z betonitów [8]. Przy ustalaniu lokalizacji miejsc badawczych uwzględniono również głębokość i miąższość horyzontów wodonośnych, chemizm i stopień agresywności wód w stosunku do materiału obudowy, szczelność obudowy oraz ciśnienie wód [6,7].

Badania niszczące materiału obudowy wykonano na próbkach rdzeniowych pobranych ok. 10 m poniżej zrębu jednego z szybów oraz w rejonie podszybi dwóch poziomów dostępnych z drugiego z szybów (rys. 5 ÷ 7).

Rdzenie odwiercono na głębokość ok. 2/3 projektowanej grubości obudowy. Proces wiercenia przebiegał bez zakłóceń a jakość uzyskanych rdzeni była dobra. Po serii przeprowadzonych prób stwierdzono, że testowany zestaw wiercący nadaje się w pełni do wykorzystania w warunkach ruchowy. Na tej podstawie podjęto również decyzję o zgłoszeniu lawety do prowadzenia górniczych wiertarek ręcznych do ochrony patentowej.

Rys. 3. Widok zestawu wiercącego w trakcie montażu na piętrze klatki
Fig. 3. View of drilling set in pit cage



Rys. 4. Widok zestawu wiercącego w trakcie pobierania prób rdzeniowych w obmurzu wykonanym z a) cegły, b) betonitów
Fig. 4. View of drilling set in the course of core sampling from shaft lining made of: a) brick, b) concrete

Ocena parametrów wytrzymałościowych obudowy szybów w miejscach pobrania prób rdzeniowych

Z rdzeni pobranych z obmurza wycięto próbki o smukłości 2, które poddano badaniom niszczącym w maszynie wytrzymałościowej MMC6431 firmy Multiserw (rys. 8) zgodnie z PNEN 125041:201908. Szczegółowa analiza próbek na etapie ich obróbki i przygotowania do badań nie wykazała występowania uszkodzeń spowodowanych procesem wiercenia.

W miejscach pobranych rdzeni wykonano również po trzy serie badań sklerometrycznych materiału obudowy, zawierające po dziewięć odczytów, przy użyciu młotka Schmidta typu NR [1,3,5].

Na podstawie uzyskanej wartości liczby odbicia oraz wyników badań niszczących próbek pobranych z obmurza określono wytrzymałość charakterystyczną materiału, z którego zostały wykonane obudowy szybów.

Wytrzymałość na ściskanie materiału, określoną w oparciu o wyniki badań próbek w maszynie wytrzymałościowej (fc,is), przedstawiono w tabeli 1 [4].

Wytrzymałości na ściskanie materiału dla poszczególnych miejsc pomiarowych uzyskane na podstawie badań nieniszczących skorelowano następnie z wynikami badań niszczących próbek pobranych z obmurza szybów wg wzoru [1]:

$$c_k = \frac{f_{cm,is}}{f_{L(n),is}} \qquad (1)$$

gdzie: c_k – współczynnik korygujący wg instrukcja ITB nr 210; $f_{cm,is}$ – średnia wartość wytrzymałości na ściskanie materiału, określona w oparciu o wyniki badań próbek w maszynie wytrzymałościowej; $f_{L(n),is}$ – wytrzymałości na ściskanie materiału dla poszczególnych miejsc pomiarowych uzyskane na podstawie badań nieniszczących. Wyniki obliczeń przedstawiono w tabeli 2.

Parametry muru, z którego wykonano obudowę szybów wyznaczono zgodnie z wynikami przeprowadzonych badań oraz wymogami normy PNB03002:2007. Przyjęto, że mur wykonano na zaprawie zwykłej. Wytrzymałość charakterystyczną muru na ściskanie obliczono z wzoru [2]:

$$f_k = K \cdot f_b^{0,65} \cdot f_m^{0,25},\ MPa, \qquad (2)$$

gdzie: K – współczynnik do potęgi 0,10, którego wartość dla murów z elementów murowych gr. 1 o 5 MPa ≤ f_b ≤ 40 MPa można przyjmować na poziomie 0,5 MPa; f_b – znormalizowana wytrzymałość na ściskanie elementu murowego, którą wyznacza się z wzoru:

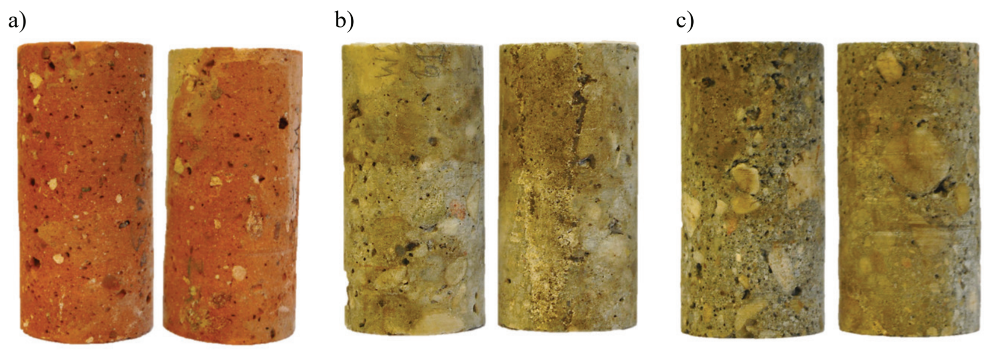
$$f_b = \eta_w \cdot \delta \cdot f_B,\ MPa, \qquad (3)$$

gdzie: η_w – współczynnik uwzględniający stan wilgotności badanych elementów, w przypadku gdy element badany jest w stanie innym niż powietrznosuchy; δ – współczynnik przeliczeniowy [2]; f_B – wytrzymałość średnia elementu murowego na ściskanie, MPa; f_m – wytrzymałość na ściskanie zaprawy, MPa.

Rys. 5. Widok rdzenia pobranego z obmurza szybu ok. 10 m poniżej zrębu
Fig. 5. Core taken from the shaft lining about 10 m below the shaft outset

Rys. 6. Widok rdzenia pobranego z obmurza szybu w rejonie poziomu I
Fig. 6. Core taken from the shaft lining at the level I

Rys. 7. Widok rdzenia pobranego z obmurza szybu w rejonie poziomu II
Fig. 7. Core taken from the shaft lining at the level II



Rys. 8. Próbki wycięte z rdzeni pobranych z obmurza szybów: a) ok. 10 m poniżej zrębu, b) w rejonie poziomu I, c) w rejonie poziomu II
Fig. 8. Samples cut from cores taken from shaft lining: a) about 10 m below the shaft outset, b) at the level I, c) at the level II

Z uwagi na brak informacji odnośnie klasy zaprawy przyjęto, że do wykonania wyrobisk wykorzystano zaprawę klasy M5, natomiast średnią wytrzymałość elementów murowych na ściskanie określono w oparciu o wyniki przeprowadzonych badań nieniszczących i niszczących.

Wytrzymałość obliczeniową muru na ściskanie obliczono z wzoru [2]:

$$f_d = \frac{f_k}{\gamma_m} \tag{4}$$

gdzie: f_k – jak we wzorze (2); γ_m – częściowy współczynników bezpieczeństwa muru uzależniony od kategorii wykonania robót oraz kategorii produkcji elementów murowych.

Parametry wytrzymałościowe muru w konstrukcji obudowy analizowanych wyrobisk przedstawiono w tab. 3.

Jak wynika z przeprowadzonych badań jakość materiału pozyskanego z konstrukcji obudów przy użyciu zaprojektowanego urządzenia jest dobra i umożliwia skorelowanie wyników badania prób rdzeniowych z wynikami uzyskanymi metodą sklerometryczną. Pozwala to na określenie parametrów wytrzymałościowych obudowy szybów zgodnie z wymogami zawartymi w Rozporządzeniu Ministra Energii z dnia 23 listopada 2016 r [9].

Podsumowanie

Zgodnie z obowiązującymi w Polsce od listopada 2016r. przepisami, ocena stanu technicznego obudowy szybów i szybików wymaga wykonywania badań obmurza zarówno metodami nieniszczącymi jak i niszczącymi [9]. Szczególne trudności sprawia pobieranie materiału do badań niszczących z uwagi na brak urządzeń przystosowanych do wykonywania

Tab. 1. Wytrzymałości na ściskanie materiału w konstrukcji obudowy szybów określona metodą niszczącą
Tab. 1. Compressive strength of material in shaft linings construction determined by the destructive method

Miejsce pobrania	Materiał obudowy	Próbka 1	Próbka 2	$f_{cm,is}$
		$f_{c,is}$		
		MPa		MPa
ok. 10 m poniżej zrębu szybu	cegła	14,0	18,6	16,3
Poz. I	betonity	51,9	47,1	49,5
Poz. II	betonity	44,6	50,6	47,6

Tab. 2. Skorelowane wartości wytrzymałości na ściskanie materiału w konstrukcji obudowy w oparciu o wyniki badań wykonanych metodami niszczącymi i nieniszczącymi
Tab. 2. Correlated values of compressive strength of shaft linings construction based on the results of tests carried out by destructive and non-destructive methods

Miejsce pobrania	Materiał obudowy	Seria 1	Seria 2	Seria 3	$f_{ckm,is}$
		$f_{ck,is}$			
		MPa			MPa
ok. 10 m poniżej zrębu szybu	cegła	16,3	15,0	17,6	16,3
Poz. 613	betonity	48,0	59,6	41,7	49,8
Poz. 680	betonity	40,5	54,2	48,6	47,8

Tab. 3. Zestawienie obliczonych parametrów wytrzymałościowych obudowy szybów w miejscach prowadzonych badań obmurza
Tab. 3. Summary of calculated strength parameters of shaft linings at test sites

Parametr	Jednostka	ok. 10 m poniżej zrębu	Poz. I	Poz. II
Materiał obudowy		cegła	betonity	betonity
f_b	MPa	10,3	43,5	41,6
f_m	MPa	5	5	5
f_k	MPa	2,9	7,4	7,2
f_d	MPa	1,3	3,4	3,3

w szybach odwiertów rdzeniowych. Dlatego zaprojektowano i zlecono wykonanie lawety umożliwiającej montaż i prowadzenie dowolnej górniczej wiertarki ręcznej przy zapewnieniu wszelkich wymogów bezpieczeństwa pracy w wyrobiskach górniczych. Skuteczność opracowanego urządzenia potwierdzono następnie podczas prób ruchowych w warunkach dołowych. Proces wiercenia przebiegał bez zakłóceń a jakość uzyskanych rdzeni była dobra. Po serii przeprowadzonych prób stwierdzono, że testowany zestaw wiercący nadaje się w pełni do wykorzystania w warunkach ruchowy. Następnie, w oparciu w wyniki badań niszczących cylindrycznych próbek wycięty z rdzeni pobranych z obmurza wykonanego z cegły i betonitów, określono parametry wytrzymałościowe materiału obudowy. W miejscach pobrania prób rdzeniowych wykonano również badania nieniszczące metodą sklerometryczną. Jakość materiału pozyskanego z konstrukcji obudów przy użyciu zaprojektowanego urządzenia pozwoliła na skorelowanie wyników badania prób rdzeniowych z przeprowadzonymi badaniami sklerometrycznymi i określenie parametrów wytrzymałościowych obudowy szybów. Potwierdza to przydatność zaprojektowanego zestawu wiercącego do stosowania w warunkach ruchowych. Do najważniejszych zalet zaprojektowanego i wykonanego urządzenia należy:

- wykorzystanie jako urządzenia wiercącego górniczej pneumatycznej wiertarki ręcznej PWR II co daje możliwość stosowania zestawu w pomieszczeniach ze stopniem „c" niebezpieczeństwa wybuchu metanu oraz klasy B zagrożenia wybuchem pyłu węglowego,
- wykonanie wszystkich elementów zestawu ze stali,
- możliwość dostosowania lawety do dowolnego typu urządzenia wiercącego,
- specjalna konstrukcja żerdzi umożliwiająca wiercenie z płuczką wodną,
- brak konieczności mocowania lawety do obudowy szybu co ułatwia prowadzenie wierceń w obmurzu skorodowanym, zanieczyszczonym i pokrytym nalotem,
- brak konieczności prowadzenia robót bez osłony klatki szybowej czy daszków głowicy naczynia wyciągowego, co przyczynia się do poprawy bezpieczeństwa pracy,
- brak zagrożenia porażeniem prądem elektrycznym,
- możliwość prowadzenia wierceń przy dużej wilgotności (urządzenie wiercące odporne na działanie wody),
- stabilna i wytrzymała konstrukcja lawety,
- prosty montaż w naczyniu wyciągowym,
- możliwość zastosowania w innych robotach wiertniczych, wymagających precyzyjnego prowadzenia koronki wiertniczej.

Na podstawie przeprowadzonych prób ruchowych oraz wyników badań korelacyjnych podjęto decyzję o zgłoszeniu lawety do prowadzenia górniczych wiertarek ręcznych do ochrony patentowej.

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The Assessment of Shaft Lining Strength Parameters Based on the Results of Core Tests Taken Using an Innovative Drilling Set

In accordance with the regulations in force in Poland since November 2016, the assessment of the technical condition of ore pass and shaft linings requires the testing of the shaft wall both by non-destructive and destructive methods. The collection of material for destructive testing is particularly difficult due to the lack of devices adapted for core drilling in shafts. In order to enable safe and precise sampling for strength tests in conditions characteristic for mining shafts, an innovative drilling assembly with pneumatic drive was developed. To confirm the effectiveness of the developed equipment, underground test runs have been carried out. Cores taken from the shaft wall were assessed for quality and precision of workmanship. Then, on the basis of the results of destructive testing of the taken core samples, the possibilities of their use for assessing the strength parameters of the shaft lining were determined.

Keywords: *mining shafts, drilling rig, technical condition of the casing, core tests*

The Role of Coal in the Polish Economy

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Abstract

The paper shows the structure of primary energy production and consumption in Poland over the last ten years, i.e. between 2010 and 2019. The authors focused in particular on energy raw materials, especially on steam coal being the basic raw material used to produce electricity and heat. The diagrams show energy production and consumption in the analysed period in Petajoule (PJ), then the consumption per capita is shown providing some indication of the living standard of the population. The structure of fuel production in Poland in the years 2010, 2015 and 2019 displays the dominant role of solid fuels, especially steam coal with its nearly 40% share in 2010. In the following years, its share decreased, but still amounts to almost 30%. The remaining solid fuels such as coking coal and lignite are less relevant in this structure, although they are very important for Polish economy. In various years, the share of coking coal ranged from 8.6 to 10.0%, and that of lignite from 9.3 to 13.0%. Liquid and gaseous fuels are produced in Poland in small quantities, and the varying percentage level depends on the volume of solid fuels produced in particular years.

Keywords: *hard coal, primary energy, production, consumption*

Introduction

Since the Second World War, hard coal and lignite have been the basic raw material for producing electricity and heat in Poland. It is safe to say that the country built its position in Europe and in the world thanks to the development of the mining industry which, in the times of the previous system, used to bring financial benefits, and Poland used to be one of the leading exporters of these raw materials. The shift in global trends and increasing share of renewable energy reduce each year the share of coal in the energy mix; nevertheless, it is still the most important energy raw material for the country. What is more, the draft Poland's Energy Policy by 2040 (Draft 2019) assumes a 60% share of coal in electricity generation by 2030. The percentage is significantly less compared to previous years, but it is still a dominant share. In the long term, there are plans to further develop renewable energy sources which are to reach 21% of gross final energy consumption in 2030. In 2033, the first nuclear unit is to appear in Poland and this will undoubtedly further reduce the importance of coal in the country's energy mix. However, the draft has not yet been approved by Parliament and is not a binding document; it can only serve as an auxiliary material for predicting how energy policy and the consumption of raw materials will develop in Poland in the coming years.

Primary energy

Primary energy is the energy produced from natural resources i.e. hard coal and lignite, oil, natural gas, nuclear fission fuels and fusion energy; but it also means renewable energy carriers such as solar, wind, biomass, geothermal, to name a few.

Figure 1 shows the production and consumption of primary energy in Poland between 2010 and 2019.

Attention should be drawn to the fact that primary energy production in Poland has decreased. In 2010, it was 2,742 PJ and over the next three years it increased to 2,975 PJ (2013), which was the highest value in the period under review. In the following year, primary energy production fell slightly, but still in 2015 it was very high and reached 2,964 PJ. From that moment, the volume was constantly decreasing and fell to 2,494 PJ in 2019. The graph showing primary energy consumption during that period looks very interesting. Between 2011 and 2012 the consumption decreased from 4,163 PJ to 3,963 PJ and remained stable for the next three years; although domestic demand remained largely unchanged. This demonstrates increased imports in those years. In turn, between 2012 and 2015, when energy production was at its highest level, its consumption decreased significantly, which demonstrates increased exports. Between 2015 and 2018, primary energy consumption continuously increased from 3,984 PJ to 4,408 PJ with only a slight drop to 4,301 PJ in 2019. It is also worth looking at the difference between production and consumption. It turns out that the smallest difference happened between 2012 and 2015, when the production was at its highest and the consumption was at its lowest. Starting from 2015, the difference between production and consumption grew systematically from 1,020 PJ in 2012 to 1,823 PJ in 2018. In turn, the year 2019 was characterised by lower consumption, but the production also fell significantly; however, the difference was still large and amounted to 1,807 PJ. The current situation due to the CODIV-19 pandemic and the resulting economic lockdown of several weeks will result in a further decrease in primary energy production and consumption, although the extent of the decline is currently difficult to estimate.

The per capita consumption of primary energy in Poland looks very interesting and its development is shown in Figure 2.

Over the last ten years the per capita consumption of primary energy in Poland varied widely, from 103.3 GJ in 2014 to 115.6 GJ in 2018. In the first five years of the analysed period,

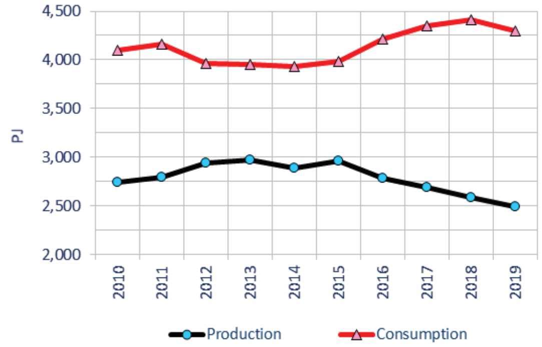

Fig. 1. Primary energy production and consumption in Poland, 2010–2019. Source: Own study based on the National Energy Balances, ARE (ARE 2011–2020)

Rys. 1. Pozyskanie oraz zużycie energii pierwotnej w Polsce w latach 2010–2019

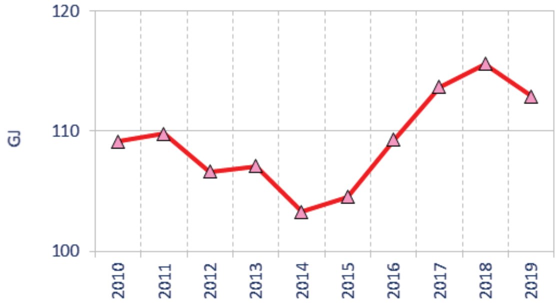

Fig. 2. Primary energy consumption in Poland per capita, 2010–2019. Source: Own study based on BP 2020 (BP 2020)

Rys. 2. Zużycie energii pierwotnej w Polsce per capita w latach 2010–2019

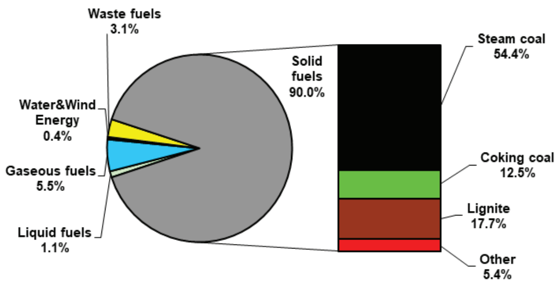

Fig. 3. Fuel production in Poland, 2010. Source: Own study based on ARE data (ARE 2011–2020)

Rys. 3. Struktura pozyskania paliw w Polsce w 2010 roku

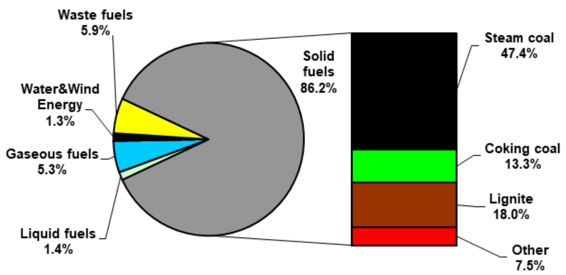

Fig. 4. Fuel production in Poland, 2015. Source: Own study based on ARE data (ARE 2011–2020)

Rys. 4. Struktura pozyskania paliw w Polsce w 2015 roku

a decreasing trend is clearly visible while the next four years are a period of rapidly growing consumption due to the economic development of the country. The year 2019 was marked by a decline in consumption both globally and per capita.

Production of fuels in Poland

Figures 3 to 5 show the structure of fuel production in Poland in 2010, 2015 and 2019.

The above three graphs show the decreasing share of solid fuels in primary energy production in Poland. Still in 2010, solid fuels had a 90% share to reach 86.2% in 2015, and only 83.0% in 2019. When it comes to the most important solid

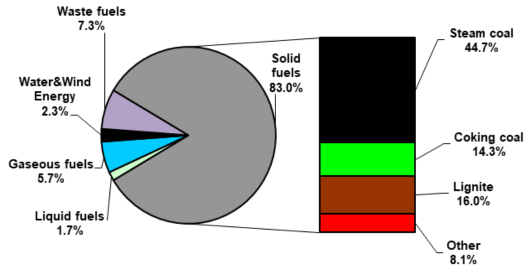

Fig. 5. Fuel production in Poland, 2019. Source: Own study based on ARE data (ARE 2011–2020)
Rys. 5. Struktura pozyskania paliw w Polsce w 2019 roku

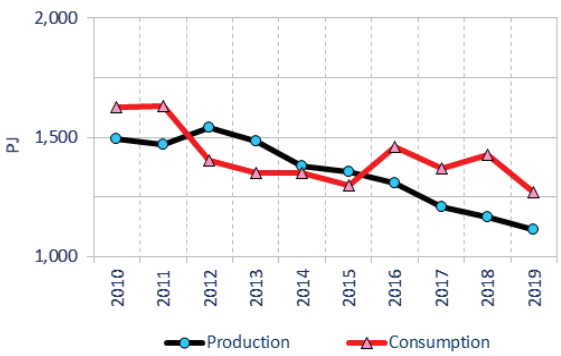

Fig. 6. Steam coal production and consumption in Poland, 2010–2019. Source: Own study based on the National Energy Balance Sheets, ARE (ARE 2011–2020)
Rys. 6. Pozyskanie oraz zużycie węgla energetycznego w Polsce w latach 2010–2019

fuel, i.e. steam coal, its share in 2010 production amounted to 54.4%, in 2015 fell to 47.4% and in 2019 to 44.7%. The share of coking coal varied from 12.5% in 2010, 13.3% in 2015 to reach 14.3% in 2019. Thus, a clear increase in the share of energy production is visible when comparing this raw material to other fuels. In the case of lignite, the values were 17.7% in 2010, 18.0% in 2015 and 16.0% in 2019.

As far as gaseous fuels are concerned, their production in 2010 accounted for 5.5% of total primary energy production in Poland; in 2015 this share increased to 5.3%, and in 2019 reached 5.7%. The share of liquid fuels in primary energy production was 1.1% in 2010, 1.4% in 2015 and 1.7% in 2019. So in this case, again, a slight percentage increase was noticed. It should be born in mind, however, that the production in absolute terms did not increase because we do not have the possibility of doing so; an increased percentage share is the effect of decreasing production of solid fuels.

Steam coal

Figure 6 presents the production and consumption of steam coal in Poland between 2010 and 2019.

The production of steam coal has declined over the last decade, although this trend can clearly be seen only from 2012. The year 2012 was the last year in the analysed period when primary energy produced from this fuel exceeded 1,500 PJ, and precisely 1,539 PJ. Starting from that year, the production of steam coal decreased steadily. As far as consumption is concerned, the downward trend is not so evident in this respect. After a marginal decrease between 2012 and 2015, coal consumption clearly increased to 1,461 PJ in the following year. In 2017, there was a significant drop in coal consumption, and although it increased in 2018, the year 2019 saw its very sharp fall to 1,269 PJ, the lowest in the last decade.

Coal prospects in Poland

The prospects for coal in Poland depend mainly on government policy, and this policy is closely linked to that of the European Union. Widespread slogans about the decarbonisation of the economies of EU Member States do not allow to be optimistic about the development of this industry in our country. The lack of an energy policy does not make it possible to predict exactly what direction the mining industry will take and how long coal will be the fundamental raw material for energy production in Poland. The share of renewable energy which is increased every year, the announcements regarding the introduction of nuclear energy into the energy mix will undoubtedly change the structure of both energy production and consumption in Poland.

Today, the basic document, although not approved by Parliament, is the draft Poland's Energy Policy by 2040 (PEP2040). It sets out the main directions of development of the sector which so far has been based mainly on coal. Therefore, it is worth taking a closer look at the provisions contained in this document.

Poland currently consumes around 4,400 PJ of primary energy, most of which is hard coal and oil. The most important players in the end-use energy consumption are households and transport. While energy consumption in households is decreasing due to improved efficiency, the consumption of energy in transport is increasing due to its ever growing importance in creating GDP.

Annex 2 to PEP2040 provides details of the historical va-

Tab. 1. Domestic production forecast by fuel, ktoe. Source: PEP2040-Annex 2
Tab. 1. Prognoza produkcji krajowej z podziałem na paliwa, ktoe

	2005	2010	2015	2020	2025	2030	2035	2040
hard coal	45 736	35 302	32 136	29 367	27 433	22 615	18 831	16 210
coking coal	9 948	8 216	9 155	9 339	8 809	8 668	8 588	8 564
coke	5 721	6 701	6 666	7 160	7 174	7 192	7 241	7 323
lignite	12 736	11 559	12 299	10 637	11 110	11 095	5 971	3 761
oil	840	681	922	1 000	1 000	1 000	1 000	1 000
natural gas	3 884	3 693	3 683	3 595	3 627	3 653	3 675	3 694
nuclear fuel	0	0	0	0	0	0	0	0
biofuels	117	446	936	1 100	1 133	1 042	1 006	972
solid biomass	4166	5 866	6 268	7 356	8 385	9 753	9 986	10 193

Tab. 2. Forecast of fuel consumption in Poland by 2040, ktoe. Source: PEP2040-Annex 2
Tab. 2. Prognoza zużycia paliw w Polsce do 2040 roku, ktoe

	2005	2010	2015	2020	2025	2030	2035	2040
hard coal	37 669	39 241	31 205	28 707	24 284	19 436	15 731	13 181
coking coal	7 884	8 694	9 488	9 396	8 957	8 891	8 874	8 906
coke	2 314	2 154	2 266	2 563	2 415	2 299	2 235	2 219
lignite	12 726	11 576	12 283	10 651	11 124	11 110	5 979	3 766
oil	18 017	22 633	25 930	27 247	27 227	26 784	26 861	26 754
petroleum products	22 338	26 856	25 338	31 280	31 225	31 060	30 817	30 510
natural gas	12 235	12 805	13 776	16 547	17 290	18 121	19 677	20 662
coke-oven gas	1 480	1 744	1 704	1 676	1 651	1 641	1 642	1 651
blast furnace gas	885	526	632	576	532	489	454	428
other gaseous fuels	161	149	162	88	76	76	75	75
solid biomass	4 166	5 866	6 774	7 896	9 023	10 522	10 778	11 004
biogas	54	115	229	284	318	352	388	425
biofuels	54	868	782	1 497	1 542	1 418	1 369	1 322
nuclear fuel	0	0	0	0	0	0	4 624	6 936
municipal and industrial waste	157	400	564	1 047	1 251	1 329	1 417	1 499

lues for 2005, 2010 and 2015 as well as the expected domestic production volumes by fuel (see Table 1).

The forecast shows that hard coal production will be steadily decreasing throughout the entire period covered by the analysis. Nevertheless even in 2040 it will be a dominant fuel in the production structure of fuels in Poland. The document states that the „fall in demand for coal in the industrial sector is mainly due to the process of modernisation of manufacturing processes. Households and services – in the framework of the fight against smog in cities – will gradually replace inefficient boilers with those meeting the highest environmental standards (with high energy conversion efficiency) and replace coal technologies with more environmentally friendly ones (district heating, RES, natural gas)". Coking coal production will decrease slightly while the production of lignite – considered to be the most harmful fuel for the environment – will fall almost threefold. Oil production will increase slightly while biofuels will grow in importance, and biomass production will more than double.

The document also forecasts fuel consumption by 2040 presented in Table 2.

The projection foresees a decrease in domestic hard coal and lignite consumption as a result of the implementation of the existing energy and climate policy and the reduction of coal consumption in households. The decline in coal consumption in the power and heating sectors will intensify significantly between 2030 and 2040. A slight fall in the consumption of oil and petroleum products is expected between 2020 and 2040. The driving force behind maintaining demand in this sector is economic growth, but the inhibiting factor is the improvement in efficiency resulting from technological progress, measures taken to improve the organisation of transport services and the development of transport infrastructure (networks of motorways and expressways). The growing use of natural gas will result from an increase in the use of this fuel in power generation, mainly as a regulatory and back-up capacity, and from the desire to improve air quality, given that it is a fuel with a lower carbon footprint than coal.

The latest estimates of July 2020 forecast the closure of several mines, which will make it necessary to increase coal imports in order to meet the needs of the power sector. Coal imports have been present since Poland joined the European Union. Previously, only coking coal was imported, and since 2004, steam coal has also been imported. In 2011, imports of hard coal to Poland increased by more than 500% compared to 2004 (Stala-Slugaj 2014). A change in the trend in Polish coal trade could already be seen earlier. In 2008, for the first time in history, coal imports exceeded exports (Olkuski 2010). The prospects for coal in Poland depend not only on the decisions of Polish government, but also on international arrangements. In May 2019, a draft National Energy and Climate Plans (NECPs) was presented, which shows how EU countries plan to use coal for electricity generation in the 2030 perspective. Out of the 21 countries using coal in the EU, only seven gave specific dates for their total coal phase-out (Olkuski, Grudziński 2019). Other countries declare they are ready to reduce the use of coal in the energy sector, but do not specify deadlines for the complete phase-out of this raw material. Poland is also in this group. The reduction of domestic coal mining will also depend on its supply and demand on international markets, as well as on its price (Grudziński 2018; Stala-Szlugaj 2018). An important aspect of the future usage of coal will be the possibility of reducing its harmful impact on the environment and thus on human health (Steel-Service 2018a, b). This mainly involves eliminating low emissions from the burning of solid fuels in households and reducing CO2 emissions (Grudziński, Stala-Szlugaj 2015; Stala-Szlugaj 2017).

Conclusion

Fossil fuels, i.e. steam coal, coking coal and lignite, are the most common source of primary energy in Poland. Their position is the result of the economic development of the country based on fossil raw materials. Poland does not have sufficient oil and natural gas resources to be able to develop its economy based on these fuels. This is the reason why in the period that immediately followed World War II, an economic model was chosen which is still valid today. Undeniably, the role of hard coal in the national economy is no longer as important as in previous years, but it is still dominant. The European Union's energy policy aimed at developing renewable energy sources together with rapidly progressing decarbonisation create pressure for changes in our country as well. This can be seen clearly from the announcements of government representatives on the development of offshore wind energy, or support for photovoltaics. As a result, the share of coal in the primary energy production will decrease. The share of coal will also decrease in the primary energy consumption, at the expense of imported gas or imported oil for the transport sector. The absence of the "Poland's Energy Policy" Act does not allow for an unambiguous determination of what the consumption of particular energy raw materials and energy will be in the future. However, it can be concluded from the projects which are being developed and submitted for public consultation that Poland will strive, as Western European countries do, to introduce the green deal - although this process in Poland will be slower than in the countries of the so-called 'old Union'.

In the next few years the consumption of fossil fuels, coal included, will depend on the policies of the world's powers. The United States has already withdrawn from the Paris Agreement; earlier Canada withdrew from the emissions reduction arrangements. Now the United Kingdom is leaving the European Union, and it is not clear whether the former will continue to support EU climate policy (Olkuski 2019). So far, the role of coal in the Polish economy has been enormous and even its gradual reduction each year does not mean that Poland will entirely phase out this raw material because it is simply impossible in the coming years.

The closure of the Ministry of Energy and the establishment of the Ministry of Climate clearly shows the direction in which Polish energy policy will be heading in the coming years.

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Rola węgla w polskiej gospodarce

W artykule przedstawiono strukturę pozyskania oraz zużycia energii pierwotnej w Polsce na przestrzeni ostatnich dziesięciu lat, czyli w okresie 2010–2019. Skupiono się zwłaszcza na surowcach energetycznych, a szczególnie na węglu energetycznym będącym podstawowym surowcem wykorzystywanym w produkcji energii elektrycznej i ciepła. Na wykresach pokazano pozyskanie energii w analizowanym okresie w PJ jak również jej zużycie, także w PJ. Pokazano również zużycie w przeliczeniu na mieszkańca, co daje pewien pogląd na poziom życia społeczeństwa. Przedstawiono również strukturę pozyskania paliw w Polsce w latach 2010, 2015 i 2019. Widać z niej dominującą rolę paliw stałych w tej strukturze, a zwłaszcza węgla kamiennego energetycznego, którego udział w 2010 roku wyniósł prawie 40%. W następnych latach jego udział spadał, ale nadal wynosi prawie 30%. Pozostałe paliwa stałe, czyli węgiel koksowy i węgiel brunatny, mają w tej strukturze mniejsze znaczenie, choć są bardzo ważne dla gospodarki kraju. Węgiel koksowy w różnych latach stanowił od 8,6–10,0% udziału, a węgiel brunatny 9,3–13,0%. Paliwa ciekłe i paliwa gazowe pozyskujemy w Polsce w niewielkich ilościach, a zróżnicowany poziom procentowy zależy od wielkości pozyskiwania paliw stałych w poszczególnych latach.

Słowa kluczowe: *węgiel kamienny, energia pierwotna, pozyskanie, zużycie*

Biowzbogacanie surowców mineralnych – modele adhezji bakterii do powierzchni mineralnej

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Abstract

Użyteczność mikroorganizmów jako modyfikatorów powierzchni w procesach biowzbogacania wzbudza ostatnio duże zainteresowanie. Właściwości powierzchniowe minerałów i mikroorganizmów odgrywają główną rolę w określaniu adhezji mikroorganizmów do minerałów, a tym samym skuteczności procesów bioługowania, bioflokulacji i bioflotacji. Do przewidywania adhezji bakterii wykorzystuje się modele Derjaguin-Landau-Verwey-Overbeek (DLVO) i rozszerzone modele DLVO (XDLVO) Klasyczna teoria DLVO wyjaśnia podwójną warstwę elektryczną (EL) na powierzchni czastek i oddziaływania Liftshitz-van der Waalsa (LW). W teorii XDLVO zostały dodane siły solwatacyjne, aby uwzględnić oddziaływania kwasowo-zasadowe Lewisa (AB).

Słowa kluczowe: *bioługowanie, adhezja bakterii do powierzchni minerałów*

Wstęp

Biomodyfikacja powierzchni mineralnej, wpływająca na zachowanie ziarn w procesach biowzbogacania, jest złożonym procesem. Pierwszy krok interakcji bakteria-minerał zależy od warunków wstępnej hodowli, takich jak siła jonowa, pH i źródło energii. Czynniki te wpływają na hydrofobowość powierzchni bakterii, właściwości elektryczne i funkcje powierzchni określając w ten sposób, jak bakterie przyczepiają się do powierzchni mineralnych. Końcowym efektem jest nie tylko modyfikacja powierzchni mineralnej, ale również selektywne rozpuszczenie składników mineralnych, bioakumulacja rozpuszczonych jonów metali oraz utworzenie bądź konwersja różnych form mineralnych. Z punktu widzenia oceny skuteczności procesów bioflotacji i bioługowania bardzo ważna jest możliwość przewidywania interakcji mikroorganizmy-minerały a tym samym sterowania procesem biowzbogacania.

Adhezja komórek bakteryjnych do powierzchni mineralnej

Przewidywanie odziaływania pomiędzy bakteriami a powierzchnią mineralną jest możliwe dzięki zastosowaniu rozszerzonej teorii DLVO albo podejściu termodynamicznemu z wyznaczeniem energii swobodnej adhezji (Rys.1) (Sharma i inni, 2002; Volpe i inni, 1997, 2004; Siboni i inni, 2004; Żenkiewicz, 2007). Metody te formułują oddziaływania Lifschitz-van der Waalsa, elektrostatyczne, hydrofilowo-hydrofobowe w równania matematyczne pozwalające wyznaczyć energię powierzchniową i jej składowe.

Podejście termodynamiczne

Warunkiem wstępnym biomodyfikacji powierzchni mineralnej jest adhezja komórek bakteryjnych (Sharma i inni, 2001). Należy tu uwzględnić energetyczne aspekty konstytuowania warstwy adhezyjnej, w których to upatruje się źródła implikacji niektórych zjawisk oraz procesów. Konsekwencją takiego stanu rzeczy jest poszukiwanie optymalnego parametru charakteryzującego stan energetyczny warstwy powierzchniowej, którego obserwacje i pomiary umożliwiłyby sterowanie właściwościami tej warstwy pod kątem przydatności w procesie biowzbogacania. Wydaje się, że parametrem, który najlepiej nadaje się do tego celu jest swobodna energia powierzchniowa. Adhezja komórek bakteryjnych na powierzchni mineralnej powoduje powstanie nowego układu mikroorganizmy-minerał kosztem istniejących układów mikroorganizmy-pożywka i minerał-ciecz. W związku z tym energię swobodną adhezji można wyrazić za pomocą wzoru:

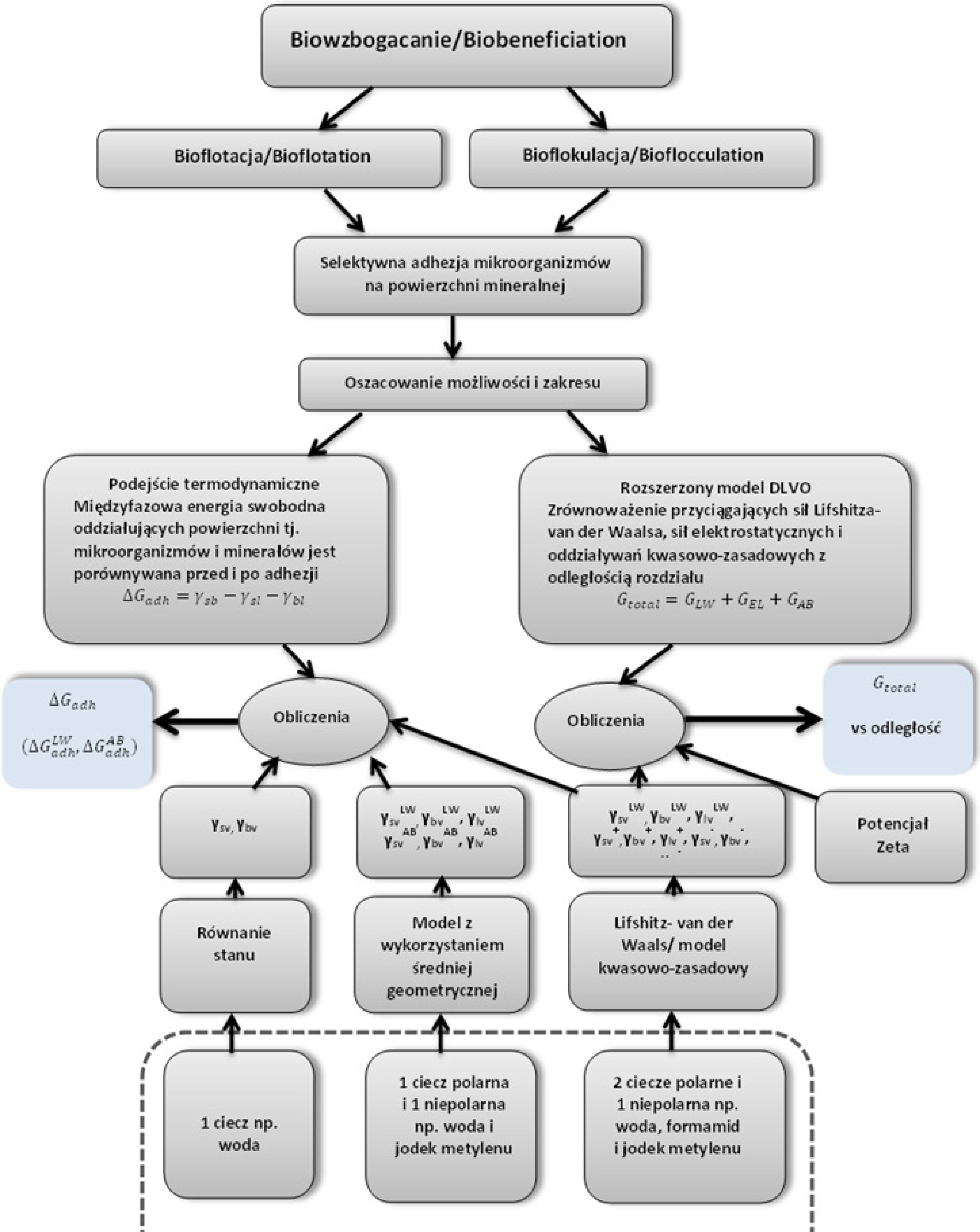
$$\Delta G^{adh}=\gamma_{bs}-\gamma_{bl}-\gamma_{sl}$$

gdzie:
ΔG^{adh} – energia swobodna adhezji
γ_{bs} – napięcie międzyfazowe (interfacial free energy) bakteria-minerał
γ_{bl} – napięcie międzyfazowe bakteria-ciecz
γ_{sl} – napięcie międzyfazowe na granicy ciała stałego i cieczy.

Z termodynamicznego punktu widzenia części składowe swobodnej energii powierzchniowej nie są zdefiniowane, dlatego nie ma możliwości zmierzenia ich w sposób bezpośredni. Ilościowe określenie tych składników jest możliwe dzięki zastosowaniu modeli zawartych w Tabeli 1.

Powszechnie stosowane modele traktują swobodną energię powierzchniową jako sumę sił dyspersyjnych γ_d i sił polarnych γ_p (takich jak wiązania wodorowe). Napięcia międzyfazowe wyznaczone na ich podstawie zawierają składowe dotyczące cieczy γ_l oraz ciał stałych γ_s. Podczas gdy wartości γ_l^d i γ_l^p są dostępne w literaturze dla powszechnie stosowanych cieczy (Tabela 2), to składowe dotyczące energii powierzchniowej ciał stałych γ_s^d i γ_s^p wymagają znajomości kątów zwilżania co najmniej dwóch cieczy o różnej polarności (Clint, 2001).

Bardziej rozszerzony model zaproponowany przez van Ossa (van Oss i inni, 1988) bierze pod uwagę chemiczną naturę faz sugerując, że charakterystyki części polarnej najlepiej dokonać w oparciu o teorię kwasów i zasad Lewisa. Składowa dyspersyjna natomiast charakteryzowana jest na podsta-



Rys. 1. Teoretyczne oszacowanie możliwości i zakresu adhezji drobnoustrojów na powierzchni ciał stałych
Fig. 1. Theoretical estimation of the possibility and extent of microbial adhesion on solid surfaces. (Sharma i inni, 2002)

Tab. 2. Napięcia powierzchniowe i jego składowe(Kwok, 1999)
Tab. 2. Surface tensions and components (mJ/m^2)

Ciecz	γ	γ_l^d / γ_l^{LW}	γ_l^+	γ_l^-
Woda	72.8	21.8	25.5	25.5
Gliceryna	64	34	3.92	57.4
Formamid	58	39	2.28	39.6
Glikol etylenowy	48.0	29	1.92	47. 0
Dimetylosulfotlenek	44	36	0.5	32
Dijodometan	50.80	50.8	0	0
1-Bromonaftalen	44.4	44.4	0	0
Heksadekan	27.5	27.5	0	0
Tetradekan	26.6	26.6	0	0
Dodekan	25.4	25.4	0	0
Dekan	23.8	23.8	0	0
Pentane	16.1	16.1	0	0

Tab. 1. Metody wykorzystywane do obliczenia energii powierzchniowej (Sharma i inni, 2001; Kwok, 1999; Chibowski, 2003; Clint, 2001; Chibowski i inni, 2002)

Tab. 1. The methods used to calculate the surface energy

Model	Składowa całkowitej energii powierzchniowej	Napięcie międzyfazowe	Równania pozwalające obliczyć składowe energii powierzchniowej ciała stałego
Równanie stanu	brak	$\gamma_{12} = \frac{(\sqrt{\gamma_1} - \sqrt{\gamma_2})^2}{1 - 0{,}015\sqrt{\gamma_1 \gamma_2}}$	$cos\theta = \frac{(0{,}015\gamma_{sv} - 2{,}00)\sqrt{\gamma_{sv} + \gamma_{lv}} + \gamma_{lv}}{\gamma_{lv}(0{,}015\sqrt{\gamma_{lv}\gamma_{sv}} - 1)}$
Model Fowkesa tylko γ_i^d	$\gamma = \gamma_i^d + \gamma_i^p$	$\gamma_{12} = \gamma_1 + \gamma_2 - 2\sqrt{\gamma_1^d \gamma_2^d}$	$cos\theta = -1 + 2\sqrt{\gamma_s^d}\left(\frac{\sqrt{\gamma_l^d}}{\gamma_l}\right)$
Metoda z wykorzystaniem średniej geometrycznej	$\gamma = \gamma_i^d + \gamma_i^p$	$\gamma_{12} = \gamma_1 + \gamma_2 - 2\sqrt{\gamma_1^d \gamma_2^d} - 2\sqrt{\gamma_1^h \gamma_2^h}$	$1 + cos\theta = 2\sqrt{\gamma_s^d}\left(\frac{\sqrt{\gamma_l^d}}{\gamma_{lv}}\right) + 2\sqrt{\gamma_s^p}\left(\frac{\sqrt{\gamma_l^p}}{\gamma_{lv}}\right)$
Lifshitz–van der Waals/ model kwasowo-zasadowy	$\gamma = \gamma_i^{LW} + \gamma_i^{AB}$ $\gamma_i^{AB} = 2\sqrt{\gamma_i^+ \gamma_i^-}$	$\gamma_{12} = (\gamma_1^{LW} - \gamma_2^{LW})^2 + 2(\sqrt{\gamma_1^+} - \sqrt{\gamma_2^+})(\sqrt{\gamma_1^-} - \sqrt{\gamma_2^-})$	$(1 + cos\theta)\gamma_l = 2\left(\sqrt{\gamma_s^{LW}\gamma_l^{LW}}\right) + 2\left(\sqrt{\gamma_s^+ \gamma_l^-} + \sqrt{\gamma_s^- \gamma_l^+}\right)$
Metoda oparta na pomiarach histerezy kąta zwilżania	$\gamma = \gamma_i^d + \gamma_i^p$	$\gamma_{12} = \gamma_1 - \gamma_2 cos\theta_a$	$\gamma_s^d = \gamma_l\left(\frac{(1 + cos\theta_a)^2}{4}\right)$ $\gamma_s^{tot} = \gamma_s^d\left(1 + \frac{2 - cos\theta_a - cos\theta_r}{2 + cos\theta_a + cos\theta_r}\right)$

i – faza; γ^d— apolarna składowa dyspersyjna energii powierzchniowej , γ^p— polarna składowa energii powierzchniowej związana z tworzeniem wiązań wodorowych, γ^{LW}— apolarna składowa związana z oddziaływaniami dalekiego zasięgu: dyspersyjnymi, polarnymi i indukcyjnymi, γ^{AB}—polarna składowa związana z oddziaływaniami kwasowo-zasadowymi, γ^+—parametr elektronoakceptorowy, γ^- —parametr elektronodonorowy; θ_a-kąt postępujący; θ_a-kąt cofający; γ_{sv} –napięcie międzyfazowe ciało stałe-powietrze; γ_{lv} - napięcie międzyfazowe ciecz-powietrze

wie oddziaływań Lifshitza, które stanowią część oddziaływań międzycząsteczkowych van der Waalsa (stąd oddziaływania Lifshitza- van der Waalsa). Zgodnie z tymi założeniami występujący we wzorach indeks „LW" oznacza składową Lifshitza- van der Waalsa, indeks „A" oznacza część kwasową składowej polarnej, indeks „B" oznacza część zasadową składowej polarnej. Składowa polarna zawiera dwa nieaddytywne parametry – elektronoakceptorowy γ^+ (electron-accepting parameter) oraz elektronodonorowy γ^- (electron-donating parameter) co prowadzi do trzech niewiadomych odnoszących się do ciał stałych γ_s^{LW} , γ_s^+ , γ_s^- których obliczenie wymaga wartości kątów zwilżania trzech cieczy pomiarowych (z których dwie muszą być polarne) (Kwok, 1999; Clint, 2001).

Należy jednak zaznaczyć, że wyznaczanie swobodnej energii powierzchniowej zarówno metodami w oparciu o teorię kwasowo-zasadową (Volpe i inni, 1997, 2004; Siboni i inni, 2004; Żenkiewicz, 2007), jak i innymi metodami opartymi na pomiarze kąta zwilżania (Chibowski i inni, 2008; Terpilowski i inni, 2008; Kwok i inni, 1999) nie pozwala wyznaczyć całkowitej wartości swobodnej energii powierzchniowej minerałów. Metody te jednak można zastosować do oszacowania składowych dyspersyjnych oraz polarnych, które pozwalają na stosunkowo szczegółową analizę oddziaływań międzyfazowych oraz identyfikację zmian, jakie mogą zachodzić w warstwie wierzchniej na poziomie technologicznym.

Teoria DLVO

Po raz pierwszy teorię DLVO (od nazwisk twórców: Derjaguin, Landau, Verwey i Overbeek) do opisu bakteryjnej adhezji zastosował Marshall w 1971 roku (Marshall K.C. i inni, 1971). Zasugerował on, że proces adhezji bakteryjnej do powierzchni obejmuje wstępną odwracalną sorpcję, po której następuje wolniejszy etap, zależny od powierzchni, prowadzący do nieodwracalnej adsorpcji. Wpływ stężenia elektrolitu w początkowej fazie odwracalnej może być wyjaśniony w oparciu o teorię stabilności koloidalnej DLVO. Obecnie znacznie częściej używa się ulepszonej wersji rozszerzonej opisanej między innymi przez Boströma (Boström et al., 2006).

Klasyczna teoria DLVO

Teoria ta wychodzi z założenia, że oddziaływanie pomiędzy komórką bakteryjną a płaską powierzchnią mineralną jest zależne od równowagi pomiędzy dwoma grupami sił. Pierwsza to wszechobecne w materii oddziaływania van der Waalsa (V_A). Energia tych oddziaływań rośnie proporcjonalnie do odwrotności odległości pomiędzy komórką a minerałem gdzie współczynnikiem proporcjonalności jest stała Hamakera (A). Stała ta opisuje nie tylko siłę oddziaływania pomiędzy powierzchnią mineralną a komórką bakteryjną, ale uwzględnia również właściwości ośrodka, w której się te ciała znajdują. Drugą składową występujących sił są oddziaływania elektrostatyczne VR wynikające z nakładania się podwójnych warstw elektrycznych komórek bakteryjnych i powierzchni mineralnej. Są to oddziaływania zazwyczaj odpychające ze względu na ujemny ładunek powierzchniowy zarówno komórek jak i minerałów. Siły te zależą od rodzaju i stężenia jonów elektrolitu w ośrodku dyspersyjnym (Hermansson M., 1999).

$$V_{TOT} = V_A + V_R$$
$$V_A = -\frac{Ar}{6d}$$

gdzie A – stała Hamakera, d – odległość pomiędzy komórką a powierzchnią minerału, r – promień komórki bakteryjnej. Przyjmuje się, że kształt komórek bakteryjnych jest kulisty.

Energia elektrostatyczna pochodzi od oddziaływań pomiędzy naładowanymi molekułami a jej siła i zasięg jest zależna od potencjału powierzchni ψ oraz odległości miedzy molekułami (maleje wykładniczo wraz z odległością). Wartość potencjału jest uzależniona od adsorpcji jonów potencjałotwórczych (najczęściej jony hydroniowe i wodorotlenowe), jonów powierzchniowoczynnych i stężenia elektrolitu. Ten ostatni wpływ jest następstwem ekranowania ładunku molekuły jonami elektrolitu co wyraża stała ekranowania Debye'a 1/κ.

Można zatem zapisać (Hermansson M., 1999):

$$V_R \propto \psi^2 e^{-\kappa d}$$

Na ogół bakterie posiadają ujemny ładunek powierzchniowy przy neutralnym pH, ale oczywiście od tej reguły zdarzają się wyjątki (Jucker B.A. i inni, 1996). Wzrost ładunku ujemnego na powierzchni komórki oraz powierzchni mineralnej skutkuje wzrostem odpychania. Niemniej jednak ponieważ grubość warstwy podwójnej zostaje zmniejszona przy wysokiej wartości siły jonowej roztworu oddziaływanie bakteria-minerał może być przyciągające dzięki istniejącym siłom van der Waalsa pomimo ujemnego ładunku powierzchni zarówno minerału jak i bakterii. Można zatem powiedzieć, że niska wartość siły jonowej może skutkować odpychaniem a wysoka przyciąganiem przy wszystkich odległościach w układzie bakteria – minerał (Hermansson M., 1999).

Rozszerzona teoria DLVO

Klasyczna teoria DLVO zawodzi w przypadku oddziaływań pomiędzy powierzchniami hydrofilowymi, dlatego zaproponowano uwzględnienie solwatacyjnych lub hydratacyjno-hydrofobowych oddziaływań strukturalnych, których pochodzenie można wiązać z obecnością specyficznych oddziaływań polarnych lub niepolarnych, występujących w tych układach. Jedno z podejść stosowanych do opisu tych sił zostało zaproponowane przez van Oss'a (van Oss, 1989).

Zgodnie z tym podejściem całkowita energia oddziaływań pomiędzy dwiema różnymi cząstkami zdyspergowanymi w środowisku wodnym może być przedstawiona jako suma udziałów:

- oddziaływań elektrostatycznych (EL), związanych z istnieniem na powierzchni cząstek podwójnej warstwy elektrycznej,
- oddziaływań Lifshitza-van der Waalsa (LW),
- sił solwatacyjnych, które mogą być wynikiem oddziaływań kwasowo-zasadowych (AB) lub w ujęciu Lewisa elektronoakceptorowych i elektrono-donorowych, pomiędzy fazami będącymi w kontakcie,
- oddziaływań osmotycznych (OS) – oddziaływanie bardzo słabe dlatego najczęściej pomijane.

Dwa pierwsze oddziaływania zaliczane są do klasycznego modelu DLVO, natomiast składowa AB została wprowadzona w celu wyjaśnienia oddziaływań pomiędzy cząstkami hydrofilowymi i hydrofobowymi w ośrodkach polarnych.

Możemy zatem zapisać, że całkowita energia adhezji wyraża się wzorem:

$$\Delta G^{adh} = \Delta G^{EL} + \Delta G^{LW} + \Delta G^{AB}$$

W ośrodkach polarnych, szczególnie w wodzie swobodna energia oddziaływań polarnych (AB) pomiędzy cząstkami rozproszonymi, jest zwykle nawet 100 razy większa niż energia wynikająca z oddziaływań LW oraz około 10 razy przekraczają one oddziaływania EL.

Podsumowanie

Do przeróbki surowców mineralnych stosuje się zazwyczaj tradycyjne metody fizyko-chemiczne jednak duże zainteresowanie kierowane jest w kierunku metod biologicznych, które mogą rozwiązać problemy ze wzbogacaniem rud o niskiej zawartości składnika użytecznego oraz mogą być stosowane tam gdzie metody tradycyjne zawodzą. Pod pojęciem metod biologicznych rozumiemy dobrze poznany proces bioługowania oraz stosunkowo nowe procesy biowzbogacania takie jak bioflotacja i bioflokulacja, które w większości są ograniczone do badań laboratoryjnych. Ponieważ bakterie przylegają do powierzchni mineralnej w ciągu kilku minut i zmieniają właściwości powierzchni, które są istotne dla wzbogacania minerałów, mikroorganizmy mają ogromne znaczenie w procesach flotacji i flokulacji. Adhezja komórek bakteryjnych na powierzchni mineralnej jest zasadniczo najważniejszym aspektem decydującym o powodzeniu procesów biowzbogacania. Selektywna adhezja bakterii do minerałów jest kluczowym czynnikiem dla selektywnej modyfikacji powierzchni istotnym dla procesów flotacji i flokulacji. Dlatego tak ważna jest możliwość oceny lub przewidywania przyczepności bakterii do powierzchni mineralnej. Uwzględniając siły fizykochemiczne w postaci podejścia termodynamicznego i XDLVO możemy w przybliżeniu ocenić przydatność danego gatunku w procesie biowzbogacania oraz zoptymalizować parametry procesu co ma olbrzymie znaczenie w możliwości wdrożenia na skalę przemysłową.

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Biobenefication of Mineral Resources – Models of Bacterial Adhesion to a Mineral Surface

The utility of microorganisms as surface modifiers in bioenrichment processes has recently attracted a lot of attention. The surface properties of minerals and microorganisms play a major role in determining the adhesion of microorganisms to minerals, and thus the effectiveness of bioleaching, bioflocculation and bioflotation processes. For predicting bacterial adhesion Derjaguin-Landau-Verwey-Overbeek (DLVO) models and extended DLVO (XDLVO) models are used. The classical DLVO theory explains the electric double layer (EL) on the particle surface and the Liftshitz-van der Waals (LW) interaction. In XDLVO theory, solvation forces have been added to account for Lewis acid-base (AB) interactions.

Keywords: *biobenefication, bacterial adhesion to a mineral surface*

Innovative Activity of Companies in the Raw Material Industry on the Example of Poland and Slovakia – Selected Aspects

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Abstract

This paper discusses selected aspects of Innovative activity of companies in the raw material industry. The analysis included two countries from the group of Moderate Innovators (according to the Global Innovation Index, GII), namely Poland and Slovakia. A general comparison of the innovativeness level of Poland and Slovakia with the EU countries was conducted using indicators such as the Innovation-friendly Environment (IFE) or the Summary Innovation Index (SII). The presented structure of expenditures on industrial innovation among the analysed countries revealed the absence of concentration in organizational and marketing innovations, which nowadays possesses significant importance. The conclusion resulting from the study is that Poland and Slovakia should undoubtedly increase their innovative potential, i.a. in the use of their mineral raw materials as non-renewable resources, by identifying the sources of innovation, as well as the opportunities and threats associated with their implementation in raw material enterprises.

Keywords: *innovative activities, mining and quarrying, Global Innovation Index, Innovation-friendly Environment, Summary Innovation Index, innovation expenditure, mineral resources*

Introduction

The raw material sector is currently experiencing many difficulties. The coal markets crisis, the imposition of stricter environmental standards and transition from the traditional to a low-carbon economy, increasing competitiveness of other energy sources on the domestic market, low prices of raw materials, high production costs, an oversupply of coal on the markets, structural changes, the lengthening of decision-making processes, low efficiency of information transmission, information noise, poor optimization of work systems, small involvement of motivational elements in remuneration systems and excessive fragmentation of wage components are only some of the challenges that occur on the energy market [1, 2, 3, 4, 5, 6, 7, 8].

Nowadays, innovation has become a relevant issue in the activity of enterprises and should be incorporated into the process of strategic management, particularly in the case of raw material businesses [9]. Innovations and innovative activities are elements which have a significant impact on the company's competitive position on the market [10]. That is why the above-mentioned difficulties, as well as the complicated economic and financial situation of the industry, develop the need for the change and innovative activity [11]. Although the companies conduct innovative activity, it is primarily focused on the processes [12, 13]. Without a doubt, they require improvement, more effectiveness, or redirection of their focus, but most importantly, there is a need for programmes which support business management. The current mission of managers is not only to recognize the sources of innovation but also to identify the opportunities and threats associated with their implementation [14, 15, 16].

Methodology

The analysis included two countries from the group of Moderate Innovators (according to the Global Innovation Index, GII), namely Poland and Slovakia. It was based on the publicly available reports and statistical data on these countries. A general comparison of the innovativeness level of Poland and Slovakia with the EU countries was conducted using indicators such as the Innovation-friendly Environment (IFE) or the Summary Innovation Index (SII). The types of innovations implemented by innovatively active industrial enterprises have been correlated. Subsequently, the expenditures on innovative activities of these businesses have been compared. The subject of the research on innovative activities consisted only of the industrial enterprises, conducting activities classified according to the Polish Classification of Activities (PKD) and the Statistical Classification of Economic Activities in the European Community (NACE), into the section of Mining and Quarrying, more particularly: extraction of hard coal and brown coal (lignite), mining of crude oil and natural gas, mining of metal ores, other mining and quarrying, as well as service activities supporting mining.

Innovation ranking of the EU countries

The EU Innovation Scoreboard is announced annually, dividing the member states into four groups [17]:

- "Innovation Leaders", with innovation levels well above the EU average,
- "Innovation Followers", with innovation levels above or close to the EU average,
- "Moderate Innovators", with innovation levels below the EU average,
- "Modest Innovators", with innovation levels well below the EU average.

Countries which have been among the Innovation Leaders for a long time are Sweden, Denmark, Finland and

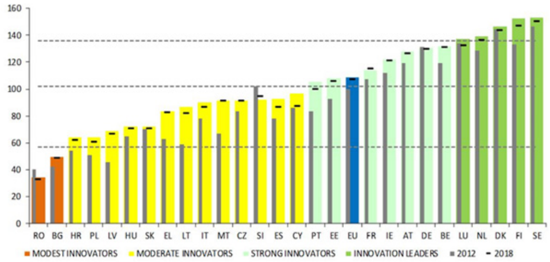

Fig. 1. Innovation Scoreboard. Source: [20]
Fig. 1. Tablica wyników innowacyjności. Źródło: [20]

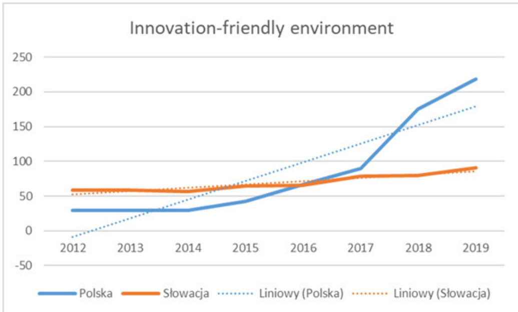

Fig. 2. Development of the Innovation-friendly Environment index for Poland and Slovakia. Source: Own study based on [21].
Fig. 2. Kształtowanie się wskaźnika Innovation-friendly enviroment dla Polski i Słowacji. Źródło: opracowanie własne na podstawie [21]

Germany. They are considered to be the most innovative countries, exceeding the average innovation level for the EU. It implies that in fields (areas) such as science base and higher education systems, entrepreneurship, intellectual capital and economic performance, the level of their innovativeness is above average, indicating a stable system of scientific research and innovation [17]. Innovative activity in the countries is undoubtedly related to their economic development. "The economic development of EU's countries depends on stable and permanent access to various energy sources" [18], and mining and the production of mineral resources in individual countries still play an important role in shaping the global economy [19].

From the innovation boards from 2010 onwards results, that Slovakia, unlike Poland, has consistently belonged to the group of Moderate Innovators. Initially, Poland was among the countries "well below the EU average", i.e., Modest Innovators, next to Bulgaria, Romania and Latvia. The country subsequently advanced to the group "below the EU average" (fig. 1). In the 2019 innovation ranking, Slovakia was ranked at the 7th, while Poland at the 4th lowest positions [20]. The shift within the group might have been influenced by the beginning of the transition from traditional to a low-carbon economy, as well as investments related to environmental protection. This situation has been reflected in the Innovation-friendly Environment index. The development of this indicator for Poland and Slovakia has been presented in Figure 2.

Between 2012 and 2019, the value of the indicator for Slovakia recorded an upward trend. With regard to Poland, the index value revealed an upward trend as well, but the growth rate of the indicator was higher. Initially, Poland's indicator value was lower than that of Slovakia's, however, since 2016 onwards, it has registered higher levels.

The study revealed that the innovativeness of Polish and Slovak enterprises significantly differs from the levels recorded in the majority of the EU countries [17, 22, 23]. It indicates that the innovation performance in the EU is improving annually (Poland changed groups while still remaining at the same position), however, the innovation gap between the EU member states is continuously widening (Fig. 3).

Figure 3 presents the development of the Summary Innovation Index for selected countries from the innovation ranking, one from each group of leaders, with Poland and Slovakia included in the comparison as countries with the level of innovation below the EU average. It reveals the amount of improvement our countries require to deliver in terms of the innovation indicator in order to be ranked at least within the group of Innovation Followers, where Austria is placed. The innovation level of Sweden, as one of the Innovation Leaders, is rather unattainable for our countries.

The above-mentioned widening of the innovation gap between the EU member states involves not only the product and process innovation but more importantly, the organizational and marketing innovation, whose importance in today's world increases [23].

Types of innovation

The participation of raw material businesses which introduce innovations is constantly increasing. According to the Central Statistical Offices of Poland and Slovakia, an innovatively active enterprise is one which, introduced at least one innovation in the studied period (product or process, or implemented a minimum of one innovative project).

The comparison of innovative activity in Poland and Slovakia reveals that between 2014 and 2016, the participation of Slovak enterprises which introduced every type of innovations was undeniably higher than the participation of Po-

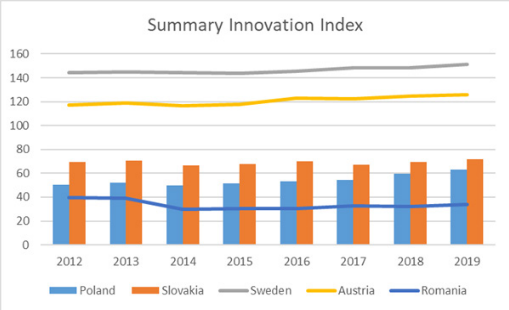

Fig. 3 Development of the Summary Innovation Index for Poland and Slovakia. Source: Own study based on [21]
Fig. 3. Kształtowanie się wskaźnika Summary Innovation Index dla Polski i Słowacji. Źródło: opracowanie własne na podstawie [21]

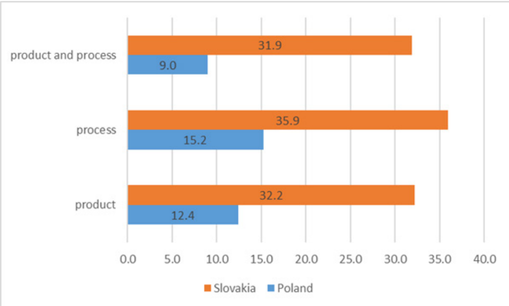

Fig. 4. Structure of the actively innovative enterprises in Poland and Slovakia in 2014–2016 [%]. Source: Own study based on [24, 25]
Fig. 4. Struktura przedsiębiorstw aktywnie innowacyjnych w Polsce i Słowacji w latach 2014–2016 [%]. Źródło: opracowanie własne na podstawie [24, 25]

lish businesses (Fig. 4). It is also confirmed by the relation between the position of Poland and Slovakia in the EU countries innovation ranking.

Process innovations in Slovakia were introduced by 35.9% of the companies, i.e. by 20.7 pp more than companies in Poland. The participation of enterprises in product innovations in Poland was 19.8 pp lower, amounting to 12.4%. On the other hand, the percentage of Slovak companies which introduced product and process innovations was 22.9 pp higher.

More information on the innovation types in the energy sector, as well as the participation of mining and quarrying companies which implemented innovations in Poland between 2016 and 2018 was provided in [13, 26]. The presented analyses have indicated, that the participation of industrial, innovatively active enterprises in the following years has increased, compared to 2016, while within the structure of the implemented changes, more process innovations appeared. Since 2016, Poland's situation in terms of innovation has improved, which is presented by the previously mentioned Innovation-friendly Environment and Summary Innovation Indexes.

Expenditure on innovation

Innovation expenditure includes science, technology and costs associated with trade as well as any steps leading to the implementation of new or significantly improved products or processes, such as expenditure on the ongoing or abandoned innovations. The structure of industrial innovation expenditure in Slovakia from 2016 is presented in Figure 5, while in Poland – in Figure 6.

With regard to Slovakia, 5 groups of expenditures on innovation may be distinguished (Fig. 5). A very broad group, consisting of the purchase of machinery and equipment, hardware, software and buildings is the main component of the innovation expenditures in industrial enterprises. As much as 68.3% of the outlays was allocated to this group in 2016. The second group within the structure of innovation expenditures was internal research and development (19.6%). Much smaller participation in the outlays structure was allocated to the purchase of external research and development (6.26%), the acquisition of knowledge from other companies or organizations (2.99%), and to all other innovative activities – 3.1%.

While comparing innovation expenditures in Poland, a different classification may be observed (Fig. 6). Although the expenditures on machinery and equipment are separated from the outlays on buildings and software (such was the case in Slovakia), they represent almost 50% of total expenditures on innovation (49.4%). The outlays on the purchase of buildings and land with 26.7% are placed second. In 2016, the expenditures on research and development activities were 8.4 pp lower than outlays on the purchase of buildings, amounting to 18.3% of the structure of the total expenditure. The smallest participation was recorded for other innovations (2.6%), software purchases (1.6%) and marketing activities (1.4%).

Due to the different distribution within the structure of expenditures on innovation in Slovakia and Poland, they were divided into three groups: machinery, hardware, software and buildings, R&D activities and others. Such sequence facilitates a better comparison (Fig. 7).

The presented comparison reveals that in 2016, Poland incurred higher expenditures (77.7%) on machines, hardware, software and buildings than Slovakia (68.29%). However, the R&D and other outlays were higher in Slovakia by 7.56 and 1.85 pp respectively.

The presented structure of expenditures on innovation in Poland and Slovakia confirms the widening of the innovation

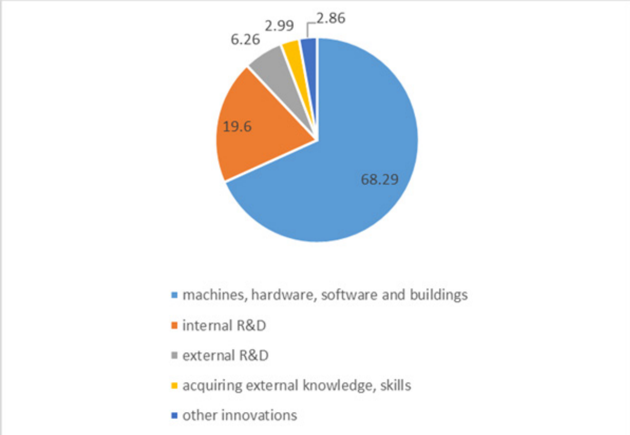

Fig. 5. Structure of expenditures on innovative activities in industrial enterprises in Slovakia, 2016 [%]. Source: Own study based on [25]
Fig. 5. Struktura nakładów na działalność innowacyjną w przedsiębiorstwach przemysłowych na Słowacji w 2016 roku [%]. Źródło: opracowanie własne na podstawie [25]

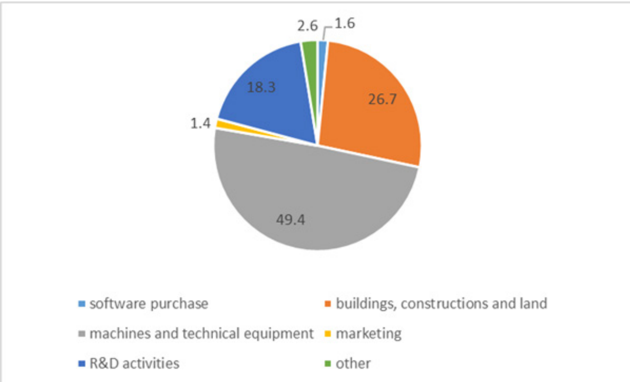

Fig. 6. The structure of outlays on innovative activity in industrial enterprises in Poland, 2016 [%]. Source: Own study based on [24]
Fig. 6. Struktura nakładów na działalność innowacyjną w przedsiębiorstwach przemysłowych w Polsce w 2016 roku [%]. Źródło: opracowanie własne na podstawie [24]

gap between the EU member states, reflected in the absence of organizational and marketing innovations. Analyses of the structure of investment outlays in the energy sector were the subject of other works and articles as well [22, 27, 28, 29].

Mineral resources in the Moderate Innovators countries versus directions of innovation activities

Both analysed countries – Poland and Slovakia – are countries rich in mineral resources. 4 groups of mineral resources occur in each of them: energy, chemical, metallic and rock raw materials. The amount of raw material deposits varies, as presented in Figure 8. The occurrence of natural resources in both countries is related to the geological past and phenomena that have been taking place over millions of years. The mineral raw materials are included in the group of finite resources, which means they are non-renewable resources. Thus, on the one hand, it is important to use them rationally, and on the other to pursue replacing them with renewable resources. This issue concerns energy raw materials the most, therefore we have a growing number of wind farms, solar and hydropower stations. The manufacture of biofuels is also increasing, which contributes to the improvement of environmental cleanliness.

While studying the mineral resources in the deposits, it can be observed that Slovakia has a small volume of raw materials, but a significant amount of non-metallic resources in relation to its other minerals (15,747 million tons in 2018). The second place in terms of resources is occupied by building materials (2,642 million tons in 2018). There appear to be slightly less metallic raw materials (1,343 million tons in 2018) and energy raw materials (1,133 million tons in 2018).

Compared to Slovakia, Poland owns a significant amount of all mineral resources deposits. The majority are chemical raw materials (91,547.17 million tons in 2018), and a slightly less energy raw materials (85,017.25 million tons in 2018) and rock raw materials (61,344.59 million tons in 2018). Metallic raw materials constitute the smallest number of resources (2,540.44 million tons in 2018).

The raw materials deposits that occur in the presented countries in the largest quantities have shaped the industry development, as well as the direction of the applied technologies. The resources provide them with a significant amount of independence [19, 33, 34, 35, 36, 37, 38], as well as reduce the costs of development of industries that use mineral resources. Such independence of Poland is possible particularly with the use of hard coal and lignite seams, which are used in the energy and metallurgy industries. Apart from the energy raw materials, in terms of the overall possessed resources, a significant amount of metallic and rock materials is extracted in Poland. However, the independence of Slovakia is possible

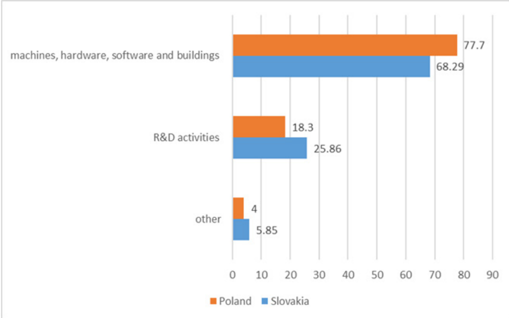

Fig. 7. Structure of expenditures on innovative activity in Polish and Slovak industrial enterprises in 2016, divided into three groups [%]. Source: Own study based on [24, 25]

Fig. 7. Struktura nakładów na działalność innowacyjną w przedsiębiorstwach przemysłowych w Polsce i Słowacji w 2016 roku w podziale na trzy grupy [%]. Źródło: opracowanie własne na podstawie [24, 25]

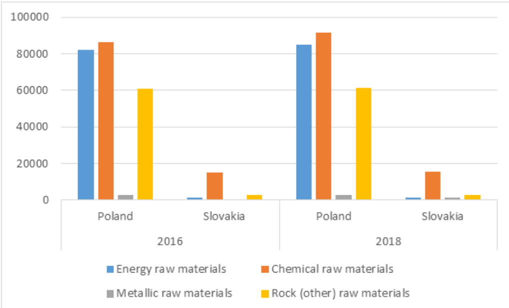

Fig. 8. Total geological resources of minerals from deposits in Poland and Slovakia in 2016 and 2018 [million tons]. Source: Own study based on [30, 31, 32]

Fig. 8. Całkowite zasoby geologiczne kopalin w złożach w Polsce i Słowacji w 2016 oraz 2018 roku [mln ton]. Źródło: opracowanie własne na podstawie [30, 31, 32]

mainly due to rock, energy and non-metallic raw materials [39]. Slovak industry still greatly influences the economy, while the metallurgy and the automotive industries possess significant importance.

Conclusion

A comparative analysis of the innovative activity of industrial, innovatively active businesses in Poland and Slovakia has revealed several challenges these countries encounter and need to overcome to remain in their position in the innovation ranking of the EU member states. The indicated in the study process of widening of the innovation gap, which includes mainly the organizational and marketing innovations, nowadays possesses significant importance. The presented structure of expenditures on industrial innovation among the analysed countries revealed the absence of such modifications.

Various types of innovation – technology-driven, digital and global megatrends, such as artificial intelligence and the closed-circuit economy, offer companies great opportunities on the one hand while leading to new challenges on the other. While the global competition intensifies and threatens the leading positions of key industries, Poland and Slovakia should undoubtedly increase their innovative potential, i.a. in the use of their mineral raw materials as non-renewable resources, by identifying the sources of innovation, as well as the opportunities and threats associated with their implementation in raw material enterprises. In the current situation of the pandemic, following the collapse of the markets, this may prove difficult. It does not change the fact that innovation and planned innovative activity of industrial businesses in Poland and Slovakia are crucial. Without a doubt, a deeper analysis of the innovative activities and expenditures, which require not only improvement or effectiveness, but above all, a change in the direction of their focus would prove to be beneficial. Such activities should be aided by the management support programs and financed by the industry, as well as the state.

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Działalność innowacyjna przedsiębiorstw branży surowcowej na przykładzie Polski i Słowacji – wybrane aspekty

W artykule przedstawiono wybrane aspekty działalności innowacyjnej firm w branży surowcowej. Analiza objęła dwa kraje z grupy Moderate Innovators (według Global Innovation Index, GII), czyli Polskę i Słowację. Ogólne porównanie poziomu innowacyjności Polski i Słowacji z krajami UE przeprowadzono za pomocą wskaźników, takich jak Innovation-friendly Environment (IFE) czy Summary Innovation Index (SII). Przedstawiona struktura wydatków na innowacje przedsiębiorstw przemysłowych wśród analizowanych krajów ujawniła brak koncentracji na innowacjach organizacyjnych i marketingowych, które obecnie mają istotne znaczenie. Z przeprowadzonych badań wynika, że Polska i Słowacja powinny niewątpliwie zwiększyć swój potencjał innowacyjny m.in. w wykorzystaniu swoich surowców mineralnych jako zasobów nieodnawialnych, poprzez identyfikację źródeł innowacji oraz szans i zagrożeń związanych z ich wdrażaniem w przedsiębiorstwach surowcowych.

Słowa kluczowe: *działalność innowacyjna, górnictwo i wydobywanie, Global Innovation Index, Innovation-friendly Environment, Summary Innovation Index, wydatki na innowacje, surowce mineralne*

Analysis of the Impacts and Proposal of Pollution Controls, Prevention and Reduction Solutions by the Activities of Industrial Parks in Ho Chi Minh City, Vietnam

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Abstract

Ho Chi Minh City (HCMC), Vietnam has a rapid growth rate, with an open economy with cooperation with many countries around the world, concentrating many industrial parks and export processing zones along with infrastructure development projects, industrial production services related to transportation, communication, water supply and environmental protection, resource exploitation, production and processing of consumer goods and exports. Along with the rapid industrialization and modernization process in Ho Chi Minh City, according to which environmental quality is increasingly reduced, in which the most significant effect is water resources, particularly water sources of rivers and canals. In recent years, there have been many studies related to the quality of surface water sources in Ho Chi Minh City, but there haven't been studies to assess the impacts, affecting the quality of surface water sources due to activities of industrial parks in the City. This study was conducted to assess surface water quality by analyzing the current status of surface water quality in areas related to the operation of industrial parks in Ho Chi Minh City. Thereby assessing the impact on the water quality and proposing solutions to control and prevent pollution due to the operation of industrial parks.

Keywords: *pollutions, industrial parks, surface water, Saigon river water*

1. Overview of Activities of Industrial Parks and Export Processing Zones in Ho Chi Minh City

Ho Chi Minh City is an economic, commercial, financial and service center of Vietnam, concentrating many industrial and export processing zones with large scale and high growth rate. After nearly 30 years of construction and development (1991-2019), industrial parks and export processing zones have been formed, diversified and actively contributed to the socio-economic and industrial development. However, along with it, the level of environmental pollution caused by IPs and EPZs is increasing, becoming a threat to sustainable economic growth. On article [1] was provided an overview of the current status of operations as well as impacts on surface water from the operation of some industrial parks (IPs), export processing zones (EPZs) in Ho Chi Minh City, Vietnam. Figure 1 shows Map of the location of IPs/EPZs in HCMC and Table 1 represents Number and area of IPs and EPZs in HCMC[2].

The strong development and great contributions of IPs/EPZs are undeniable. However, the process of developing industrial parks in Ho Chi Minh City as well as in Vietnam in the past time still exists with many challenges and shortcomings including the problem of environmental pollution despite many remedial measures, but still going on complicated developments, more and more tend to increase the level of pollution. Out of 42 industrial parks and export processing zones established, put into operation, only 27 industrial parks and export processing zones have built wastewater treatment systems (64.2 %). According to Ho Chi Minh City Export Processing and Industrial Zones Authority (HEPZA), the remaining IPs/EPZs do not have a wastewater treatment system or are in the process of construction. It is worth mentioning that even the IZs/EPZs have built a waste treatment system, the operational efficiency is not high, especially for industrial parks with long time of operation located next to Saigon river basins, Dong Nai,... because the wastewater treatment system of these areas has deteriorated.

In addition, many other IPs/EPZs have built a centralized wastewater treatment system, but in fact they do not operate or operate only in response to the inspection [2].

In the following part of this article is described analysis of water quality at some typical ips in Ho Chi Minh City.

2. Results of Water Quality Analysis at Some Typical IPs in Ho Chi Minh City

2.1. Sampling sites

To analyze the quality of surface water in some sections of rivers, canals in Ho Chi Minh City, this study conducted a survey, sampling at the nearby locations in a number of industrial parks. Detailed information on sampling locations is shown in Table 2.

The method of sampling and on-site analysis as well as tools for sample preservation, sample preservation, sample transport, sample reception strictly follow the instructions in the corresponding standards, as follows: TCVN 6492:2011, TCVN 7325:2016, TCVN 6001-1:2008, SMEWW 5220C:2012, SMEWW 6625:2000, SMEWW 4500-NH3.B&F:2012, SMEWW 4500-NO3-.E:2012, SMEWW 4500-P.E:2012, TCVN 6187-2:1996, TCVN 6216:1996, TCVN 6194:1996, SMEWW 3120B:2012.

Fig. 1. Map of the location of IPs/EPZs in HCMC. Source: Hochiminh City export processing and industrial parks authority (HEPZA)[2]
Rys. 1. Mapa lokalizacji IP / EPZ w HCMC. Źródło: Urząd ds. Przetwórstwa eksportowego i parków przemysłowych miasta Hochiminh (HEPZA) [2]

The parameters analyzed in the laboratory are officially recognized in accordance with the requirements of ISO 17025: 2005, requirements of VIMCERTS certification/Ministry of Natural Resources and Environment of Vietnam.

2.3. Data analysis

The results of surface water quality analysis at the sampling locations in this study are detailed in Table 3.

The results of surface water quality analysis at the locations are shown in Table 3, showing that the nutrient content assessed through the parameters N-NO3, P-PO4 exceeds QCVN 08:2015/BTNMT [3] on surface water quality. The concentration of N-NO3 ranged from 7.8-9.8 mg/l (Figure 2), higher 2-5 times than the limits of raw surface water quality standards for water supply (QCVN 08: 2015/BTNMT column A2). Especially, P-PO4 content ranges from 1.171-1.164 mg/l, much higher than the level permitted by QCVN 08:2015/BTNMT column B2, which is regulated for water sources used for waterway traffic and other purposes with low water quality requirements (Figure 2).

In addition, high concentrations of organic substances measured in water samples were obtained at the analytical sites. Specifically, the COD content in the study sites was from 49.6 to 192 mg/l, nearly 20 times higher than the permitted level of A1 (10 mg/l) and BOD5 were higher than B1 (15 mg/l), ranging from 18.26 to 97.62 mg/l, the highest concentration near Hiep Phuoc industrial parks, 20 times more than the limits of raw surface water quality standards for water supply (QCVN 08:2015/BTNMT column A1), TSS measured at a high level especially 82.0 mg/l is also found in this area (Figure 3).

Besides, the measured Coliform and Phenol content at the survey sites are almost higher than the allowable levels of A1 and A2 of QCVN 08:2015/BTNMT, respectively (Figure 4). Normally, Phenol has a high content in wastewater from some industries such as plastic, paper, pharmaceutical, pesticide.

Through the survey results and analysis of parameters at the sampling locations, it is shown that surface water sources near industrial parks in Ho Chi Minh City have been polluted quite high by organic substances and nutrition and microorganisms. Therefore, it is necessary to consider, evaluate and come up with suitable solutions to control and improve water quality in areas where production activities are concentrated.

In the study of water quality assessment along the Saigon River in Ho Chi Minh City area, water quality was found to be well represented by DO, organic, nutrient, heavy metals upstream and strongly increased in the urban areas, especially Cr and Hg (higher up to 10 times), are likely to originate from industrial waste [4]. The results of analysis and measurement of water quality indicators show that the concentration of organic, nutrients, chemicals, microorganisms pollutants exceeds the permitted standards and it is possible that they arise from production activities such as food processing, paper, fertilizer, wood, tanning industry, etc. [4]. In addition, EDCs compounds were also identified with relatively high concentrations in water samples taken from Saigon and canals in Ho Chi Minh City [5], this is a compound discharged from the wastewater activation, industrial wastewater and medical waste or by products arising from the processes of plastic, pharmaceutical, cosmetic, plant protection products, cleaning products and chemicals [6]. Through the survey re-

Tab. 1. Number and area of IPs and EPZs in HCMC. Source: Ho Chi Minh City export processing and industrial parks authority (Hepza) [2]
Tab. 1. Liczba i obszar IP i EPZ w HCMC. Źródło: władze Ho Chi Minh City zajmujące się przetwórstwem eksportowym i parkami przemysłowymi (Hepza) [2]

No.	IPs/EPZs	Area (ha)
1	Hiep Phuoc IP (phase 1)	311,4
2	Hiep Phuoc IP (phase 2)	597
3	Tan Phu Trung IP	542,64
4	Tan Tao IP	380,15
5	Tan Thuan EPZ	300
6	Dong Nam IP	286,76
7	Tay Bac Cu Chi IP	208
8	Vinh Loc IP	203
9	Le Minh Xuan III IP	155,75
10	Tan Binh IP	128,7
11	Cat Lai II IP	124
12	An Ha IP	123,51
13	Le Minh Xuan IP	100
14	Co khi Oto IP	99
15	Linh Trung 1 EPZ	62
16	Linh Trung 2 EPZ	61,7
17	Tan Thoi Hiep IP	28
18	Binh Chieu IP	27,34
19	Da Phuoc IC	116,8
20	Pham Van Coi IC	75
21	Tan Quy A IC	65
22	Tan Quy B IC	97
23	Long Son IC	25,37
24	Handicraft District 2 IC	18
25	Tan Thoi Nhi IC	87
26	Tan Hiep A IC	25
27	Tan Hiep B IC	40
28	Nhi Xuan IC	180
29	Dong Thanh IC	36
30	Duong Cong Khi IC	55
31	Bau Tran IC	95
32	SAGRI IC	89
33	Tran Dai Nghia IC	50
34	Quy Duc IC	70
35	Tan Tuc IC	40
36	Long Thoi IC	57
37	Binh Khanh IC	97
38	Hiep Thanh IC	50
39	Binh Dang IC	33
40	Phu My IC	80

sults reports, the water source on the Saigon River has high nutrient, organic and microbiological content, the pollution on the Saigon River becomes more serious and makes it difficult and expensive in water treatment [7].

According to the results of recent research on water quality of the Saigon River, the raw water quality of Saigon River has been reduced due to the increase of pollutants such as organic, nitrogen and pathogens related to agricultural, industrial and domestic activities [4]. The Saigon River is polluted by organic, BOD and COD content exceed the limits of raw surface water quality standards for water supply (column A2 QCVN 08:2015/BTNMT [8], [3].

According to the review report also showed that surface water quality in Ho Chi Minh City is currently polluted by organic substances, nutrients, heavy metals, microorganisms and some other compounds and causes. The main pollution is caused by industrial production activities of the IPs/EPZs [1].

3. Impacts Caused by Polluted Water from the Activities of the IPS/EPZS

Tab. 2. Sampling sites
Tab. 2. Miejsca pobierania próbek

No.	Name	River/canal section	Neighboring industrial parks
1	M1	An Ha canal, the river section passes An Ha bridge	Tan Phu Trung
2	M2	B canal, the section crossing the B canal river bridge	Le Minh Xuan
3	M3	Ba Bo canal, the section nearby Ngo Chi Quoc street	Linh Trung II
4	M4	Ky Ha canal, passing Ky Ha bridge	Cat Lai
5	M5	Kinh river, Dong Dien bridge intersection	Hiep Phuoc

Tab. 3. Results of analysis of water quality indicators at sampling locations. Source: Environmental Monitoring and Assessment Center, Ton Duc Thang University, Viet Nam (May 2019)
Tab. 3. Wyniki analizy wskaźników jakości wody w miejscach poboru próbek. Źródło: Ośrodek monitorowania i oceny środowiska, Uniwersytet Ton Duc Thang, Wietnam (maj 2019 r.)

No.	Parameter	Unit	Result					Test methods
			M1	M2	M3	M4	M5	
1	pH	-	7.74	7.45	7.50	7.29	7.32	TCVN 6492:2011
2	DO	mg/l	7.68	5.11	7.32	7.90	8.91	TCVN 7325:2016
3	BOD_5	mg/l	18.26	49.19	73.02	25.62	97.62	TCVN 6001-1:2008
4	COD	mg/l	49.6	94.40	140.8	53	192	SMEWW 5220C:2012
5	TSS	mg/l	36.0	5.70	22.30	24.70	82.0	SMEWW 6625:2000
6	N-NH_4	mg/l	0.03	0.09	0.08	0.05	0.06	SMEWW 4500-NH_3.B&F:2012
7	N-NO_3	mg/l	8.5	7.8	9.8	8.2	7.8	SMEWW 4500-NO_3-.E:2012
8	P-PO_4	mg/l	1.201	1.256	1.464	1.171	1.187	SMEWW 4500-P.E:2012
9	Coliform	MPN/100ml	5000	3000	5000	2100	3000	TCVN 6187-2:1996
10	Phenol	mg/l	0.01	0.01	0.02	0.01	0.01	TCVN 6216:1996
11	Clorua	mg/l	42.295	59.710	-	333.383	771.258	TCVN 6194:1996
12	Fe	mg/l	0.137	-	-	-	-	SMEWW 3120B:2012
13	Mn	mg/l	0.099	-	-	-	-	SMEWW 3120B:2012
14	Pb	mg/l	-	<0.01	<0.01	<0.01	<0.01	SMEWW 3120B:2012
15	Cu	mg/l	-	0.009	0.01	0.013		SMEWW 3120B:2012
16	Ni	mg/l	-	<0.01	-	<0.01	-	SMEWW 3120B:2012
17	Zn	mg/l	-	-	0.027	-	-	SMEWW 3120B:2012
18	Cr	mg/l	-	-	0.011	-	0.01	SMEWW 3120B:2012

The problem of environmental pollution due to industrial production activities in general and EPZs/EPZs in particular has been adversely affecting the natural ecosystems and people's lives in the region. Especially, waste water produced without treatment and discharged directly into the environment will directly affect the water ecosystem, causing significant damage to agricultural and fishery production and aquaculture in the surrounding area. In addition, the problem of environmental pollution caused by industrial production also increases the burden of disease, increases the rate of sick people working at the IPs/EPZs and communities living around the area. area. Alarmingly, this rate has tended to increase in recent years and caused significant economic losses for the locality. Details are presented below.

3.1. Loss of Ecosystem Productivity of Agriculture and Aquaculture

The system of rivers and canals in Ho Chi Minh City is the source for receiving and transporting waste water containing pollutants from IPs/EPZs. Waste water containing organic matter exceeding the permissible limit will cause eutrophication, reducing the amount of oxygen in the water, leading to some species being killed. The occurrence of toxic substances such as grease, heavy metals, chemicals in the water will affect aquatic plants and animals and enter the food chain of living species, eventually affecting the health of people.

In Ho Chi Minh City, the amount of wastewater from IPs/EPZ operations in recent years is much larger than that of other activities and increases at a rapid rate. According to the general assessment of the PC49 Environmental Crime Prevention Police Department, around 62% of industrial parks nationwide have built centralized wastewater treatment systems but these works are inefficient, leading to The situation of 75% of industrial wastewater discharged to industrial parks still contains high levels of pollutants, exceeding permitted standards many times. This data is quite similar to the data on the status of HCMC (64.2% of IPs /EPZs built wastewater treatment systems). The amount of untreated waste water discharged directly into the environment has caused people in the area around the IPs/EPZs to suffer. Illustrative images for polluted canals in Thu Duc District, HCMC are shown in Figure 5 [9].

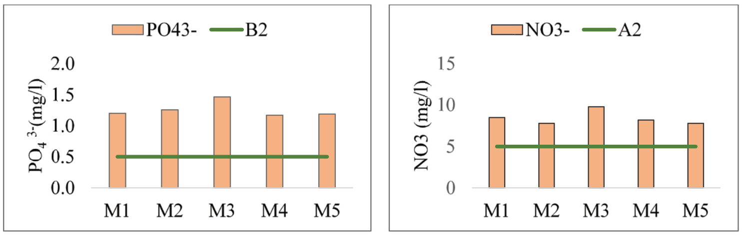

Fig. 2. Concentration of P-PO_4 and N-NO_3 at the locations
Rys. 2. Stężenie P-PO_4 i N-NO_3 w lokalizacjach

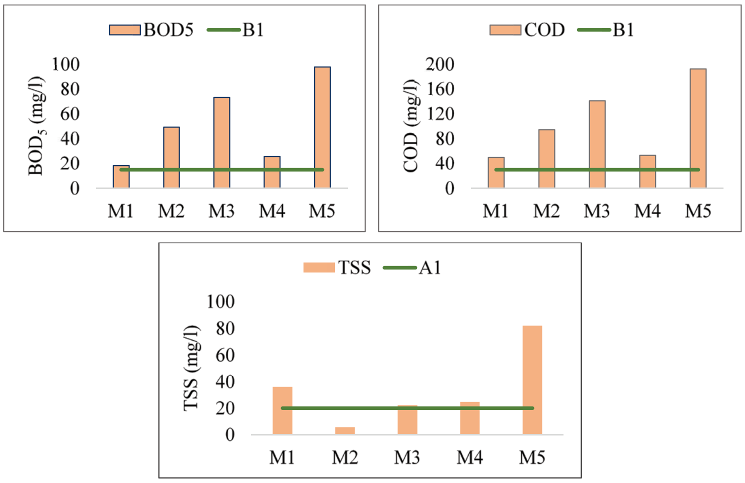

Fig. 3. Concentrations of BOD_5, COD, and TSS
Rys. 3. Stężenia BZT_5, ChZT i TSS

In southern Vietnam, water pollution of Thi Vai river is one of the typical examples of industrial pollution causing direct impacts on water ecosystems, causing significant damage to agricultural production. and fisheries of people in the region. The discharge of pollutants with high concentrations and large flows into river water environments, in the middle and lower reaches of the river (where many large-scale IPs/EPZs are concentrated) cannot be controlled, causing heavy pollution to the environment. In the affected area, shrimp, fish and aquatic species are almost impossible to survive and grow. Ecosystems in this area only exist a few species of zooplankton and phytoplankton; the species of algae that grow mainly are those that adapt to a high nutrient environment and their development also increases the risk of toxicity to the aquatic environment.

3.2. Polluting water, soil and health effects

Wastewater from IPs/EPZs must not be treated, causing pollution to surface and groundwater sources, thereby affecting the quality of water supply and may cause adverse impacts on human health through the food chain. The main diseases related to water quality are intestinal diseases, parasitic diseases, bacteria, viruses, mold..., diseases caused by intermediate insects and micro-elements and other substance.

According to the study, assessing the impact of production activities in metal processing zones on the health of people living around the National Institute of Occupational and Environmental Health in Vietnam, showing the lead content in waste water exceed the permitted standards many times; respectively, the content of lead and arsenic in the soil in the study area is 1.2–2.5 times higher than the standard, and the content of lead and arsenic in the domestic water is 1.5–6 times higher.

In a study assessing the effect of lead metal (derived from industrial textile dyeing, battery production, bleaching, metallurgy) domestic canal in Ho Chi Minh City to vegetable quality Aquatic plants show that: the content of lead in Ipomoea aquatica grown in some specialized areas, growing on canals is relatively high, in comparison with the permitted standards, there are 16/25 vegetable samples on the market with content lead higher than specified. The untreated industrial wastewater discharged directly into the river and canal system has increased the content of heavy metals, including lead and other toxins in vegetables, greatly affecting consumers' health.

3.3. Increasing the burden of disease

Economic losses due to increasing burden of diseases related to water pollution are very large. Statistics from the Institute of Occupational Medicine and Environmental Sanitation on industrial pollution and public health show that from 1976 to 1990 in Vietnam there were 5,497 cases of occupational diseases, but in the period In the period of 2006 to 2016, the number of infected people has tripled with a total of 21,597 people. It is forecasted that the number of new occupational diseases by 2020 will be over 30,000, according to which, the total expenditure on occupational diseases in the period of 2006 to 2016 is calculated at more than 50 billion VND.

This data proves that: environmental pollution has significantly affected the health of people living in the vicinity of factories, IPs/EPZs, thereby causing economic losses for the locality, specifically loss for medical examination and treat-

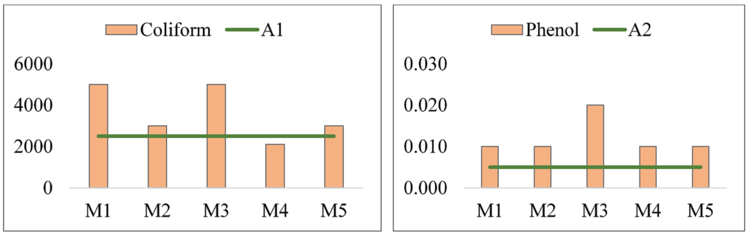

Fig. 4. Concentrations of Coliform and Phenol
Rys. 4. Stężenia pałeczek coli i fenolu

Fig. 5. Untreated wastewater discharged directly to Kenh Ba Bo, Thu Duc District, HCMC
Rys. 5. Nieoczyszczone ścieki odprowadzane bezpośrednio do Kenh Ba Bo, dystrykt Thu Duc, HCMC

ment and other damages caused by illness. It is estimated that the average economic loss for each person in a year in the area affected by the IPs/EPZs is 3.5 times higher than in other regions.

According to a World Bank study [10] "Risks due to water pollution are becoming more serious, causing impacts on human health as well as the economy and the environment, a major threat, and they can cause nearly 6 % of GDP losses by 2035, if no changes are made".

4. Solutions to Control and Prevent Pollution Due to the Operation of Industrial Parks

4.1. Management solutions

Completing institutions on environmental protection; review, adjust and supplement issued policy documents, specific legislation on the environment, the documents guiding the implementation of the law.

Taxes and environmental charges on the principle of "polluters must pay environmental treatment, remedial, renovation and restoration costs", "people benefit from environmental values must be paid" should be applied to promote the role of economic tools, limit activities causing pollution and degradation, promote socio-economic development towards green growth.

Planning and relocating industrial parks to separate areas, suburban areas, far from residential areas, is an essential factor to protect and take measures to isolate and handle environmental safety. The planning must be classified by type of production to facilitate management, especially waste collection, advanced production technology application, construction of waste treatment system.

4.2. Technical solutions

Continuous improvement of environmental waste treatment processes, prioritizing clean, green and clean production lines with the living environment to ensure that industrial parks do not negatively affect the surrounding area.

Enhance capacity, fully equip necessary equipment and facilities, maintain regular monitoring activities, detect cases of violation of the law on pollution control.

Focusing on measures to prevent and reduce pollution in industrial parks, strategic environmental assessment and environmental impacts must be improved, ensuring scientific, focused, feasible, public and participatory.

5. Conclusion

Activities of industrial parks have grown rapidly, contributing significantly to the country's economic development process, but there are also many risks of environmental pollution, especially for surface water. The results of analysis at a number of locations near industrial parks in Ho Chi Minh City show that surface water has been polluted, the level is quite high, focusing on organic matter and nutrition content, chemicals and harmful microorganisms. Thus, it is predicted that surface water pollution in HCMC's rivers and canals will become more serious, making it more difficult and expensive to control and manage.

Therefore, the implementation of measures to control and prevent pollution in industrial parks in Ho Chi Minh City is very necessary, in which the completion of institutions in environmental protection activities; reviewing, modifying and promulgating additional environmental policies and legislation, and guiding documents for implementation of laws are very important. When complete policies and institutions can effectively implement the introduction of appropriate technical solutions to contribute to minimizing, controlling and preventing water pollution due to the operation of industrial parks.

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Rozwiązania w zakresie kontroli, zapobiegania i redukcji zanieczyszczeń w działalności parków przemysłowych w mieście Ho Chi Minh, Wietnam

Ho Chi Minh City (HCMC) w Wietnamie charakteryzuje się szybkim tempem wzrostu, otwartą gospodarką i współpracą z wieloma krajami, skupiając wiele parków przemysłowych i stref przetwórstwa eksportowego wraz z projektami rozwoju infrastruktury przemysłowej, usługi produkcyjne związane z transportem, komunikacją, zaopatrzeniem w wodę i ochroną środowiska, eksploatacją zasobów, produkcją i przetwarzaniem dóbr konsumpcyjnych oraz eksportem.

Wraz z szybkim procesem industrializacji i modernizacji w Ho Chi Minh City coraz bardziej obniża się jakość środowiska, w którym najważniejszym czynnikiem są zasoby wodne, zwłaszcza wodne źródła rzek i kanałów. W ostatnich latach przeprowadzono wiele badań dotyczących jakości wód powierzchniowych w Ho Chi Minh City, ale nie przeprowadzono badań oceniających oddziaływanie wpływające na jakość źródeł wód powierzchniowych z powodu działalność parków przemysłowych w mieście.

Badania przeprowadzono w celu oceny jakości wód powierzchniowych poprzez analizę aktualnego stanu wód, zbadano jakość wód powierzchniowych na obszarach związanych z funkcjonowaniem parków przemysłowych w Ho Chi Minh City. W ten sposób oceniono wpływ czynników na jakość wody i proponowano rozwiązania w zakresie kontroli i zapobiegania zanieczyszczeniom wynikającym z funkcjonowania parków przemysłowych.

Słowa kluczowe: *zanieczyszczenia, parki przemysłowe, wody powierzchniowe, wody rzeki Sajgon*

Coking Coal in the European Green Deal Strategy

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Abstract

Achieving climate neutrality in the EU economy by 2050 is a huge challenge to which all European Union plans and strategies have been submitted. Achieving the EU's climate and environmental goals requires, among other things, a profound transformation of the power sector, as well as decarbonisation and modernisation of energy-intensive industries such as steel production, for instance.

The European steel industry has to face the challenges of reducing carbon emissions; the evidence suggests that hydrogen will play a major role in the decarbonisation of the sector, provided cheap renewable energy is available on a large scale. However, in the near future, most of the steel produced in the EU will continue to be produced using the BF-BOF route, which requires a stable supply of coking coal.

The paper describes the structure of world steel production according to production technology and indicates the projects implemented by European companies, aimed at moving towards emission-free steel production.

The European Commission has recognised the key role of coking coal in the EU economy by placing it on the 2020 list of critical raw materials. The list identifies those raw materials which need to be protected in the EU due to their high economic importance and high supply risk. The paper presents the results of the criticality assessment for coking coal included in the fourth technical review, which qualified it for the third time as a material to be kept on the list of critical raw materials.

Keywords: *EU, critical raw materials, coking coal, steel, decarbonisation*

1. Introduction

The Green Deal is a long-term strategy for the development and growth of the European Union; it strengthens its innovation and global competitiveness in the strategic industrial sectors, and creates new jobs in a modern and green economy. In 2019, the Commission announced the pace and direction of the Green Deal. The EU economy is to achieve climate neutrality by 2050 mainly through a profound transformation of the power sector, but also of that of transport, industry, construction and agriculture. This is a huge challenge to which all the European Union's plans and strategies have been submitted (Commission Communication... COM(2019)640 final).

A new industrial policy is needed based on a circular economy to achieve the EU's climate and environmental goals. It is necessary to decarbonise and modernise energy-intensive industries such as steel and cement production, for example. Today, the target to reduce CO_2 emissions by 2030 is 40 percent as compared to 1990 levels, but the European Commission maintains its plan to increase the reduction target to 50–55 percent.

The steel industry contributes to some of the largest carbon dioxide emissions, accounting for some 7 to 9 percent of direct emissions from global fossil fuel consumption. The growing population and increased urbanisation, as well as the development of renewable energy sources (RES), are factors that increase global demand for steel; therefore, the environmental impact of steel production is a major challenge both in Europe and worldwide. As part of the industrial strategy, which supports the green transition, the European Commission will put forward a legislative proposal to support the transition to carbon-free steel production by 2030.

2. Decarbonisation projects for steel production

Today's steelmaking methods are based on the use of fossil fuels. A dominant position is occupied by an integrated blast furnace – basic oxygen furnace (BF - BOF) route in which the furnaces are fed with blast furnace pig iron. In the BF route the main raw material apart from iron ore is coke derived from coking coal. Globally, the share of steel produced using the technological route: coking plant – blast furnace – basic oxygen furnace systematically increased to reach 71.9 percent in 2019 (Figure 1) with total crude steel production of 1,869 million tonnes. The consumption of metallurgical coal to produce 1 tonne of crude steel in this system is on average 780 kg (worldsteel).

In the second method, steel is produced in electric furnaces where the charge (mainly steel scrap) is melted using an electric arc furnace (EAF). The carbon consumption in the EAF production cycle is about 150 kg per tonne of crude steel (worldsteel).

Iron production that does not use the blast furnace, excluding coke, is called direct reduction of iron ore (DRI). MIDREX is a process of iron reduction in its solid state (without melting the iron ore) mainly by means of natural gas or coal. The product is the so-called sponge iron used to feed the EAF. An alternative route for the production of pig iron that does not use the blast furnace is iron reduction in its liquid state: the two-stage COREX process. The combustion of steam coal in a shaft furnace in oxygen generates a strongly

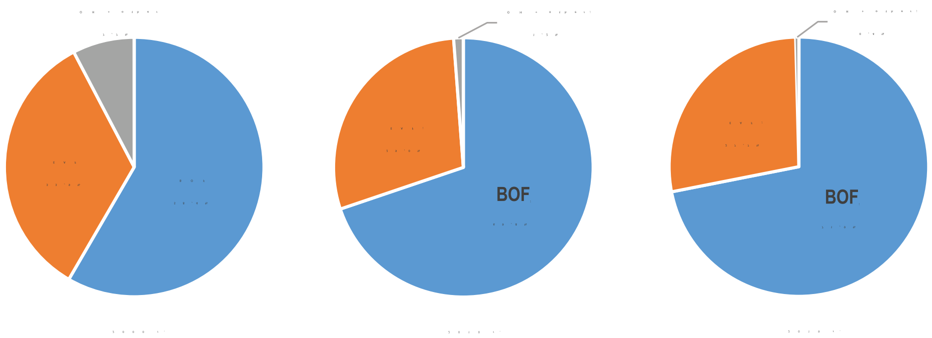

Fig. 1. Crude steel production by process. Source: worldsteel
Rys. 1. Produkcja stali surowej według procesów. Źródło: worldsteel

reducing gas and heat to melt the reduced iron (https://www.primetals.com).

In the last two years, global DRI production exceeded 100 million tonnes per year but is concentrated in the Middle East (mainly Iran) and Asia (main India). For comparison, world production of blast furnace pig iron in that period exceeded 1,250 million tonnes per year (worldsteel).

In the EU-28, more than half (59.1% in 2019) of crude steel is produced using the BF-BOF route. DRI production is present only in Sweden and Germany (in total 0.7 million tonnes in 2019).

In order to support the concept of the Green Deal adopted by the European Commission, the major steel makers in Europe have announced plans to achieve climate neutrality by 2050. To achieve their ambitious goals, they will follow three different paths enabling significant reductions in carbon dioxide emissions:

- development of production technologies that include direct reduction of iron ore (DRI) using green hydrogen,
- taking into account the electrolysis process involving RES,
- use of carbon capture and storage (CCS) technology,
- use of biomass products to replace coking coal.

A number of projects are currently underway to develop these processes and move towards commercialisation.

HYBRIT: In 2016, SSAB, LKAB and Vattenfall established a partnership for fossil fuel-free steel production using a modified DRI-EAF route. The aim of the project is to replace coking coal, traditionally needed for iron ore-based steelmaking, with hydrogen. Hydrogen will be produced in the pilot plant by electrolysis of water using electricity without fossil fuels. The construction of the pilot plant began at SSAB's Luleå steelworks in Sweden in 2018. The authors of the HYBRIT initiative announced that they would start activities to prepare for the demonstration phase three years ahead of schedule. The construction of the pilot plant was officially completed in August 2020. The tests will be carried out between 2020 and 2024, first with natural gas and then with hydrogen in order to be able to compare production results.

The plan is for the HYBRIT demonstration plant to be ready in 2025, at the same time as the conversion of SSAB's Oxelösund steel furnace in Sweden, allowing SSAB to produce fossil fuel-free iron ore-based steel starting from 2026 (Carbonomics; www.ssab. com). A decision has also been taken to build a pilot hydrogen storage facility 25-35 m underground on the LKAB site in Svartöberget, near the Luleå plant under construction. The pilot storage is planned for 2022–2024.

SALCOS (SAlzgitter Low CO_2 Steelmaking) is an initiative to produce steel with significantly reduced CO_2 emissions, undertaken by Salzgitter AG and Fraunhofer Institute. Salzgitter AG and Tenova officially declared their mutual cooperation on the project by signing the Memorandum of Understanding (MoU) on 2 April 2019. The aim is to go through a gradual transformation of the integrated steel production path, moving from blast furnace-based high-carbon steel production to direct reduction and arc furnace method, including flexible incremental hydrogen use. In the first stage of development that could be implemented by 2025, SALCOS would be able to reduce CO_2 emissions from steel production at the Salzgitter site by about a quarter, and in the final stage of implementation by 2050 by up to 95 percent. Tenova will provide ENERGIRON-ZR, an innovative HYL direct reduction technology with integrated CO_2 absorption system (www.tenova.com; https://steelguru.com).

In June 2020, Salzgitter AG reached an agreement with the Land of Lower Saxony and industrial partners Rhenus and Uniper to carry out a feasibility study for the construction of a DRI plant in Wilhelmshaven. If the results of the feasibility study prove positive, further steps towards the project are planned. The results are to be available by 31 March 2021 at the latest. The target is to produce two million tonnes of direct reduced iron per year; the iron will be transported by rail to Salzgitter and processed at the integrated steelworks of Salzgitter Flachstahl GmbH.

ΣIDERWIN (Development of new methodologis for Industrial CO_2-free steel production by electrowinning) is a European project under Horizon 2020 and the SPIRE initiative. The process, based on the ULCOWIN technology developed in 2004, enables the production of steel by electrolysis without direct CO_2 emissions. The aim of the project is to demonstrate the feasibility of electrolysis technology by designing a large pilot unit (3x1m) to be installed on the research campus of Maizières (Carbonomics; www.arcelormittal.com). The project participants are ArcelorMittal (Coordinator, France), JohnCockerill (Belgium), EDF (France), CFD-Numerics (France), QUANTIS (Switzerland), TECNALIA (Spain),

Tab. 1. EU Critical Raw Materials (2020). Source: Communication from the Commission ... COM(2020) 474 final 3.09.2020
Tab. 1. Surowce krytyczne UE (2020). Źródło: Komunikat Komisji ... COM (2020) 474 final 3.09.2020

List of 2020 Critical Raw Materials (CRMs)							
Antimony	Sb	Fluorspar	Fl	Magnesium	Mg	Silicon metal	Si
Baryte	Brt	Gallium	Ga	Natural graphite	Gr	Strontium	Sr
Bauxite	Bx	Germanium	Ge	Natural Rubber	Nr	Tantalum	Ta
Beryllium	Be	Hafnium	Hf	Niobium	Nb	Titanium	Ti
Bismuth	Bi	Heavy rare earth elements	HREEs	Platinum group metals	PGMs	Tungsten	W
Borate	Bo	Indium	In	Phosphorus	P	Vanadium	V
Cobalt	Co	Lithium	Li	Phosphate rock	Phs		
Coking coal	CC	Light rare earth elements	LREEs	Scandium	Sc		

Tab. 2. Comparison of 2017 and 2020 assessment results. Source: Study on the EU's list of Critical Raw Materials (2020) Final Report
Tab. 2. Porównanie wyników ocen z 2017 i 2020 roku. Źródło: Badanie dotyczące unijnej listy surowców krytycznych (2020) Raport końcowy

Criticality studies	2017		2020	
Coking coal	SR	EI	SR	EI
	1.0	2.3	1.2	3.0

Tab. 3. Coking coal applications, 2-digit and examples of associated 4–digit NACE sectors. Source: Study on the EU's list of Critical Raw Materials (2020) Final Report; NACE Rev. 2
Tab. 3. Zastosowania węgla koksowego, 2-cyfrowe i przykłady powiązanych 4-cyfrowych sektorów NACE. Źródło: Badanie dotyczące unijnej listy surowców krytycznych (2020) Raport końcowy; NACE Rev. 2

Applications	Share	2-digit NACE sector	4-digit NACE sector
Coke for steel production	82%	C24 –Manufacture of basic metals	C24.10 – Manufacture of basic iron and steel and of ferro-alloys
Coke for other applications	9%	C23 –Manufacture of other non-metallic mineral products	C23.99 - Manufacture of other non-metallic mineral products n.e.c.
Other uses (chemical products from tar and benzole; gas for heat and power generation)	9%	C20 – Manufacture of chemicals and chemical products	C20.14 - Manufacture of other organic basic chemicals – distillation of coal tar C20.15 – Manufacture of fertilisers and nitrogen compounds - ammonia

UAVR (Portugal), Mytilineos (Greece), NTUA (Greece), N-Side (Belgium), Dynergie (France), NTNU (Norway).

Initiatives and technologies being implemented or planned by ArcelorMittal in Europe include (https://corporate.arcelormittal.com):

- direct reduction of iron ore with the use of hydrogen (an investment project worth EUR 65 million is carried out in Hamburg, Germany);
- Carbalyst – a method involving the conversion of metallurgical gases from a blast furnace into bio-ethanol (a EUR-120-million project implemented at ArcelorMittal in Ghent);
- IGAR – a technology to capture CO_2 from blast furnace processes and convert it into synthetic gas that can replace fossil fuels to reduce iron ore in the blast furnace process (a pilot project is currently being carried out at ArcelorMittal in Dunkirk, France);
- Torero – assumes the production of bio-carbon from wood waste replacing fossil fuels currently used in the blast furnace (a EUR-40-million project, Ghent).

The European steel industry has to tackle the challenges of reducing carbon emissions and the evidence suggests that hydrogen will play a major role in the decarbonisation of the sector, provided that cheap renewable energy is available on a large scale. However, in the near future, most of the steel produced in the EU will continue to be produced using the BF-BOF route, which requires a stable supply of coking coal.

The European Commission has recognised the fundamental role of coking coal in the EU economy placing it on the 2020 list of critical raw materials. The list identifies the materials that need to be protected in the EU given their high economic importance and high supply risk.

3. Coking coal on the EU list of critical raw materials

Critical raw materials (CRMs) are those raw materials which are economically and strategically important for the European economy, but their supply is associated with high risk due to very large dependence on imports and high concentration of critical raw materials in individual countries. These materials, used in environmental technologies, consumer electronics, health care, steel production, defence and aviation, are not only 'critical' for key industrial sectors and future applications, but also for the sustainable functioning of the European economy.

The first comprehensive report and preliminary list of critical raw materials was published in the European Union in June 2010 by the EU Commission - Enterprise and Industry: "Critical raw materials for the EU - Report of the Ad-hoc Working Group on defining critical raw materials". As a result

Tab. 4. Criticality assessment results for coking coal. Source: Communication from the Commission …, COM(2020)474 final, 3.09.2020
Tab. 4. Wyniki oceny krytyczności węgla koksowego. Źródło: Komunikat Komisji…, COM (2020) 474 final z 3.09.2020

Stage	Main global producers	Main EU sourcing countries [1]	Import reliance rate IR[2]	Substitution indices[3] SI(EI)/SI(SR)	End-of-life recycling input rate[4]	Selected Uses
Extraction	China (55%) Australia (16%) Russia (7%)	Australia (24%) Poland (23%) United States (21%) Czech Republic (8%) Germany (8%)	62%	0.99/0.99	0%	Coke for steel Carbon fibres Battery electrodes

1) Based on Domestic production and Import (Export excluded)
2) IR (Import Reliance) – the import reliance rate takes into account global supply and actual EU sourcing in the calculations of supply risk, and it is calculated as follows:

$$IR = \frac{EU\ net\ imports}{EU\ domestic\ production + EU\ net\ imports}$$

3) SI (Substitution Index) – the substitution index is a measure of the difficulty in substituting the raw material, scored and weighted across all applications, calculated separately for both economic importance and supply risk parameters. Values are between 0 and 1, with 1 being the least substitutable
4) The End of Life Recycling Input Rate (EoL-RIR) is the percentage of overall demand that can be satisfied through secondary raw materials

of the research carried out at that time, fourteen raw materials of significant economic importance, characterised primarily by a high risk of shortage or lack of supply, were identified as the most critical for the EU's economy (Communication COM(2011) 25 final). The list of critical raw materials for the EU is subject to a regular update, at least every three years, in order to take account of changes in production, market and technological developments.

In the second list, fifty-four raw materials were analysed using the same methodology as in the previous study. The 2014 list of critical raw materials (Communication COM(2014) 297 final) included twenty items, i.e. thirteen raw materials from the previous list and six new raw materials, including coking coal; rare earth elements (REE) were split into 'heavy' and 'light' categories and placed as separate items (Blaschke W., Ozga-Blaschke U., 2015).

The third list of critical raw materials was established using a refined methodology developed by the Commission following the recommendations of the 2014 report, while ensuring comparability with previous methodological approaches (Methodology for Establishing the EU list of Critical Raw Materials).

The two basic parameters used to determine the criticality of a raw material still remained:

- Economic Importance (EI) - calculated based on the importance of a given material in terms of end-use applications, based on EU industrial applications and on the performance of its substitutes in those applications;
- Supply Risk (SR) - calculated based on factors that measure the risk of a disruption in the supply of a given material (e.g. supply mix and reliance on imports, governance performance measured by the World Governance Indicators, trade restrictions and agreements, availability and criticality of substitutes).

The changes to the methodology consisted, among other things, in: (i) including substitution as a factor correcting both economic importance and supply risk; (ii) allocating the raw materials in a more precise manner to the relevant end-use applications and corresponding production sectors instead of mega-production sectors; (iii) introducing an initial bottleneck review to determine which stage (extraction or processing) represents the highest risk of supply of raw materials for the EU, taking into account the availability and quality of data. The calculations were based on an average of the data from the most recent five-year period, while previous criticality assessments used only the last available year.

In the two previous assessments, the criticality thresholds were set at: SR ≥ 1 and EI ≥ 5. In the third assessment, several elements introduced in the updated methodology affected the calculations, which was reflected in particular in the values of the EI parameter. The application of the revised formula to the EI calculation resulted in an overall decrease in the value of this parameter for most of the materials assessed; therefore, on the basis of the average shift of results for the materials covered by all three assessments, the threshold for economic significance was set at EI ≥ 2.8 while the threshold for SR ≥ 1 remained unchanged (Study on the review of the list of Critical Raw Materials). The list of CRMs includes those materials that meet or exceed the thresholds for both parameters.

The 2017 review carried out a criticality assessment for seventy-eight raw materials, i.e. fifty-eight individual raw materials and three groups containing twenty REEs and the platinum group metals (PGM). The updated 2017 list of CRMs for the EU published in Communication COM(217) 490 final of 13 September 2017 contained twenty-seven raw materials including coking coal - considered however a borderline case (Ozga-Blaschke 2019). Although the economic importance threshold EI=2.3 for coking coal did not meet the criticality requirement, for reasons of caution, it was kept on the EU's list of critical raw materials with the proviso that it will be phased out from the next list should it fail to meet the criteria in full.

The assessment of the critical raw materials to be listed in 2020 was built on the same methodology as in 2017, but unlike previous assessments, a closer attention was given to where criticality appeared in the value chain – in extraction or in processing. The calculations were based on the average for the most recent complete five-year period for the EU-27 without the United Kingdom. The assessment screened eighty-three raw materials (sixty-three individual and three groups containing twenty REEs and PGMs). The Commission Communication COM(2020)474 final of 3 September 2020 listed thirty critical raw materials of which twenty-six were transferred from the 2017 list and four (bauxite, lithium, titanium and

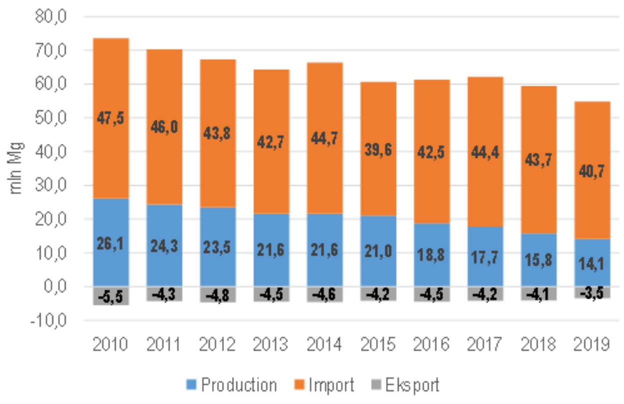

Fig. 2. Coking coal balance in the EU(28). Source: Eurostat
Rys. 2. Bilans węgla koksowego w UE (28). Źródło: Eurostat

strontium) appeared on the list for the first time (Table 1).

In the case of coking coal, in the 2020 technical assessment, the values of SR and EI parameters exceeded the criticality thresholds and the coal was kept on the CRM list (Table 2)

The increase in the value of the EI parameter from 2.3 to 3.0 was due to the allocation of an additional manufacturing sector to NACE Rev.2 two digit level: C20 - Manufacture of chemicals and chemical products" with high added value, and to a reduction in the share of the sector "C24 - Manufacture of basic metals" with lower added value (Table 3).

This time, the importance of coke making by-products was taken into account when assessing coking coal as a critical raw material. Tar and benzole are used to produce chemicals, while coking gas is used to produce heat and energy. Moreover, coking gas contains about 55 percent of hydrogen, so intensive research is being carried out to implement a technology to separate this valuable element from the gas.

Carbon fibres made from coal tar are used in the aerospace and automotive industries, as well as in hydrogen storage tanks. Tar is also a key material for electrode production. The rapid development of the electric and hybrid vehicle industry has led to an increase in demand for needle coke, a direct product of coal tar used to produce anodes (Study on the EU's list…. Factsheets (Final).

The increase in the SR parameter compared to the 2017 assessment had two reasons. Firstly, when calculating the substitution rate, an assumption was made that the use of pulverised coal for injection (PCI) did not contribute to the substitutability of coking coal since the technique is widely applied in the EU steel industry and has already reached its technical limits (in a previous assessment, the PCI coefficient introduced for calculating the substitution rate was 30 percent). Secondly, an error in the calculation formulas of the EU supply risk component resulted in lower supply risk in the previous assessment by a value of 0.1 (i.e. SR was 1.0 instead of 1.1. (Study on the EU's list…. Critical Raw Materials Factsheets (Final))

The results of the criticality assessment for coking coal in terms of supply risk (e.g. import reliance of EU countries, geographical structure of production) are presented in Table 4.

The most important supply-risk factors include the political and economic stability of producing countries, the level of concentration of production, substitutability and recycling level.

The European Union has long been a net importer of coking coal because demand far exceeds the production capacity of the Member States. The largest coal producer among the EU countries is Poland with a mining output of 12-13 million tonnes per year. Production is still ongoing in the Czech Republic (around 2 million tonnes in 2019), but its only hard coal producer OKD is expected to stop mining by 2023. In Germany, the last two hard coal mines were closed in 2018. As a result, the EU share in world coking coal production in 2019 fell to 1.4 percent.

(Net) imports of coking coal from third countries into the EU-28 have been at 38–40 million tonnes in recent years, falling to 37 million tonnes in 2019 (Eurostat). Imports of coking coal into the EU come mainly from Australia and the United States, but also from Canada, Russia and Mozambique (ICR Platts).

The balance of coking coal in the EU-28 between 2010 and 2019 is shown in the graph in Figure 2.

Both the production and consumption of coking coal in Europe is in decline. The fall in consumption is associated with a fall in the production of pig iron and with improvements in blast furnace technology, which results in a lower rate of unit coke consumption per tonne of pig iron produced.

4. Conclusion

By definition, coking coal in low-carbon technologies is not applicable, but it is an essential component in steelmaking, and the importance of steel in all key sectors of the economy is not in doubt. Steel is essential for low-carbon technologies and for the generation of renewable energy (wind turbines, solar energy). Moreover, some products derived from by-products of the coking process are also used in innovative technologies; these are carbon fibre or needle coke made from coal tar, to name a few.

In the EU, almost 60 percent of crude steel is produced using the BF-BOF route where coke made from coking coal is the basic raw material for blast-furnace pig iron production.

However, the European steel industry has to tackle the challenges of reducing carbon emissions and the evidence suggests that hydrogen will play a major role in the decarbonisation of the sector. Most of the pilot projects to eliminate coal from steel production are being carried out in North-Western Europe, involving SSAB and LKAB, Salzgitter, Arcelor-

Mittal and Voestalpine. However, in the near future, most of the steel produced in the EU will continue to be produced using the BF-BOF route, and this requires a stable supply of coking coal. The lack of sufficient own supply sources means that the European Union is almost entirely dependent on imports. Following the closure of hard coal mines in Germany and the planned closure of coal mines in the Czech Republic after 2023, Poland will remain the only producer of coking coal in the EU.

The European Commission has recognised the key role of coking coal for the EU economy, placing it for the third time on the 2020 list of critical raw materials.

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Węgiel koksowy w Europejskiej Strategii Zielonego Ładu

Osiągnięcie neutralności klimatycznej w gospodarce UE do 2050 r. jest ogromnym wyzwaniem, któremu poddano wszystkie plany i strategie Unii Europejskiej. Osiągnięcie unijnych celów klimatycznych i środowiskowych wymaga między innymi głębokiej transformacji sektora elektroenergetycznego, a także dekarbonizacji i modernizacji energochłonnych gałęzi przemysłu, takich jak np. hutnictwo. Europejski przemysł stalowy musi stawić czoła wyzwaniom związanym z redukcją emisji dwutlenku węgla; analizy sugerują, że wodór będzie odgrywał główną rolę w dekarbonizacji sektora, pod warunkiem, że na dużą skalę dostępna będzie tania energia odnawialna. Jednak w najbliższej przyszłości większość stali produkowanej w UE będzie nadal produkowana na drodze BF-BOF, co wymaga stabilnych dostaw węgla koksowego. W artykule opisano strukturę światowej produkcji stali według technologii produkcji oraz wskazano projekty realizowane przez firmy europejskie, zmierzające do przejścia na bezemisyjną produkcję stali. Komisja Europejska doceniła kluczową rolę węgla koksowego w gospodarce UE umieszczając go na liście surowców krytycznych 2020 roku. Lista identyfikuje te surowce, które należy chronić w UE ze względu na ich duże znaczenie gospodarcze i wysokie ryzyko dostaw. W artykule przedstawiono wyniki oceny krytyczności węgla koksowego zawartego w IV przeglądzie technicznym, który zakwalifikował go po raz trzeci jako materiał do umieszczenia na liście surowców krytycznych.

Słowa kluczowe: *UE, surowce krytyczne, węgiel koksowy, stal, dekarbonizacja*

Cash Management in Energy Companies

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Abstract

The paper presents issues surrounding the management of free cash assets in listed energy companies. The reasons for keeping free cash presented in relevant literature, i.e. transactional, prudential and speculative, do not exhaust the list of reasons behind companies' decisions. The environment in which they operate encourages companies to use free cash to carry out current purchase transactions and to take advantage of price discounts for purchases settled with cash or for accelerated payment for deliveries in relation to contractual payment terms. Companies can pursue different cash management strategies as part of their financial strategy. Conservative, moderate and aggressive strategies depend on their trade policy. The development of the financial market creates ample opportunities to engage free cash in various financial instruments. The company's choice of instruments is mostly determined by the risk of loss of part of the invested funds, without ignoring the income from these instruments and their management. Research carried out in energy companies indicates that Polish energy companies have a large cash surplus in relation to their current assets and revenues. This surplus is higher than in global listed energy companies.

Keywords: *free cash, reasons for keeping free cash, cash management strategies, types of free cash investment*

Introduction

Cash is one of the most important assets of any company. The company must manage it effectively, regardless of the way in which it is raised. Cash management policies should suit the company's operational strategy in such a way as to ensure the implementation of their underlying assumptions. The optimization of the company's resource management processes is an internal source of shaping its value and its competitive advantage. Rational cash management should be an integral part of the financial system of any company. Companies should keep such levels of free cash on their current accounts that allow benefits to outweigh costs.

As a component of current assets, cash originates in specific sources of financing in the form of equity and external capital. The rate of income from their management is very low in relation to the cost of capital needed to finance this very asset. Therefore, a surplus of funds results in opportunity costs and reduces company profitability. On the other hand, a shortage of funds may lead to a loss of liquidity and result in penalty interest on overdue liabilities. This means that economic entities should maintain a rational level of cash and cash equivalents.

This paper aims to analyse the cash equilibrium in selected energy companies and compare cash resources maintained by Polish energy companies with those of their global counterparts. The purpose of this analysis is to verify the hypothesis in which it is assumed that Polish energy companies maintain cash levels comparable to those of global companies. The main sources of cash are net income and depreciation.

Reasons for Keeping Free Cash

The vast majority of relevant publications distinguishes three basic reasons for keeping free cash in the account: transactional, prudential and speculative. The primary reason though is the necessity to finance current needs and maintain the ability to pay liabilities on time. The level of cash kept for transactional reasons depends on many factors, including the specific nature of the activity pursued and its size, the situation on a given market and the general economic situation. The second reasons for maintaining cash resources – prudential – is related to the need to have funds on hand to cover unplanned expenses arising from unforeseen situations. When they take into account the prudential aspect, companies determine the amount of cash resources on hand based on estimated cash flows. In conditions of excessive fluctuations in the inflow of funds, the company is forced to accumulate a larger amount of free cash, and when the opposite happens, the necessary cash resource will not be high (Goławska-Witkowska, Rzeczycka A., Zalewski H., 2006, p.143). Another reason for keeping free cash resources in the company is speculation. Having free cash at its disposal, the company will be able to take advantage of the opportunities offered by the market to buy property, plant and equipment, purchase stocks and shares, and acquire other companies at an exceptionally favourable price.

Relevant literature mentions yet another reason for keeping free funds. The reason is banks' fees and commissions for the services they provide. Banks may require customers to maintain a certain minimum balance i.e. an amount of funds on deposit. It is of benefit to them, as banks operate on the interbank market with funds deposited by their customers. Companies having the required level of funds on deposit enjoy easier access to a bank credit line, other banking products and are able to have more favourable agreements with banks ((Brigham E.F., Houston J.F., 2005, pp. 109–110).

The cash on the account makes it easier to negotiate more favourable terms with suppliers of raw materials and materials. It gives companies the opportunity to take advantage of rebates and price discounts available in many industries, not only in the industrial sector. Suppliers, especially in hard economic conditions, offer favourable discounts and price reductions for the payment of invoices before their due date in order to maintain liquidity. Companies that do not exploit the opportunity for a discount often lose much more than they could otherwise gain through alternative investments.

It should also be noted that in some industries, the need to maintain free cash is due to the occurrence of economic crises, off-season periods and other cyclical and non-cyclical phenomena that can be predicted only with some accuracy. The size of the company has a large impact on the level of cash resources maintained. A survey of corporate cash resources indicates that cash and company size vary inversely. This is because large companies have less need to hold cash due to better access to the short-term loan market. Thus, companies with easier access to capital markets, large entities and highly creditworthy entities maintain lower levels of cash compared to their total non-monetary assets than small and medium-sized companies (Opler et al., 1999, pp. 3–46).

Corporate strategies of cash management

Cash management comes down to minimizing the amount of current cash deposits in the company. On the other hand, it aims to maximize income from investing any free funds. Minimizing the funds held requires ensuring the synchronization of inflows and expenses i.e. acceleration of the collection of receivables and delay in the payment of liabilities to suppliers. The increase in profit on total cash resources can be achieved either by investing in more profitable securities or by reducing the share of non-interest bearing cash, or indeed by combining these two options (Fuksa, 2017, p. 242, (Michalski 2013, p. 136).

The overall cash management strategy determines the amount of cash and its structure. Pertinent literature most often indicates three strategies: conservative, moderate and aggressive. The first of these assumes keeping of relatively high cash balances on the account, coupled with a high level of receivables from recipients. By extending the payment terms of invoices for recipients, the company can increase sales and obtain a relative reduction in manufacturing overhead. The funds kept on the account will facilitate maintenance of liquidity. However, the company has to obtain external capital to finance increased current assets, which, in turn, will increase its financing costs.

By implementing a moderate cash management strategy, the company will pursue a rational trade credit policy, it will not generate excessive receivables and, at the same time, the funds held will be exploited instead of being kept in the bank account by purchasing low risk liquid securities. The inflow of the necessary funds can be ensured by the sale of these securities. The aggressive strategy, on the other hand, comes down to maintaining the lowest amounts of cash in the account and a rigid policy towards recipients. Such a policy towards recipients may, however, lead to a decrease in sales and increase the risk of business activity, especially in an economic slowdown. Yet, the systematic collection of receivables will help maintain liquidity. The company will not bear opportunity costs arising from the maintenance of high cash balances in the current account.

In practice, it is not always possible to clearly specify the cash management strategy – rather than that, it is only possible to sketch its framework for the purpose of calculating the effects of the actions taken by company managers. Cash strategies can only be of a short-term character and be flexibly adapted to the changing environment. The company must develop a strategy to optimise its free cash in order to properly balance the direct and indirect costs of collecting cash as well as the costs of having too little of these funds (Michalski, 2007, pp. 365–375).

Techniques of Managing Free Cash

The dynamic development of the financial market provides access to a wide variety of financial instruments that allow effective management of free cash. Firms can allocate temporary cash surpluses to gain income benefits and, at the same time, to be able to quickly pull out of investments when cash is needed to finance current activity.

The most popular method of investing surplus cash used by companies involve term deposits in banks. Their diversity is increasing and ranges from overnight, tomorrow/next, tom/ next, to monthly, quarterly and even longer deposits. The interest on the deposit is not equal to the actual profits, because it is eroded by the capital gains tax and inflation. In addition, some banks charge fees on deposits, which reduces the actual interest rate. For example, in December 2019, Pekao, mBank and ING Bank Śląski banks charged fees of 0.15–0.30 percentage points on deposits above PLN 20 million. (Rudke, 2020, p. A20). These fees reflect the necessity for commercial banks to maintain required reserves at the central bank. In March 2020, the Monetary Policy Council lowered the required reserve rate from 3.5% to 0.5% and increased the interest rate on funds held in the form of a reserve from 0.5% to 1%, i.e. to the NBP reference rate mark (the MPC lowered the rate ... 2020).

The main feature of bank deposits is their very low risk. Deposits of up to 100,000 euros are guaranteed under the Bank Guarantee Fund. The company may request that it is repaid the amount above that as part of bank's bankruptcy proceedings. It can therefore be concluded that deposits are a safe form of free cash management (Lipiński M., 2008, pp. 199–200). Another feature of this type of investment is its flexibility, which depends on the term of the cash investment. An equally important feature of bank deposits is the level of the interest rate and the method and frequency of interest payments. Relevant literature most often mentions two main types of deposits: the classic fixed or floating rate deposits and the more advanced structured deposits. Recently, more and more attention has been paid to structured deposits as they promise the possibility of a higher return relative to that of classic deposits. A structured deposit is a hybrid instrument that merges a debt instrument with an option (simple or multi-factor). The income from the investment in this instrument consists of two components: interest, where the interest rate is lower compared to that of the classic deposit, and income depending on the value of one (in the case of a regular option) or several (in the case of a multi--factor option) indexes of the financial market or the commodity market (Jajuga K, Jajuga T., 2015, pp. 393–394).

Another safe form of investing free cash involves treasury bills, i.e. bearer debt securities issued by the State Treasury in order to finance its current budget deficit, negative external trade balance or to cover long-term liabilities. The zero risk of a breach of contract terms and price risk make them an attractive investment instrument. That reason underlies bills' very low profitability. The interest rate on treasury bills is of a discount nature. The yield on these securities is the difference between the purchase price and the face value of the bill. They are issued for periods of 1 to 90 days or up to 52 weeks. They exist in a dematerialized form, i.e. only as an electronic record on the account, and are traded on the primary or secondary market (Lipiński, 2008, pp. 199–200).

Treasury bonds and corporate bonds may be an attractive alternative for cash investments. Bonds are the main debt instrument on the capital market. In terms of the interest rate, there are fixed or floating rate bonds and zero-coupon bonds. For a financial director who decides how to manage cash, the primary criterion, however, will be the risk of losing money. Treasury bonds are risk-free, while corporate bonds may pose the risk of loss for some of the funds, hence investment funds that invest the money entrusted to them in all financial instruments available on the market will be a safer form of investment. Investments funds tend to be highly diversified. Each of them follows a different investment strategy and uses different forms and places of capital allocation. The undoubted advantages of an investment fund are economies of scale and the effect of professionalism, which are absent from individual investments. In addition to typical investment funds, there are also investment funds whose operation is often not formally regulated. They include, among others, hedge funds, venture capital and private equity companies. Hedge funds employ a-typical strategies, usually characterized by high risk and high income potential, and are not subject to the regulations typically governing investment funds. Very rarely do financial directors invest money in high-risk funds.

"Venture capital funds are companies that invest in small business, innovative projects that are at an early stage of development, with potentially high income, coupled however with a high degree of risk. Private equity funds are companies that invest in relatively new companies that are not traded on the stock exchange. As with venture capital funds, there is a potential for high income, but risk is also high. Venture capital/private equity (VC/PE) companies combine the features of both of the above types of funds "(Jajuga K, Jajuga T., 2015, pp. 70–71).

Another market that offers investment opportunities is the currency market. Its popularity has been on the rise for a number of years. The development of electronic communication, the ever-present computerisation and availability of the Internet have created favourable conditions for all companies to enter the currency market, regardless of their size. Investing in currencies, like any other strategy, has its advantages and disadvantages. Potential gains or losses can be huge. The foreign exchange market is highly liquid, which, in many cases, reduces the effectiveness of attempts to influence exchange rates, even those undertaken by the central banks of the world's largest economies. On the other hand, investments in the currency market are encumbered with the risk of losses in the event of a sudden drop in the value of the currency, the risk of inflation absorbing the entire profit earned on investments in a given currency or falling into the debt trap, which may result from an increase in the value of a loan in the currency (Wojtasińska, 2017 , pp. 123–138, Miciuła, 2014, pp. 153–163).

A joint-stock company with surplus cash may buy back some of its own shares. As the researchers investigating this practice write, the main reason for buy-back operations on the stock markets is the possibility of using this instrument as an alternative way of investing free cash (Lazonik, 2015, pp. 1–22). Although the basic problem of most economic entities is the lack of cash, many companies also have problems with excess cash. In recent years, characterized by an increasing pool of unused cash, treasury share buyouts have become an attractive technique of liquidating free cash.

Companies can also buy shares of listed companies, especially when they are planning to take over a controlling block of shares in a given company. Such transactions are, however, more like financial investments than a way of investing surplus cash. Shareholders purchasing the company's shares expect a rate of return that exceeds the interest rate on safe securities, such as Treasury bonds or bank deposits. This is so because the functioning of any entity operating on the market is inherently associated with operational and financial risk. Shareholders, aware of the high probability of unforeseen events, expect a high rate of return on shares as a reward for the risk of losing some or all of their funds. When placing them, they are guided by the rate of return on capital and the level of risk (Sierpińska-Sawicz, 2014, pp. 232–243).

The right choice of investment instruments in which to invest financial surpluses increases the company's profitability, however, it is necessary to compare the potential costs with the expected returns that may arise as a result of the investment activities. In capital groups, surplus cash is managed within the framework of cash pooling. The service consists in concentrating funds on a joint bank account of entities belonging to a given busines structure (capital group, concern, holding) in order to flexibly manage them. Some business entities have a cash surplus on their account, while others experience a shortage of short-term funds. The surplus cash can therefore be used to cover the shortfall. This helps reduce interest expense, as these surpluses are made available at the price of a bank deposit. By consolidating the bank account balances of companies participating in cash pooling, these companies can optimize the use of cash resources and manage the group's liquidity more effectively (Sierpińska, Sierpińska-Sawicz, Węgrzyn, 2019, p. 162). However, cash pooling is not an option for all entities. What is required is that the entire corporation has a stable financial standing and individual entities achieve significant turnover, while showing differences in current account balances (Grzywacz, 2017, pp. 159–175).

Research Methodology

In order to achieve the aim of the paper, use was made of critical analysis of the literature on the above subject and of methods of descriptive statistics. The data for the calculations were taken from the financial statements obtained from the Reuters Eicon database for the last five years. These reports are prepared as of 31 December. The balance sheets of SSE PLC and Tokyo Electric PC companies are prepared as of March 31, hence the data for each year cover the period from 1 April of a given year to 31 March of the following year. The analysis of empirical data was based on selected financial ratios. Based on data taken from the balance sheet, profit and loss account and cash flow statement, the following ratios were calculated: ratio of cash and short-term debt securities to current assets, ratio of cash and its equivalents to total cash resources, ratio of cash and short-term investments to sales revenues and the ratio of the sum of net income and depreciation to cash from operating activities.

Comparative Analysis of Cash Levels in Energy Companies

A comparative analysis of cash levels in energy companies listed on the stock exchanges of various countries was carried

Tab. 1. The ratio of cash and short-term debt securities to current assets in selected energy companies in 2015–2019. Source: author's own calculations based on data from the balance sheets of analysed companies as extracted from the Reuters Eikon database

Tab. 1. Udział gotówki i krótkoterminowych papierów dłużnych w aktywach obrotowych w wybranych spółkach energetycznych w latach 2015–2019. Źródło: obliczenia własne na podstawie danych zawartych w bilansach analizowanych spółek, które zostały pozyskane z bazy Reuters

Company	2015	2016	2017	2018	2019
Enea	42.73	46.45	43.92	39.89	41.68
Energa	44.27	35.29	60.79	50.68	35.46
PGE	26.54	40.72	26.82	14.03	10.44
Tauron Polska Energia	10.11	11.14	23.85	28.15	26.76
Iberdrola	17.24	20.64	27.52	25.28	20.69
Nextera Energy Inc.	8.40	17.44	23.87	9.98	8.10
SSE PLC	5.90	16.36	5.96	7.91	4.75
Tokyo Electric Power Company Holding Inc.	60.88	47.45	53.43	47.66	45.54
Valero Energy Corp.	27.61	28.67	30.29	16.87	13.62
Xcel Energy Inc.	2.92	2.96	2.79	4.75	7.97

Tab. 2. Ratio of Cash and Equivalents to Cash and Short Terms Investments in selected energy companies in 2015–2019. Source: author's own calculations based on the balance sheets of analysed companies

Tab. 2. Udział gotówki i jej ekwiwalentów w sumie gotówki i krótkoterminowych papierów dłużnych w wybranych spółkach energetycznych w latach 2015 –2019. Źródło: obliczenia własne na podstawie bilansów analizowanych spółek

Company	2015	2016	2017	2018	2019
Enea	89.09	99.74	98.17	95.91	99.71
Energa	82.26	98.86	97.77	99.20	87.8
PGE	41.96	16.21	51.19	85.18	90.71
Tauron Polska Energia	91.23	80.21	19.48	65.03	67.39
Iberdrola	62.63	64.72	84.17	83.04	75.30

out for 2015–2019. This period was characterised by a relatively stable economic situation. It is one of the important factors influencing the level of cash resources kept in the company. In times of crises, businesses hold off investments and maintain larger cash resources than in the boom times. Table 1 presents the share of cash and short-term securities in current assets, defined in Polish balance sheets as short-term investments. They include cash and cash equivalents (bills of exchange, checks) as well as short-term debt securities and other forms of cash management from which cash can be pulled out within up to a financial year. These can, for example, be marketable fixed assets.

Compared to other companies surveyed, the Polish energy companies Enea and Energa as well as the Tokyo energy company held an exceptionally high share of cash in current assets. In Tokyo, in 2019 this ratio exceeded 45%, in Enea – almost 42%, and in Energa – over 35%. Three companies reported this ratio in 2019 to be below 10%, and the remaining companies – in the range of 10–27%. Only in two entities, Tauron and Xcel, did the ratio of cash to current assets increase, and in the remaining companies surveyed, it decreased. Across the industrial sector, the ratio of short-term investments to current assets stood at several percent on average.

In order to obtain information in what forms energy companies kept their free cash, the ratio of cash and cash equivalents to the total cash resources was calculated. It is presented in Table 2, which shows only 5 companies, as the remaining companies did not tie up free cash in short-term investments.

Only the Polish companies and the Spanish Iberdrola did invest free cash in short-term debt securities. In 2019, Tauron invested over 30% of its free funds in short-term debt securities, and Energa over 12%. Iberdrola tied up 25% of its funds in debt securities. Table 3 presents the ratio of cash and short-term investments to sales revenues.

The highest ratio was confirmed in the Polish company Enea. In 2019, almost 24% of its sales revenue was deposited in bank accounts, compared to 14% in Energa and 9% in Tauron. In Tokyo Electric, the same reached almost 14% and in the Spanish company Iberdrola – 7.5%. In the remaining companies, the ratio of cash to revenues ranged between 2.2–3.5%. On average the ratio stood at 1.5% across the entire industrial sector. This indicates that Polish energy companies kept a large cash surplus in their accounts in the analysed period. In 2017, Energa held over 35% of its revenues from the sale of energy on its account. In the long run, such a high level of free cash is not beneficial for the company. This is due to the fact that it generates financing costs in the form of interest, cash coverage is sourced out from external capital, and if this source is equity, opportunity costs arise. These costs cause an increase in the average cost of capital, which reduces the number of profitable development projects. The excess cash held in the company therefore curtails its development. In companies listed on stock exchanges, shareholders are demanding that excess cash is paid out in the form of dividends. Companies also pass on this cash to shareholders by purchasing their own shares.

Table 4 shows the ratio of the sum of net income and depreciation to Cash from operating activities. It illustrates the sources of these flows. These mainly consists of net income and depreciation. The sum of these two values is described in pertinent literature as a financial surplus.

The share of the financial surplus in excess of 100 means that the surplus was engaged in operating activities. Funds sourced from net income and depreciation were allocated to boost inventories and receivables or to liquidate short-term liabilities. If, on the other hand, the ratio is below 100, it means that some cash was released from operating activities due to a decrease in inventories and receivables or an increase in short-term liabilities. These liabilities do not include interest expenses, i.e. short-term loans and advances, short-term debt securities, factoring or forfaiting, as these are included in the category of the company's financing activity, just like other external sources of financing of corporate operations.

Analysis of the performance of Polish companies presented in Table 4 leads to the conclusion that their financial surpluses were the main source of operating cash flow generation. In 2015 and 2019, PGE generated losses. In 2015, the net loss totalled

Tab. 3. Ratio of cash and short-term investments to revenue in energy companies in 2015–2019, %. Source: author's own calculations based on data from the balance sheets of analysed companies as extracted from the Reuters database

Tab.3. Relacja sumy gotówki i krótkoterminowych papierów dłużnych w przychodach ze sprzedaży w spółkach energetycznych w latach 2015–2019, %. Źródło: obliczenia własne na podstawie sprawozdań finansowych pozyskanych z bazy Reuters

Company	2015	2016	2017	2018	2019
Enea	20.76	20.84	24.00	21.81	23.88
Energa	18.78	14.61	35.35	26.56	13.67
PGE	10.89	17.74	11.07	4.94	3.49
Tauron Polska Energia	2.18	2.72	6.48	6.99	8.96
Iberdrola	5.86	7.70	12.14	9.62	7.46
Nextera Energy Inc.	3.44	8.24	10.25	3.90	3.25
SSE PLC	1.25	4.92	0.85	5.92	2.43
Tokyo Electric Power Company Holding Inc.	24.58	18.47	21.77	16.59	13.84
Valero Energy Corp.	4.68	6.36	6.22	2.55	2.38
Xcel Energy Inc.	0.77	0.76	0.73	1.28	2.17

Tab. 4. Ratio of the sum of Net Income and Depreciation to Cash from Operating Activities in selected energy companies in 2015–2019. Source: author's own calculations based on data from the balance sheets of analysed companies as extracted from the Reuters Eikon database

Tab.4. Udział sumy zysku netto i amortyzacji w operacyjnych przepływach pieniężnych w wybranych spółkach energetycznych w latach 2015–2019. Źródło: obliczenia własne na podstawie danych zawartych w bilansach analizowanych spółek, które zostały pozyskane z bazy Reuters

Company	2015	2016	2017	2018	2019
Enea	17.73	80.81	91.46	90.22	97.41
Energa	122.69	65.21	90.51	103.28	25.54
PGE	118.95	111.69	92.26	119.27	96.96
Tauron Polska Energia	-105.03	71.06	96.97	105.44	97.09
Iberdrola	108.46	107.76	123.03	111.09	134.79
Nextera Energy Inc.	97.53	100.77	123.27	150.51	96.46
SSE PLC	112.02	144.25	127.02	218.38	146.95
Tokyo Electric Power Company Holding Inc.	76.03	103.54	94.49	158.91	159.97
Valero Energy Corp.	105.92	89.44	112.04	124.04	91.10
Xcel Energy Inc.	73.83	83.84	88.19	97.44	100.40

PLN 3,756 million, depreciation and amortisation totalled PLN 11,817 million and the sum of net income and depreciation was almost 19% higher than the generated operating cash flow. In 2019, the net loss totalled PLN 4,703 million and depreciation and amortisation stood at PLN 11,316 million. One of the reasons for the net loss was the high above-average level of depreciation included in the costs. It resulted, among others, from the implementation of IAS 16 and amendments to legal provisions regarding recognition of land in the balance sheet as lease. Tauron also incurred losses in 2015 – these amounted to PLN 2,188 million, more than the level of accrued depreciation totalling PLN 1,833 million. The negative difference in the amount of operating cash flows was 5% higher than these flows. In 2019, the loss reported by Tauron was not large and amounted to only PLN 15.4 million, while depreciation totalled PLN 1,992 million and accounted for 97% of operating cash flows. In 2019, also Energa incurred losses totalling PLN 759 million. Depreciation amounted to PLN 1,079 million. After losses are covered, the remainder of the depreciation accounted for 25% of operating cash flows, which means that these cash flows were generated by a decrease in inventories, receivables and an increase in one-off short-term liabilities. In 2020, Energa was acquired by PKN Orlen. In 2019, only Enea generated net income and its operating cash flow was slightly higher than the sum of net income and depreciation.

In the analysed global energy companies, operating cash flows were generated not only from by financial surplus, which was the case in the Polish companies, but also flexible management of current assets and rational selection of short-term sources of financing operating activities.

Conclusions

To sum up, it should be emphasised that the hypothesis adopted in the introduction, according to which Polish energy companies listed on the stock exchange conduct a policy of cash management similar to that of global companies was not confirmed. Polish companies maintain a higher level of cash relative to their current assets and sales revenues than the analysed global energy companies. The management boards of Polish companies do not attach much importance to the issue of optimising the level of free cash. They do not identify opportunity costs that limit the development of companies. This may result from the lack of access to flexible, short-term sources of financing when the company has loans for the implementation of development projects, the lack of development programs in the conditions of systematic reconstruction of the state's energy policy resulting from changes in EU regulations, the need to change energy sources and increasingly stricter emission standards. Other reasons for the free cash surplus may also be the lack of flexible management of operating activities. Energy companies, like most Polish business entities, do not implement cash management systems that would include alternative ways of obtaining cash in the event of a shortage so as not to lose liquidity. Such programs may include undertakings related to the release of funds from fixed assets through leaseback, sale of a part of funds, sale of stocks and shares, sale of subsidiaries in capital groups. In the area of current assets, companies can make changes to their inventory management policy, shorten the terms of payment of invoices and extend the terms of payment for deliveries. The lack of cash equilibrium programs in the company may lead to unreliable or even incorrect valuation of assets that the company intends to sell to raise cash in a crisis situation. To a large extent, this approach is a sign of weaknesses in financial management. Rational cash management is especially important in crisis situations, where the risk of losing liquidity is high. In an economic boom, flexible cash management is an important tool in gaining the company a competitive advantage on the market.

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Zarządzanie środkami pieniężnymi w spółkach energetycznych

W artykule zaprezentowane zostały problemy zarządzania wolnymi środkami pieniężnymi w spółkach energetycznych notowanych na rynkach giełdowych. Prezentowane w literaturze motywy utrzymywania wolnej gotówki: transakcyjny, ostrożnościowy i spekulacyjny nie wyczerpują przesłanek, którymi kierują się przedsiębiorstwa. Warunki otoczenia skłaniają firmy do wykorzystania wolnej gotówki w bieżących transakcjach handlowych i korzystania z opustów cenowych za zakupy za gotówkę bądź przyspieszenie płatności za dostawy w relacji do umownych terminów płatności. Firmy mogą prowadzić różne strategie zarządzania gotówką będące częścią ich strategii finansowej. Strategie konserwatywna, umiarkowana i agresywna są zależne od polityki w obszarze kredytu kupieckiego. Rozwój rynku finansowego stwarza szerokie możliwości zagospodarowania wolnej gotówki w różnorodne instrumenty finansowe. Dobierając instrumenty firmy kierują się głównie ryzykiem utraty części zainwestowanych środków, nie pomijając dochodu z tych instrumentów oraz czasu ich zagospodarowania. Przeprowadzone w spółkach energetycznych badania wykazały, że polskie spółki energetyczne mają spory nawis gotówki w relacji do poziomu aktywów obrotowych i przychodów ze sprzedaży. Nawis ten jest wyższy niż w światowych spółkach energetycznych notowanych na giełdach.

Słowa kluczowe: *wolna gotówka, motywy utrzymywania, strategie gotówkowe, formy inwestowania wolnej gotówki*

Polish Energy Policy Concerning Hard Coal Mining Economy after 1989

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Abstract

Energy policy is part of the national economy policy of each government. Assurance of national energy security, based on the country's own energy raw material resources and the prospects of their import and export belong to the essential tasks of energy policy. Hard coal was and has been the most important energy raw material for Poland, and this paper is devoted to that topic.

In 1990–2009, five documents entitled "Assumptions of the Polish Energy Policy" or "Assumptions of the Energy Policy of Poland...," with references to particular years, were drafted together with the "Evaluation of the Implementation and Revisions of the Assumptions of the Polish Energy Policy until 2020." After 2009, however, the Polish Parliament failed to approve any such document, although several more or less recognised prognostic documents had been prepaid, but none was ever approved or implemented. Consequently, the "Energy Policy of Poland until 2030," approved by the Polish Parliament on 10 November 2009, is the last binding document in that area. This paper presents the evolution of the approach to coal in subsequent government documents in the recent years. Besides, drafts or bills were intentionally omitted here, as they have never been approved by the Parliament and have remained unofficial.

Keywords: *energy policy, energy security, hard coal*

Introduction

The purpose of the government's energy policy is to ensure energy security of the nation. That type of security, according to the Polish Energy Law (the "Law"), is understood as such a condition of economy that allows for covering both current and prospective demand for fuel and energy, in the manner that is technically and economically justified, with the observation of environmental protection requirements (the "Law 1997"). The Law determines the principles of developing the government's energy policy and the principles and conditions of supply and consumption of fuels and energy, also specifying the government agencies that are responsible for fuel and energy economy in the country. As we know, Poland has based its energy generation system on coal, mainly hard coal. For that reason, the regulations concerning that raw material, acted in the government documents, were and have been so important to determine the Polish energy policy.

Assumptions of the Polish Energy Policy in 1990–2010

On 4 September 1990, the Polish Council of Ministers approved the "Assumptions of Polish Energy Policy in 1990–2010" (the "Assumptions 1990"). That document was drafted in connection with the Resolution of the Parliament of the People's Republic of Poland of 24 May 1989, regarding rationalisation of the energy and fuel consumption in the national economy. The contents of the document concerned the development prospects of the national fuel and energy complex twenty years ahead. The data presented there and the scenarios of possible future directions of the development of the national power industry were based on the simulation analyses performed with the use of certain computer models. The authors of those "Assumptions" realised that the figures presented there were only tentative because no-one was able to assume any continuation of current trends in the future, in the abruptly changing socio-economic situation in Poland at that time. The transition from a centrally planned economy to a market economy created a new situation that had been previously unknown in the world. For that reason, the assessment of the future fuel and energy demand by the country was very difficult a challenge. In addition to own scenarios, the Polish Ministry of Economy also used analytical documents drafted by foreign expert consultants, applying the methods that had been successful in market economy. Besides, relevant research was conducted in co-operation with the World Bank's International Energy Agency and the French Ministry of Industry. When evaluating the then energy generation situation, the analysts identified basic assets of the Polish economy. The essential ones included the following (Assumptions 1990):

- Unfavourable structure of mining primary-energy sources from national resources.
- Inappropriate structure of primary energy source application.
- Considerable air pollution.
- High changeability of weather conditions.
- Low primary energy source consumption per person.
- Low energy consumption in the municipal and household sectors and in agriculture per person.
- Low gross national income (GNI) per capita.
- High energy intensity of the GNI.
- Low energy consumption effectiveness.

The local evaluation results were compared to similar results obtained in well developed countries. The following three scenarios were considered in the assumptions of the nation's economic development:

- Low (L), with the average rate of economic growth of about 3%/year in 1991–2010

Tab. 1. Primary energy source demand under particular scenarios, PJ. *tcu: ton of coal equivalent. Source: Assumptions 1990
Tab. 1. Zapotrzebowanie na energię pierwotną w poszczególnych scenariuszach, PJ

No.	Energy Source			Scenarios					
				L		M		H	
		Year							
		1988	1990	2000	2010	2000	2010	2000	2010
1.	Hard coal	3,606	2,930	3,123	3,267	3,211	3,756	3,331	3,994
2.	Lignite	592	589	545	551	545	551	560	700
3.	Natural gas	406	308	577	779	715	946	894	1,105
4.	Liquid fuels	740	621	832	1,011	993	1,227	1,134	1,301
5.	Nuclear fuel	0	0	0	231	0	375	0	375
6.	Other	102	135	135	135	135	135	135	135
TOTAL	PJ	5,447	4,583	5,212	5,974	5,599	6,991	6,053	7,609
	10^6 tcu*	186	156	178	204	191	239	207	260
GNI energy intensity (1985=100)		94	111	90	80	82	64	68	52

Tab. 2. Primary energy source demand under particular scenarios, %. Source: Assumptions 1990
Tab. 2. Zapotrzebowanie na energię pierwotną w poszczególnych scenariuszach, %

No.	Energy Source			Scenarios					
				L		M		H	
		Year							
		1988	1990	2000	2010	2000	2010	2000	2010
1.	Hard coal	66.2	63.9	59.9	54.7	57.4	53.7	55.0	52.5
2.	Lignite	10.9	12.9	10.5	9.2	9.7	7.9	9.3	9.2
3.	Natural gas	7.4	6.7	11.1	13.0	12.8	13.5	14.8	14.5
4.	Liquid fuels	13.6	13.6	15.9	16.9	17.7	17.6	18.7	17.1
5.	Nuclear fuel	0.0	0.0	0.0	3.9	0.0	5.4	0.0	4.9
6.	Other	1.9	2.9	2.6	2.3	2.4	1.9	2.2	1.8
TOTAL		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

- Medium (M), with the average rate of economic growth of about 5%/year in 1991-2010,
- High (H), with average the rate of economic growth of about 8%/year in 1991-2000.

The three scenarios, presented in the above Table, assumed the growth of primary energy demand. For obvious reasons, the highest demand was assumed under the High Scenario. That involved not only hard coal, but also the remaining energy sources. From today's perspective, it is interesting that the nuclear fuel demand was expected to be available in Poland in 2010. A limited development of nuclear energy production of up to 2,000 MW in 2005 and 6,000 MW in 2010 was planned at the time of drafting Assumptions 1990. To improve the energy production effectiveness and the production structure adjustment to the parameters existing in developed countries, a drop in GNI energy intensity was planned under all scenarios, mostly for 2010.

The Table below presents the proportional primary energy source demand under particular scenarios.

When we analyse the proportional shares of particular energy sources in primary energy demand, we can notice that only the share of hard coal exceeded 50%, under each scenario.

The scenarios of the production, export and import of particular energy sources looked quite interesting. Table 3 shows only the data relating to hard coal.

It is equally interesting that import of coal to Poland was planned for as early as 1990. The 2010 import figures were the following: 4.2 mio. tons under the Low Scenario, 13.2 mio. tons under the Medium Scenario, and 15.9 mio. tons under the High Scenario. However, in reality, coal import figures exceeded export figures already in 2008. The document stated that the import of 27 mio. tons of thermal coal (20% of the total thermal coal import in respect of all the European OECD countries) could face shortage of supply and cause a significant rise of coal prices.

The document also stressed the necessity of deep restructuring of the Polish hard coal industry, resulting in the liquidation of about 10% of coal-mine divisions that generated high costs of extraction. It was also proposed to close down the coal mines in those regions where such actions would not cause significant social problems, and the laid off miners could be offered new jobs in other coal mines. It was further suggested to increase coal mining concentration in large mines to reduce operating costs. The document also discussed the issue of effective environmental protection, underground storage of mining-waste, and underground water management. The authors considered an economic justification of coal preparation, especially in old and small coal mines. It was concluded that the justification of thermal coal import should be considered, instead of coking coal export from Poland. Economic analyses demonstrated that such a replacement would be profitable. The price differences allowed for transportation cost reduction, and thus the northern regions of Poland would be rather supplied with imported coal.

On 9 November 1990, the Parliament of the Republic of Poland, having considered the "Assumptions," approved the 1990 Resolution, recognizing that the submitted study was inadequate and inconsistent with the ecological policy assumptions, as well as failed to provide proper economic analysis. The Parliament identified the following basic directions of the national policy as regarded primary energy sources:

Tab. 3. Production, export and import of hard coal under the scenarios, mio. tons. Source: Assumptions 1990
Tab. 3. Produkcja, eksport i import węgla kamiennego w zależności od scenariusza, mln ton

	1988	1990	Scenarios					
			L		M		H	
			2000	2010	2000	2010	2000	2010
Production	193	163	145	145	144	154	144	162
Export/Import	31.2	28.6	2.2	-4.2	-0.9	-13.2	-2.5	-15.9

Tab. 4. Hard coal balance under the "survival" scenario. Source: own study, based on Assumptions 2000
Tab. 4. Bilans węgla kamiennego w scenariuszu Przetrwania

Specification	2005	2010	2015	2020
	[mio. tons]			
Output	101.0	90.0	85.0	80.0
Import	2.0	2.0	2.0	3.5
Export	10.1	4.1	1.0	0.0
Demand	92.9	87.9	86.0	83.5
Including:				
- Households	7.6	7.4	6.7	6.0
- Power plants and CHP's	50.7	53.7	53.7	53.6

- Reduction of the shares of solid fuels, with the increase of the proportion of hydrocarbon fuels and various types of renewable energy sources.
- Improvement of hard coal quality.
- Analysis of the actual costs of using the local lignite deposits, taking into account the environmental protection requirements.
- Increase of the supply of natural gas originating from both local resources and import.
- The development of the refinery and petrochemical industries adapted to the changes in the directions from which crude oil was imported, including the increase of reloading capabilities in the liquid fuel handling terminals in the Polish ports.

Polish Energy Policy Assumptions until 2010

On 17 October 1995, the Polish Council of Ministers approved the government document called the "Assumptions of the Polish Energy Policy until 2010" (the "Assumptions 1995"). Three functions of the government were distinguished there as follows: the energy policy developer, the business activity regulator, and the enterprise owner.

In the fourth chapter of the document on the energy policy implementation instruments, it was determined that restructuring projects would be implemented in the Polish hard coal industry, intended to retire the coal mines that were permanently unprofitable, with the strengthening of the economic and financial condition of the remaining coal mines through some financial restructuring processes. It was assumed as a rule that it was required to preserve the business structure allowing for the competition of mining companies, taking into account technical and environmental conditions that were specific in particular coal mines. It was expected that the past due financial obligations, including unpaid social insurance premiums and other fees, owed to the government, would also be restructured on the condition that the mining companies would adopt effective projects facilitating their operation on local and foreign markets. The costs of the technical retirement of coal mines and the costs of the social protection schemes for miners would be covered by the government.

As to hard coal price setting, no long-term government involvement was expected to continue, in the form of determination of raw material prices in Poland. It was assumed that prices should be established in compliance with the world market trends. Besides, long-term contracts would be signed for the delivery of Polish coal to the Polish power plants and CHP's, with the government's determination of contract prices in that case, as well as the methods of price revisions, in respect of the changing trends on international markets. The document stated that customs protection measures would be applied only exceptionally, in the case of threat to the local coal mining industry and to the degree that would control the government's energy security policy, but still with the observation of the international obligations of Poland.

Hard coal prices were deregulated in Poland in the third quarter of 1992. The price level was established then upon negotiations between the mining companies on one side and the power plants and CHP enterprises on the other side. In 1994, the price level was agreed as equivalent to 31.00 USD/ton, in respect of reference coal, with the calorific value of 21 MJ/kg, ash content of 22%, and sulphur content of 0.9%. Since the beginning of 1995, the price level was agreed at 35 USD/ton for both local and foreign customers, while the economic price of extraction amounted to 36-42 USD/ton. The difference in respect of the economic price was covered by non-payment of past-due financial obligations and suspension of necessary replacement or modernisation capital investments.

In reference to the power plants, CHP's, and heating enterprises, the document imposed the requirement of holding at least 30-day fuel reserves for basic operations, in reference to either the average level of power generation, or the maximum storage-yard capacity.

The document stated that the Polish Coal Corporation (WWK) would be replaced by the State Coal Agency (PAWK), as part of a restructuring project. The state sector structure was supplemented by the establishment of seven companies, solely owned by the State Treasury, to manage 57 coal mines. Other four coal mines were transformed into single-member State Treasury companies, three into limited liability companies, and five remained as state-owned enterprises. Nine coal mines were put in liquidation, and other five were subjected to a partial liquidation process. In addition, the Central Coal Sale Office (CZW) was transformed into the "Węglozbyt" owned by the State Treasury.

Tab. 5. Hard coal balance under the "reference" scenario. Source: own study, based on Assumptions 2000
Tab. 5. Bilans węgla kamiennego w scenariuszu Odniesienia

Specification	2005	2010	2015	2020
	[mio. tons]			
Output	101.0	90.0	85.0	80.0
Import	2.0	2.0	2.0	2.0
Export	11.7	7.7	3.1	0.1
Demand	91.3	84.3	83.9	81.9
Including:				
- Households	7.4	7.2	6.4	5.7
- Power plants and CHP's	49.6	51.2	53.0	53.1

Tab. 6. Hard coal balance under the "progress plus" scenario. Source: own study, based on Assumptions 2000
Tab. 6. Bilans węgla kamiennego w scenariuszu Postępu-plus

Specification	2005	2010	2015	2020
	[mio. tons]			
Output	101.0	90.0	85.0	80.0
Import	2.0	2.0	2.0	2.4
Export	17.5	7.4	2.5	0.0
Demand	85.5	84.6	84.5	82.4
Including:				
- Households	7.3	7.1	6.3	5.6
- Power plants and CHP's	43.6	46.9	48.3	47.3

Besides, the second stage of the restructuring programme was also mentioned, specifying the following directions (Assumptions 1995):

- Maintenance of the hard coal extraction profitability, without subsidies.
- Staged restructuring programme.
- Coverage of a portion of past due financial obligations of the unprofitable coal mines to be liquidated, from the government's special-purpose financial reserves.
- Coverage of the costs of the technical liquidation of unprofitable coal mines and of the costs of social protection schemes for miners by the government.

In Chapter II entitled the "Projections of the development of energy situation in Poland until 2010," hard coal consumption was anticipated at 42.3 mio. tons in 2010, based on the projections provided by the Polish Academy of Sciences (IPPT PAN), or 51.1 mio. tons, based on the Polskie Sieci Energetyczne S.A. projections.

It was concluded that hard coal demand would be completely covered by local supplies. However, the local supplies were not considered to be critical for the national economy, although an economically justified level of mining capacities of the Polish coal mines would obviously increase the security of primary energy source supply. The authors also predicted the drop of coal export, owing to high costs of mining in Poland, and anticipated arrival of low coal prices on the European market.

In the subsection devoted to environmental protection issues, it was noticed that the fossil fuel domination, including especially the high share of coal, in the primary energy source consumption structure, created serious ecological problems at that time, to be continued in the future, and that would lead to the limitation of the global energy consumption rates. The increasing environmental protection requirements could turn into serious barriers facing development, especially in case of poor countries. That could lead immediately to an abrupt limitation of coal consumption, and, once hydrocarbon fuels have been exhausted, to the limitation of primary energy source limitations, reducing the development of global civilisation.

Assumptions of the Polish Energy Policy until 2020

The "Assumptions of the Polish Energy Policy until 2020," approved by the Polish Council of Ministers on 22 February 2000, with the main government energy policy targets, indicated the following (the "Assumptions 2000"):

1. Energy security understood as such a condition of the Polish economy that allows for covering both current and future fuel and energy demand.
2. Increase of the competitiveness of local businesses, products, and services offered on both international and local markets.
3. Environmental protection by control of the negative effects of energy generation processes.

That "survival" scenario was definitely the most pessimistic, in terms of the macroeconomic development of Poland. The scenario assumed potential global political shock waves causing suppression of global development. The Polish economy was supposed to continue its raw-material structure, with the average GNP growth rate of ca. 2.3%. The unemployment rate was anticipated at 14%. It was predicted that if the "survival" scenario came true, the Polish membership in the European Union would be either postponed beyond 2010, or completely excluded.

The "reference" scenario assumed the continuation of unfavourable economic transformations in a stable international business environment. What was a weak point of that scenario was the exhaustion of simple development reserves, causing regular drops of GNP growth rates in the future, down to ca. 4.0%. That, however, would not prevent Poland to enter the EU, although it could have caused the delay in obtaining membership until about 2010.

The "progress plus" scenario was the only optimistic scenario among all the three projections drafted by the Polish government. That one anticipated favourable economic transformations in Poland at concurrent favourable international conditions. The planners assumed a high GNP growth rate of ca. 5.5%, what would allow Poland to join EU before 2005. The

Tab. 7. Proportional shares of hard coal in the final energy demand, within the baseline and effectiveness options. Source: own study, based on Short-Term Forecast 2002
Tab. 7. Procentowy udział węgla kamiennego w zapotrzebowaniu na energię finalną w wariancie bazowym i efektywnościowym

Baseline Option		Effectiveness Option	
2003	2005	2003	2005
26.8	25.6	25.9	24.3

Tab. 8. Hard coal mining capacity. Source: Short-Term Forecast 2002
Tab. 8. Zdolności wydobywcze węgla kamiennego

Specification	2000	2001	2002	2003	2004	2005
Output	102.2	102.8	103.4	102.9	102.8	101.5
Local sales, including	78.2	76.9	77.2	77.4	77.6	77.0
Thermal coal	66.3	63.4	64.0	64.5	64.7	64.2
Coking coal	11.8	13.6	13.3	12.9	12.8	12.8
Export, including	23.0	25.4	24.6	23.6	23.7	23.1
Coking coal	17.6	20.7	19.7	18.0	18.2	17.7
Total sales	101.2	102.3	101.9	101.0	101.3	100.1

Tab. 9. Demand for primary energy generated from coal, within the baseline and effectiveness options. Source: own study, based on Short-Term Forecast 2002. *) statistical data, without adjustment for weather, **) statistical data, with adjustment for weather
Tab. 9. Zapotrzebowanie na energię pierwotną z węgla w wariantach, bazowym i efektywnościowym

				Baseline Option		Effectiveness Option	
Units	1999	2000*	2000**	2003	2005	2003	2005
PJ	2,026	1,851	1,943	1,969	1,939	1,897	1,829
mio. tons	86.14	80.18	84.17	85.78	84.58	83.06	80.25

development of such sectors, as e.g. pharmaceutical, computer, or telecommunication industries was further assumed, similarly to IT, consulting, or banking services.

Assumptions 2000 also presented the national fuel and energy balance figures for hard coal, lignite, natural gas, crude oil, petroleum products, renewable energy, cogeneration sources (thermal and electricity sources), electricity, and heat.

As regards the Polish membership in EU, the "progress plus" scenario was fulfilled; however, as regards coal import and export, neither scenario was right.

Evaluation and Revision of Assumptions 2000

On 2 April 2002, the "Evaluation and Revision of the Assumptions of the Polish Energy Policy until 2020" (the "Evaluation 2002") was published. The authors criticised the previous implementation actions under the relevant policy, as well as the intended and never implemented actions. The general evaluation of the actions taken by the government, ministers, regional government administration, local governments, and business companies or state enterprises was negative. Out of nearly sixty planned tasks, only several were either completed or at some stage of implementation. The main charges specified lack of consistent actions and lack of progress monitoring.

In the section concerning solid fuels, the authors stated that the thermal coal reserves amounted to more than 14 mio. tons in 2000 of which 7 mio. tons were stored by power plants. The indicators describing the solid fuel reserves in Poland were close to those applied in EU at that time. Such reserves guaranteed the maintenance of electricity and thermal energy source supplies at the levels required by the energy generating customers.

The section concerning the Polish Energy Policy Revision claimed that the "progress plus" scenario was a preferred scenario. However, the beneficial changes in the external environment, assumed under that scenario, never occurred. The global economic growth rate was lower, while the Polish government failed to develop active and progressive development policies. The changes occurring in the external environment and the national economy caused that the GNP rate reached only the "survival" scenario projections in 2000-2001. Besides, structural transformations were rather closer to the ones anticipated under that scenario. The economic slowdown resulted in the reduction of demand for fuel and energy. Consequently, the fuel and energy consumption figures were lower than those projected in Assumptions 2000. However, the authors stated that the most arduous issue, for both the citizens and the government finances, were the costs of maintenance of a huge production surplus occurring in nearly all branches of the fuel and energy generation sectors (power plants, CHP's, heating plants, and hard coal and lignite mines). It was stated straightforward that, in view of reduced electricity and heat demand, together with power surplus, the fuel and energy generation sector had turned into economic ballast that prevented further development of the country.

Evaluation 2002 requested that the desired government's targets should primarily include the attainment of a balanced structure on the primary fuel source market, taking into account the local energy raw-material resources. In the light of imminent Poland's accession to the EU, it was necessary to make all efforts for the fuel and energy generation sectors to become ready for seamless integration with the European structures between 2003 and 2004, without harming the interests of both citizens and state.

In the "Short-Term Forecast" for the national energy generation sector, attached to the document, the projected fuel and energy balances were supposed to satisfy the demand resulting from the economic development under all the scenarios presented in the Polish Government's Economic Strategy of January 2002; however, the baseline option for the energy generation forecast was closer to the development scenario of the whole Polish economy, contained in that document, as regarded both basic macroeconomic figures and mechanism for the simulation of economic growth.

Tab. 10. Projected hard coal balance until 2005. Source: Short-Term Forecast 2002
Tab. 10. Prognozowany bilans węgla kamiennego do 2005 roku

			Baseline Option		Effectiveness Option	
Specification	1999	2000	2003	2005	2003	2005
Local output	110.2	102.8	103.9	102.5	103.9	102.5
Import	2.4	1.5	2.2	2.2	2.2	2.2
Export	24.1	23.2	20.3	20.1	23.0	24.5
Local demand, including:	88.5	83.4	85.8	84.6	83.1	80.2
- Power plants and CHP's	43.4	44.5	41.1	42.4	40.4	41.5
- Heating plants	7.7	6.7	7.0	6.2	6.4	5.4
- Corporation power plants	11.3	10.7	9.5	9.1	10.2	9.6
- Coking Plants	11.4	12.3	11.1	10.9	10.7	10.3
- Households	12.2	9.0	12.1	11.4	11.3	10.3

Tab. 11. Projections of demand for primary energy from hard coal in 2005–2025, Mtoe. Source: own study, based on Policy 2002
Tab. 11. Prognozy zapotrzebowania na energię pierwotną z węgla kamiennego w latach 2005–2025, Mtoe. Źródło: opracowanie własne na podstawie Policy 2002

Option	Year				
	2005	2010	2015	2020	2025
Treaty	43.7	42.0	41.8	46.5	48.2
Baseline, coal	44.3	45.3	44.5	48.7	50.1
Baseline, natural gas	44.1	45.6	42.3	42.3	42.5
Effectiveness	43.8	45.2	41.3	41.6	42.1

The data presented in the Table above demonstrate that one could have expected a drop in the hard coal share in the final energy consumption until 2005.

Table 8 presents the hard coal mining capacity in Poland. The data were collected from the database of the Hard Coal Mining Restructuring Agency, the reports on hard coal trading, and the reports obtained from particular coal companies.

Table 9 presents the demand for primary energy generated from coal, within the baseline and effectiveness options.

Table 10 presents the projected hard coal balance until 2005.

It was anticipated in the professional power plants and CHP's (however, corporation power plants, owned by large companies, are mentioned here only in Table 10 above) to maintain coal demand, in respect of the increased electricity demand and low competitiveness of generation technologies burning natural gas. It was rightly concluded that a continuous improvement of competitiveness, depending on the hard coal mining restructuring processes, would be of key importance for coal mining.

Energy Policy of Poland until 2025

The "Energy Policy of Poland until 2025" was implemented in January 2005. The document was composed of two parts (the "Policy 2005"):

The "Doctrine of the Polish Energy Policy until 2025," formulating the energy policy objectives, principles, and priorities, and stressing energy security management in market conditions (EU market after 2004), and

The "Long-Term Directions of Actions until 2025, with the Implementation Tasks until 2008," determining the tasks within nine areas (in compliance with the EU requirements).

Those tasks were the following (Policy 2005):

1. Capacity for the production of local fuel and energy sources.
2. Types and quantities of fuel reserves.
3. Electricity transmission capacity, including trans-border capacity.
4. Energy effectiveness of the Polish economy.
5. Environmental protection.
6. Use of renewable energy sources.
7. Restructuring and ownership transformations in the fuel and energy generation sectors.
8. Research and development works.
9. International co-operation.

Four options of energy demand were prepared, in respect of energy demand in Poland until 2025:

1. Treaty Option.
2. Baseline Coal Option.
3. Baseline Natural Gas Option.
4. Effectiveness Option.

The Treaty Option took into account the provisions of the EU Accession Treaty as follows: reaching 7.5% of electricity consumption from renewable sources in 2010, reaching 5.75% of biofuel share in the total petrol and diesel fuel sales in 2010, and limitation of total pollution emission from large fuel-burning facilities, down to the values specified in the Treaty.

The Baseline Coal Option was different from the Treaty Option by inclusion of the requirement to fulfil the provisions of the Treaty in the area of pollution emission; however, large fuel-burning facility issue was replaced by the implementation of the National Plan for Pollution Emission (KPRE) that permitted to postpone until 2020 the deadline of the attainment of pollution emissions established in the EU Accession Treaty until 2012. The second Option did not assume any limitation of coal supplies, or decisions whether coal should be delivered by the local producers or imported.

The Baseline Natural Gas Option assumed that the hard coal supplies to electricity generators would be maintained at the then existing level, while natural gas would be burnt to produce indispensable additional quantities of electricity.

The Effectiveness Option provided for obtaining additional improvement in the effectiveness of electricity generation, transmission, distribution, and consumption, based on active government's policy. The relevant forecast specified the maximum possible effectiveness increase, in respect of the other Options. The relevant values were the following:

– Increase of the average electricity generation efficiency by

Tab. 12. Forecast of hard coal consumption for electricity generation in 2005–2025. Source: own study, based on Policy 2002
Tab. 12. Prognoza zużycia węgla kamiennego do produkcji energii elektrycznej w latach 2005–2025. Źródło: opracowanie własne na podstawie Policy 2002

Option	Year				
	2005	2010	2015	2020	2025
Treaty	24.3	22.1	23.8	30.0	32.9
Baseline, coal	24.8	25.3	26.4	32.2	34.8
Baseline, natural gas	24.6	25.8	24.0	24.9	25.6
Effectiveness	24.4	25.3	23.0	24.7	26.0

Tab. 13. Demand for final energy generated from coal in particular years of the projected period, Mtoe. Source: Enclosure 2, 2009
Tab. 13. Zapotrzebowanie na energię finalną wytworzoną z węgla w poszczególnych latach prognozowanego okresu, Mtoe. Źródło: Załącznik 2, 2009

Unit	Year					
	2006	2010	2015	2020	2025	2030
Mtoe	12.3	10.9	10.1	10.3	10.4	10.5

Tab. 14. Demand for primary energy generated from hard coal in particular years of the projected period, Mtoe and tons. Source: Enclosure 2, 2009
Tab. 14. Zapotrzebowanie na energię pierwotną wytworzoną z węgla kamiennego w poszczególnych latach prognozowanego okresu, Mtoe i tony. Źródło: Załącznik 2, 2009

Unit	Year					
	2006	2010	2015	2020	2025	2030
Mtoe	43.8	37.9	35.3	34.6	34.0	36.7
Mio. tons	76.5	66.1	61.7	60.4	59.3	64.0

1.3 of a percentage point, in the areas of electricity transmission and distribution.

– Reduction of grid losses by 1.5 of a percentage point, in the areas primary energy source consumption.

– Reduction of GNP energy intensity by 5.0% and of general energy intensity by 7.0%.

All the options provided for the construction of the first nuclear power plant in Poland about 2021–2022.

When evaluating the implementation of the then energy policy, in respect of coal mining, the authors of Policy 2005 mentioned such coal mining reforms, carried out in the preceding years, as the Hard Coal Mining Reform in Poland in 1998–2002 (the "Reform 1998"), or the Hard Coal Restructuring Programme in Poland in 2003–2006, under anti-crisis regulations, as well as the initiation of the privatisation processes in certain coal mines (the "Programme 2003").

It was estimated that the fulfilment of the sector reform programme caused a considerable reduction of the coal production capacity and of the number of employees. Considerable public resources were spent on the reform implementation. It was stated in Policy 2005 that, owing to the significance of hard coal in the Polish energy balance, the coal mining restructuring processes should be continued.

When evaluating the accessibility of primary fuel sources, it was mentioned that the local hard coal resources would be adequate to cover the coal demand in the whole projected period. Coal supply limitations could be, however, caused by the reduction of mining capacities, resulting from the programmes of adjusting the local mining industry to the global market conditions. If that happened, the relevant limitations would be compensated by import of coal available on global markets.

The authors also forecast the demand for particular primary energy sources. Table 11 presents the demand for primary energy from hard coal in 2005-2025 under several options.

Rapid increase of electricity demand was projected under all the Options. For example, the demand under the Effectiveness Option would amount to 211.9 TWh, 223.1 TWh under the Baseline Natural Gas Option, 225.1 TWh under the Baseline Coal Option, and the most under the Treaty Option: 225.6 TWh, all in 2020. However, in the cases of Treaty and Baseline Coal Options, the increase of electricity production would be based on hard coal burning.

Table 12 presents a forecast of hard coal consumption for electricity generation in 2005–2025.

In the document under discussion, the costs of covering local demand for energy were also presented. We can conclude that the Baseline Coal Option would be less expensive than the Baseline Natural Gas Option, as reflected by lower electricity production costs and lower electricity costs for customers. And lower dependence of Poland on fuel import would be an additional advantage under the former Option.

The document also contained a statement that the implementation of the Treaty Option would not be possible because of capital investment and substantive limitations. Such resources would be required to spend on large ecological projects. However, own hard coal and lignite resources and the cost of generating electricity and thermal energy from those sources indicated that the Polish sources would provide base fuels for the generation of both types of energy (electrical and thermal), within the projected period. However, in another section of the text, the authors pointed out that the then self-sufficiency of Poland in the areas of hard coal and lignite, as well as the progressing deregulation of the electricity market, both in Poland and the EU, would contribute in the future to the reduction of the significance of coal reserves, as means to support electricity supply security on the way to improve energy effectiveness, power grid synchronisation, expansion of inter-system links, and strengthening of the Third Party Access (TPA) policy.

Energy Policy of Poland until 2030

On 10 November 2009, the Polish government published its document entitled the "Energy Policy of Poland until 2030" (the "Policy 2009"). It was hard to expect at that time that the document would be still valid during the subsequent dozen of years, because, even today, in 2020, the Polish Council of Ministers has not adopted any new policy, although several drafts were published but failed to be approved by the Parliament.

Tab. 15. Demand for electricity generated from hard coal in particular years of the projected period, TWh. Source: Enclosure 2, 2009
Tab. 15. Zapotrzebowanie na energię elektryczną wytworzoną z węgla kamiennego w poszczególnych latach prognozowanego okresu, TWh. Źródło: Załącznik 2, 2009

Unit	Year					
	2006	2010	2015	2020	2025	2030
TWh	86.1	68.2	62.9	62.7	58.4	71.8

Tab. 16. Hard coal consumption for electricity generation, together with the consumption for cogeneration purposes, ktoe. Source: Enclosure 2, 2009
Tab. 16. Zużycie węgla kamiennego do produkcji energii elektrycznej wraz ze zużyciem na cele kogeneracyjne, ktoe. Źródło: Załącznik 2, 2009

Unit	Year					
	2006	2010	2015	2020	2025	2030
ktoe	25,084	20,665	18,897	17,722	16,327	18,331

Tab. 17. Gross capacity of electricity generation from hard coal. Source: Enclosure 2, 2009
Tab. 17. Zdolność wytwarzania energii elektrycznej brutto z węgla kamiennego. Źródło: Załącznik 2, 2009

Technology	Year					
	2006	2010	2015	2020	2025	2030
PC/Fluidal	15,878	15,796	15,673	15,012	11,360	10,703
CHP	4,845	4,950	5,394	5,658	5,835	5,807

The document in question took into account the conditions set by the EU, as regards ecology, or Directive 2009/29/WE (the "Directive 2009"), containing a collection of binding regulations intended to implement the EU assumptions on counteracting climate change. The Directive determined the climate targets for 2020, including the reduction of greenhouse gas emission by 20%, in comparison to the 1990 values, reduction of energy consumption by 20%, in comparison to the EU forecasts for 2020, increase of the renewable energy source share of up to 20% of the total energy consumption in the EU, as well as the increase of the use of energy from renewable sources in transportation by up to 10%. The "Energy Policy of Poland until 2030" was intended to respond to the essential challenges facing the Polish energy generation sector, both in short-term and long-term perspectives. The following were recognised to be the basic directions of energy policy (Policy 2009):

- Improvement of energy effectiveness.
- Increase of fuel and energy supply security.
- Diversification of the electricity generation structure by the implementation of nuclear power generation.
- The increase of the consumption of energy generated from renewable sources, including biofuel.
- Increase of the competitiveness of fuel and energy markets.
- Limitation of the influence of power generation on the environment.

The Energy Policy under discussion was prepared in compliance with the priorities specified in the "National Development Strategy for 2007–2015," approved by the Polish Council of Ministers on 29 November 2006 (the "Strategy 2006").

The diversification of raw material and fuel supplies to increase energy security was strongly stressed in the Policy. The diversification was understood there as the varieties of technologies, not just the choice of suppliers. Due to gradual exhaustion of hard coal and lignite deposits in the currently mined locations, the planning horizon reached 2030 to include the preparation and commencement of new deposits for mining. The authors also pointed out the necessity to correlate mineral mining plans with the capital investment plans in other sectors, e.g. road construction. The document clearly stated that all available coal-based energy generation technologies would applied, with the assumption that they assure the reduction of air pollution. As to the objectives and actions involving coal, the document specified, in bold, that "The main purpose of energy policy, in respect of coal, is to manage reasonably and effectively the coal deposits of the Republic of Poland." That was followed by the idea that coal would remain to be the main fuel for power generation to guarantee energy security in the country.

Detailed objectives (Policy 2009):

- Assurance of the national energy security by satisfaction of the local demand for coal, with the provision of stable supplies to customers, as well as the required quality parameters.
- Use of coal, with the application of efficient and low-emission technologies, including those of coal gasification and liquefaction to obtain fuels.
- The implementation of modern technologies in the coal mining sector to increase competitiveness, work safety, and environmental protection, as well as create foundations for technological and research development.
- Maximum possible use of methane released during coal mining.

To attain those objectives, it was planned to approve proper legal regulations to motivate enterprises and business to maintain necessary mining capacities, remove legal barriers that prevented making new deposits available, protect strategic coal resources by including them in local physical plans, protect access to coal resources, intensify geological prospecting, and complete the ongoing organisational and structural transformations. The policy makers also offered support for economic use of methane released during hard coal mining, including recuperation of methane from exhaust ventilation air, obtain funds designated for coal mine development through the privatisation of coal enterprises, support research and development works on the technologies for the use of coal to produce liquid and gas fuels, reduce negative influence of coal-burning energy production on the environment, and produce coal fuel cells.

Enclosure 2 to the "Polish Energy Policy until 2030" ("Enclosure 2, 2009) predicted that the thermal coal prices (USD value of 2007), paid for coal imported to Poland would be as follows: 140.5 USD/ton in 2010, 121.5 USD/ton in 2015, 133.5 USD/ton in 2020, 136.9 USD/ton in 2025, and 140.3 USD/ton in 2030. It was further assumed that the local hard coal prices would equal the import prices in Poland in 2010. Besides, taxation of the energy sources would be harmonised with the EU requirements and an additional excise tax would be imposed on coal, coke, and natural gas, with concurrent coal and coke excise tax exemption until 1 January 2012 and natural gas excise tax exemption until 31 October 2013. Another assumption stated that the CO2 emission permit prices would reach the level of 60.00 EUR/ton after 2012.

Table 13 presents the demand for final energy generated from coal in particular years of the projected period. Year 2006 is the base year.

Table 14 presents the demand for primary energy generated from hard coal in particular years of the projected period.

Table 15 presents the demand for electricity generated from hard coal in particular years of the projected period.

Table 16 presents hard coal consumption for electricity generation, together with the consumption for cogeneration purposes.

Table 17 presents the gross capacity of electricity generation from hard coal.

Enclosure 3 ("Enclosure 3, 2009") to the document under discussion presented the planned implementation actions for the years 2009-2012. What was especially interesting was Priority II entitled "The increase of fuel and energy supply security." Ten tasks were distinguished in the section devoted to coal. Implementation methods and the positions of responsible officials were assigned to each of the tasks. The tasks were the following (Enclosure 3, 2009):

1. Implementation of legal regulations, taking into account the targets proposed in the Energy Policy, and, in particular, the instruments to motivate people to conduct preparatory works and maintain suitable mining capacities, as well as develop modern coal preparation technologies to be used in energy generation.
2. Removal of legal barriers that prevent making new hard coal and lignite deposits available.
3. Identification of national strategic hard coal and lignite resources, with their protection by inclusion in local physical plans, and the protection of access to the strategic resources by the implementation of capital investment projects, as public-purpose projects of supra-local significance.
4. Intensification of geological prospecting to expand the availability of coal resources, with the application of modern exploration and appraisal methods.
5. Completion of the ongoing organisational and structural transformations.
6. Supporting the business use of methane released during hard coal mining.
7. Implementation of technological solutions allowing for the recuperation of methane from exhaust ventilation air removed from coal mines.
8. Obtaining funds for the development of mining through the privatisation of coal enterprises, whose justification, volumes of shares, and the dates of public offers will be analysed in compliance with the implementation of the Energy Policy.
9. Supporting research and development works on the technologies for the use of coal to produce liquid and gas fuels, reduce negative influence of coal-burning energy production on the environment, and produce coal fuel cells.
10. Keeping current competences of the Minister of Economy, as the minister proper for the State Treasury matters, in respect of mining enterprises.

Various persons and agencies were appointed to carry out those tasks, including the following: the Minister proper for Economy, the Minister proper for the Environment, the Minister proper for Building, Economy, Spatial Planning, and Housing, the Minister proper for the State Treasury, the Minister of Education, the President of the Government Legislation Centre, Mining Enterprises, Coal Company Managements, and Research and Development Units.

In Priority VI, related to the limitation of the influence of power on the environment, Action 6.9 was dedicated to coal. That Action concerned the use of coal waste as follows:

1. Implementation of actions in mining enterprises designed to limit the quantities of waste generated during coal mining: until 2010.
2. Making coal waste, stored in heaps, available to the interested businesses: continuous operation.
3. Analysis of the possibilities to apply and introduce financial instruments to encourage business entities to process coal waste: until 2011.

The Minister proper for Economy and the coal mining companies were responsible for the implementation of those tasks.

"The Energy Policy of Poland until 2030" was the last government document approved by the Polish Parliament in that matter. Similar subsequent documents were only drafts and bills.

Conclusions

After the economic and political transformations that happened in Poland in 1989, some government documents determining the directions of the Polish Energy Policy for the subsequent years were published every several years. Initially, they were entitled the "Assumptions of the Polish Energy Policy," later as the "Energy Policy of Poland until Year..." The documents contained national development scenarios, in respect of energy demand. The studies complied with the policies conducted by changing governments, with their contents corresponding to a large extent to the preparation of Polish membership in the EU. Once Poland joined the EU, the country had to harmonise the Polish regulations with the EU legislation, although Poland enjoyed certain derogations in the area of energy generation transformations, allowing for the country's adjustment to the conditions prevailing in the so-called "old EU" countries.

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Polityka energetyczna Polski w zakresie gospodarki węglem kamiennym po 1989 roku

Polityka energetyczna jest częścią polityki gospodarczej każdego państwa. Najważniejszym jej zadaniem jest zapewnienie bezpieczeństwa energetycznego kraju w oparciu o własne zasoby surowców energetycznych oraz możliwość ich importu i eksportu. Dla Polski najważniejszym surowcem energetycznym był, i jest nadal, węgiel kamienny i właśnie temu surowcowi poświecony jest ten artykuł. W latach 1990–2009 opracowano pięć dokumentów o nazwie Założenia polityki energetycznej Polski lub Polityka energetyczna Polski do określonego roku oraz Ocenę realizacji i korektę Założeń polityki energetycznej Polski do 2020 roku. Po 2009 roku nie przyjęto przez parlament RP żadnego nowego dokumentu, choć opracowano kilka prognoz mniej lub bardziej udanych, żadna jednak nie została wdrożona. Tak więc przyjęta przez parlament 10 listopada 2009 roku Polityka energetyczna Polski do 2030 roku jest ostatnim obowiązującym dokumentem w tym zakresie. W artykule przedstawiono jak zmieniało się podejście do węgla w kolejnych dokumentach rządowych na przestrzeni lat. Świadomie pominięto projekty, gdyż nie zostały one nigdy zatwierdzone przez parlament i przez to nie są oficjalnymi dokumentami.

Słowa kluczowe: *polityka energetyczna, bezpieczeństwo energetyczne, węgiel kamienny*

Effect of Marble Dust and Glass Fiber on Expansive Soil

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Abstract

India shares a significant production of glass fiber and marble wastes in the world, which poses a big disposal problem. This study assesses the suitability of glass fiber and marble dust to enhance the behaviour of expansive soil. The Atterberg's limits and plasticity index improves by mixing marble dust into the soil. Whereas, the effect of glass fiber on the Atterberg's limit is not very encouraging. The shear strength increases with the addition of marble dust as well as glass fibers. The effect of glass fiber on strains corresponding to peak stress is significantly higher than the marble dust. The strength of fiber-reinforced soil initially increases with the addition of marble dust, to a certain extent, beyond which it decreases. The effect of marble dust on variation in peak stress and corresponding strains is that fiber-reinforced soil is almost the opposite. The optimum quantity of marble dust and glass fiber is found to be 10%-15% and 3%, respectively.

Keywords: *compressive strength, reinforcement, fibers, marble dust, stabilization*

Introduction

Expansive soils, which is popularly known as black cotton soil is spread over more than 22% (Shukla and Parihar, 2016). The colour black is contributed to the presence of high iron, magnesium minerals and humus. Soils cover, Gujrat, Madhya Pradesh, Maharashtra, Karnataka Andhra Pradesh, and Tamilnadu states of India. These soils contain a large quantity of montmorillonite and illite minerals, and soil swell and shrink with absorption and discharge of water. The bond between soil elements brokes with the absorption of water (Wang, 1998). A number of studies presented photographs showing the cracks developed in the road, buildings and other civil engineering structures (Shukla et al., 2014).

India is a developing country and growing industrialisation results in the production of waste products as a byproduct of various construction activities. Agarwal et al. (2015) presented a study discussing the scenario of waste produced in India. A similar scenario exists in almost all developing countries. Though, the waste management policy available at the municipal level or state level, there is no national policy or guideline to store and utilize these waste materials for sustainable development. Some of the waste materials are hazardous but some waste materials are non-hazardous, which can be used as a construction material for sustainable development (Letcher & Vallero, 2019). These materials include, fly ash, sawdust, metal slags, alccofine, ground granulated blast furnace slag, natural and synthetic fibers, marble dust and other stone dust (Parihar et al., 2017; Ikeagwuani, & Nwonu, 2019).

India shares a significant production of marble waste in the world. Almost 3,172 thousand tons of dust was created by marble industry in 2009-10. It is nowadays available very easily in the market at 15 US dollar/ tonne, which is very cheap comparing other alternative materials. A number of studies have explored the use of marble dust (MD) as a construction material for different purposes. Waste marble dust has been used as brick material and building material (Karasahin & Terzi, 2007; Sarkar, et al., 2006). Some studies used marble dust in the production of cement, infiltration material and mortar (Davini, 2000; Acchar et al., 2006; Saboya et al., 2007; Hwang, 2008). A few studies used marble dust to stabilize the expansive soils (Palaniappan & Stalin, 2009, Agrawal et al., 2011; Sabat & Nanda, 2011). However, these studies were mostly considered some properties in the analysis.

Production of glass fiber waste in India is increasing every year. In the last decade, few studies explored the application of glass fiber (GF) on different soils. Yin and Yu (2009) found that glass fiber along with cement could be an alternative to reinforce the soft subgrade. Fang et al. (2011) observed that glass fiber are more efficient at large strains in sandy soil. Asadollahi and Dabiri (2017) varied glass fiber content from 0.25 % to 1.5 %, and maximum shear strength is found at 1% fiber content. Saha and Bhowmik (2018) determined the effect of glass fibers on shear strenth for different water contents on the sand-clay mixture. Syed and GuhaRay (2020) varied polypropylene (PPF) and glass fiber (GF) from 0 to 0.4%, and observed an increase in unconfined compressive strength and CBR of expansive soil.

The literature review shows that some recent studies determined the effect of fiber and marble dust on soils, separately. Only a very few studies considered the effect of marble dust on expansive soils. However, studies have not explored the effect of glass fibers on shear strength of expansive soil. Earlier studies mostly limited fiber content to 1%. It needs to explore the possibility of using fibers more than 1%. The main objective of the study is to find out the effect of glass fiber on expansive in the presence and absence of marble. The fiber content has been varied from 0 to 4% with an increment of 1%, and marble dust has been varied from 0 to 25%.

Fig. 1. Sampling location (modified after Chadha, et al.,2005)
Rys. 1. Miejsce pobierania próbek (zmodyfikowane za Chadha i in., 2005)

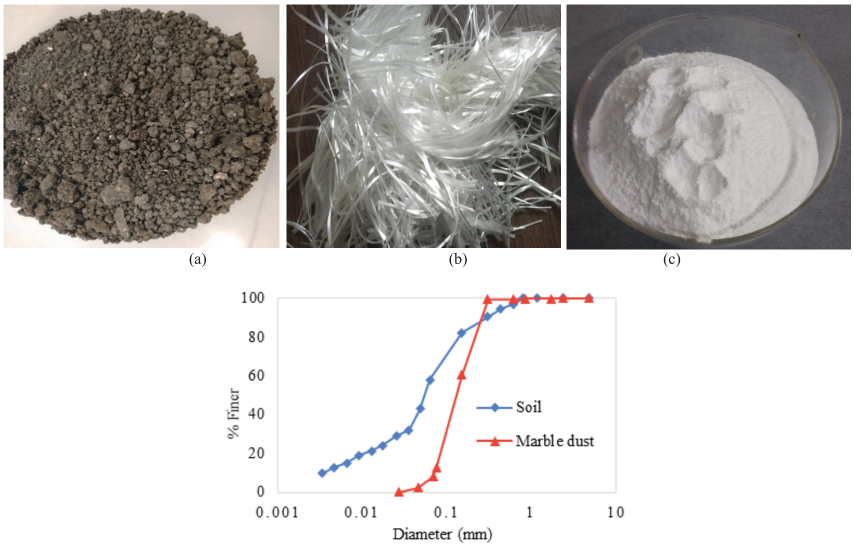

Fig. 2. Material used in testing: (a); Soil (b) glass fiber; (c) marble dust (d) grain size distribution of soil and marble dust
Rys. 2. Materiał użyty do badań: (a); gleba b) włókno szklane; c) pył marmurowy, d) rozkład wielkości ziaren gleby i pyłu marmurowego

The material used in the study

The expansive soil used in the present study is collected near to Ashok Nagar society, Navsari district of Gujrat.

The sampling location is shown in Fig. 1 and highlighted in red colour. The expansive soils cover almost 30% of the land cover of the Gujrat state. Based on Indian standard, the soil is classified as soil clay of high plasticity (CH). Considering its free swelling index (FSI), the soil is grouped into highly expansive soil (FSI>50%). This soil is also classified as a deep black cotton soil by government. The marble dust and glass fiber used in the study is collected from the market of Ahmedabad.

The marble dust consists of calcium oxide, silicon dioxide, magnesium oxide, and ferric oxide. The specific gravity of marble dust is found to be 2.78-2.80, which is greater than the specific gravity of used soil. The glass fibers and marble dust used in the study is shown in Figure 1. Fig. 1 (d) shows the grain size distribution of expansive soil and marble dust. The particle size of marble dust is relatively larger than the soil particles. The majority of marble dust falling in the range of 0.3 mm to 0.75 mm, which is size of fine sand.

Methodology

The liquid limit of untreated and modified soils was determined using the Casagrande apparatus. The plastic limit of soil was evaluated by the thread rolling method. The detailed procedure to determine the LL and PL is given in IS: 2720: Part-V. Shrinkage limit of soil samples was estimated by mercury displacement method by following a procedure specified in IS: 2720: Part-VI. To determine the Atterberg limits of modified soil, sufficient time was provided to allow the uniform mixing of water within the soil samples. Following the plasticity chart is given in the Indian standard, IS 1498 (2007), this soil is classified as clay of high plasticity (CH).

The relationship between moisture content and dry density of soil was determined by the method described in, Indian standard IS: 2720: Part-VII was used. Unconfined compressive strength tests, performed with and without the inclusion of glass fiber and marble dust as per IS: 1943, Part X: 1981 The specimens for determination of UCS were prepared with the help of a metallic split mould having a detachable collar. This mould is having a diameter of 38mm and height 76 mm. The detachable collar is attached to the end of the mould and it remains orthogonal with the vertical axis of mould. Water equal to OMC of soil was added to the soil to get the maximum advantages of soil reinforcement and modification. After mixing the fibers in the soil, the soil samples of different fibre content and different aspect ratio were prepared for testing. The samples were prepared and then tested for the unconfined compressive strength to evaluate the effect of different amount of fibre content and aspect ratio of fibers on the unconfined compressive strength of the soil. The fiber content was varied from 0 to 4% with an increment of 1%, while marble dust was varied from 0 to 30% with an increment of 5%.

Tab. 1. Properties of expansive soil used in the study
Tab. 1. Właściwości gruntów ekspansywnych zastosowanych w badaniach

Properties	Description	Properties	Description
Specific gravity (G)	2.62-2.65	Shrinkage limit (SL)	10-12 %
Liquid limit (LL)	70-72 %	Maximum dry density	1.45 gm/cc
Plastic limit (PL)	20-22 %	UCS	84 kPa
Plasticity index (PI)	49-52 %	Free swelling index	88-92%

Result and Discussion

Fig. 3 shows that the addition of marble dust (MD) improves the stress-strain behavior of expansive soils. The improvement in peak stress is more pronounce in soil treated with 10% marble dust. The peak stress corresponding to 10% of marble dust is significantly higher than other MD content. However, interestingly, the post-peak behavior does not shows any significant improvement. In all cases, the peak is always more than untreated soil. The effect of marble dust on sample failure is shown in Fig. 4. The soil sample always fails in shearing, irrespective of marble dust content.

The stress-strain behaviour of glass fiber reinforced soil is shown in Fig. 5 for different glass fiber content. It shows improvement in the stress-strain behaviour of soil with an increase in fiber content. Expansive soil with a glass fiber content of 3% fibers exhibits relatively higher peak stress than other fiber contents (1%, 3%, and 4%). However, the strains corresponding to peak stress increases with an increase in the fiber content. In general, the ductile behaviour of reinforced soil enhances with increase the fiber content, irrespective of peak stress. Soil shows an abrupt reduction in stress after peak stress; however, this post-failure behaviour of expansive soils improves significantly with fiber content.

Variation in unconfined compressive strength (UCS) and corresponding strain in glass fiber reinforced expansive soil is shown in Fig. 6. It shows that the UCS increases significantly up to 3% of glass fiber (Figure 6a) and then reduces. Earlier studies also observed a linear increase in the shear strength of soil polypropylene fiber content (Hussein and Ali (2019; Shukla et al., 2016). Contrary to variation in stress, the strains corresponding to peak stress (UCS) increases continuously with glass fiber content (Fig. 6c, d).

The strain increases by 700% for 4% of glass fiber, which is a substantial change as compared to change in UCS, which is almost 56% (Fig. 6 b, d). It indicates a huge increase in deformation resistance with the incorporation of glass fiber.A similar observation was made in earlier studies for other types of fibers (Sharma et al., 2015; Parihar et al., 2018). Also, the rate of increase in peak strain enhances with fiber content, which is again in contrast to variation in peak stress (Fig. 6 a-d). The increase in the peak stress and corresponding stains are due to the bridging effect induced by fibers in the soil-fiber matrix. It prevents extensive dissertation and the formation of cracks in the soil..

The effect of fiber content on expansive soil sample failure is shown in Fig. 7 The unreinforced soil fails within a small strain level (2.6 %) with large cracks. The size of cracks developed on the failed sample reduces significantly with glass fibers (Fig. 7 b-e). With further increase in the fiber content (>3 %), the cracks on soil samples decrease significantly, but bulging increases continuously. This is contrary to MD-treated soil, where soil samples fail in shearing with a number of cracks on soil samples (Fig. 4). At 4 % fiber content, the fibers start coming out from the soil sample, indicating excess fiber content. The interfacial friction between soil and fiber also contributes to enhancing ductile behaviour and stretching resistance (Tang et al., 2007). Similar to the present study, earlier studies also found that the inclusion of fibers in the clay matrix reduces the brittleness behaviour and soil deformation (Tang et al., 2016).

Fig. 8 shows the effect of marble dust on the stress-strain behaviour of glass fiber reinforced expansive soil. The modulus of elasticity (Ei = stress/strain) is maximum for 5-10% of marble in glass fiber reinforced soil. However, with the further addition of marble dust, the modulus of elasticity reduces significantly, and the minimum is observed for the marble dust of 20%. The detailed variation in peak stress (UCS) and corresponding strain with the addition of marble dust in fiber-reinforced soil are shown in Fig. 9. The peak stress of soil increases up to 10% of fiber content, and further addition of marble causes a reduction in peak stress (Fig. 9 a). The addition of marble dust of 20% reduces the shear stress even less than those observed when marble is absent. Fig. 9 b shows a 16 % increase in UCS of fiber-reinforced soil with the addition of marble dust. However, when comparing with unreinforced soil, the increase is found to be 80% due to the combined effect of glass fiber and marble dust, which is more than the distinct effect of glass fiber, where UCS was increased by 57% (Fig. 9 c and Fig. 8 b).

The marble dust in the glass fiber-soil matrix may enhance the geo-polymerization reaction and modifies the montmorillonite morphology (Syed et al., 2020). Marble dust causes the agglomeration of the soil particles and the better formation of clay-fiber-marble dust matrix. Glass fiber also induces the bonding effect. These effects contribute to increased soil shear strength. The decrease in soil strength with higher marble dust (MD>10%) may be attributed to expansive soil's enhanced moisture capacity at excess marble contents. Though the stresses increase significantly up to marble dust of 5%, the corresponding strains are less than those recorded for GF reinforced soil without any marble dust (Fig. 9 d). However, a further increase in the marble dust increases the strain corresponding to peak stress, and for 20% marble dust, it almost reaches the level of fiber-reinforced soil. The strain corresponding to peak stress reduces to 40% of fiber-reinforced soil with the addition of 5% MD (Fig. 9 e). Compared with unreinforced soil, the increase in strain is 380% due to 3% glass fiber. However, the addition of marble dust reduces the strain level from 380% to 110% with 5% marble dust (Fig. 9 f). However, further addition of marble dust enhances the strain corresponding to peak stress.

Effect of marble dust and glass fibers on soil expansion is

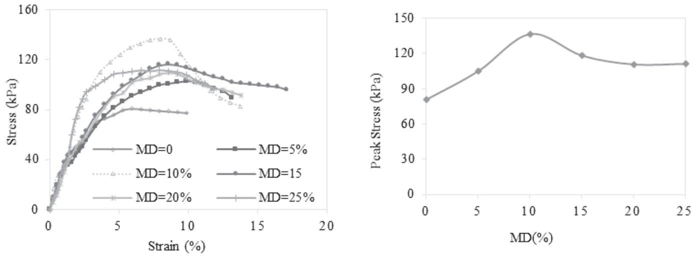

Fig. 3. Variation in liquid limit with marble dust and glass fiber
Rys. 3. Zmiana granicy płynności w przypadku pyłu marmurowego i włókna szklanego

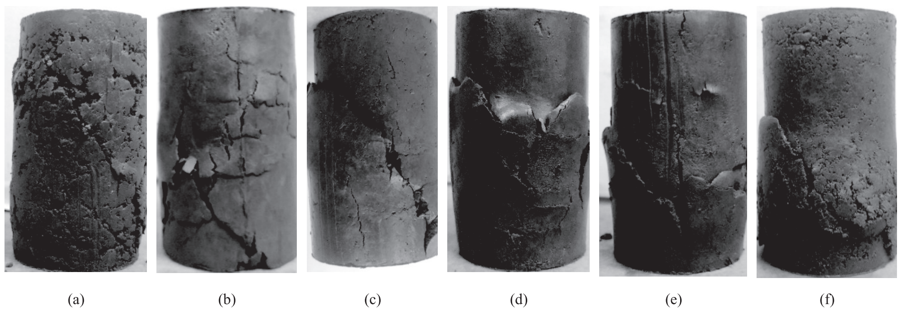

Figure 4. Effect of MD on failure of soil sample: (a) MD= 0%; (b) MD= 5%; (c) MD=10%; (d) MD=15; (d) D=20%; (e) MD=25%
Rys. 4. Wpływ MD na zniszczenie próbki gruntu: (a) MD= 0%; (b) MD= 5%; (c) MD=10%; (d) MD=15; (d) D=20%; (e) MD=25%

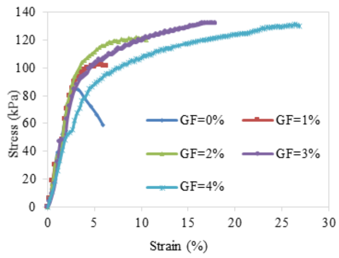

Fig. 5. Stress-stain characteristic of GF reinforced soil
Rys. 5. Naprężenie-plama charakterystyczna dla gruntu zbrojonego GF

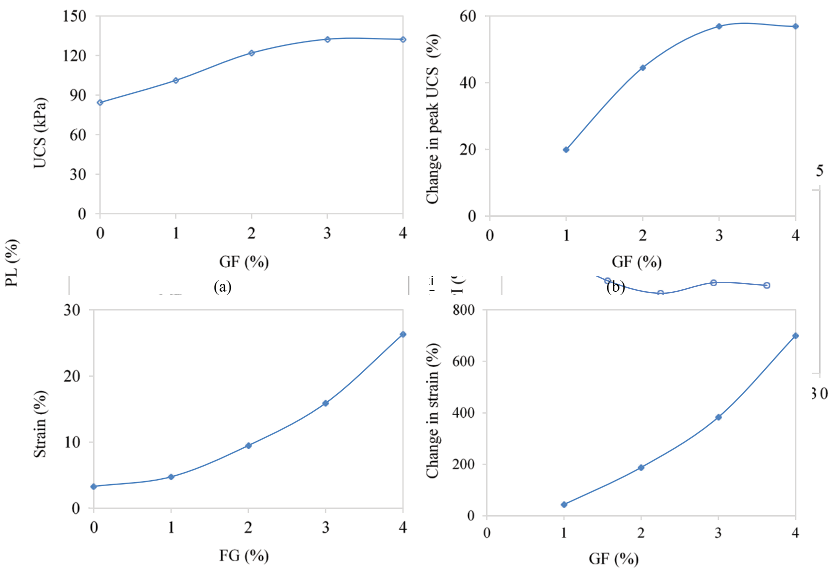

Fig. 6. Effect of glass fiber: (a) UCS; (b) change in UCS; (c) Strain corresponding to peak stress; (d) change in strain corresponding to peak stress
Rys. 6. Wpływ włókna szklanego: (a) UCS; b) zmiana UCS; (c) odkształcenie odpowiadające szczytowemu naprężeniu; (d) zmiana odkształcenia odpowiadająca szczytowemu naprężeniu

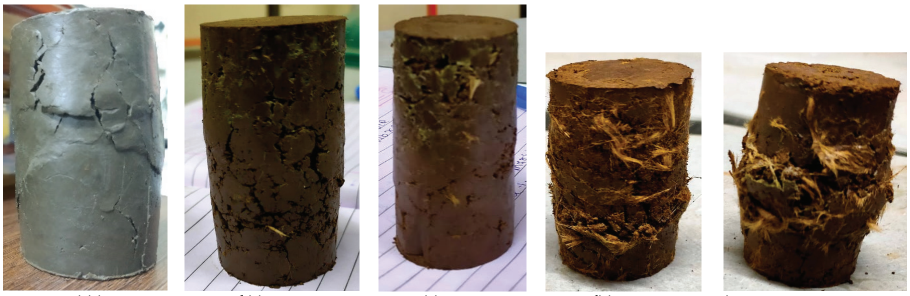

Fig. 7. Failure of soil samples with glass fiber content: (a) Unreinforced, (b) 1%, (c) 2%, (d) 3%, (e) 4%
Rys. 7. Uszkodzenie próbek gruntu z zawartością włókna szklanego: (a) niewzmocniony, (b) 1%, (c) 2%, (d) 3%, (e) 4%

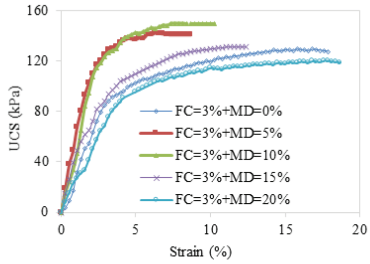

Fig. 8. Effect of marble dust on fiber reinforced soil
Rys. 8. Wpływ pyłu marmurowego na grunt zbrojony włóknem

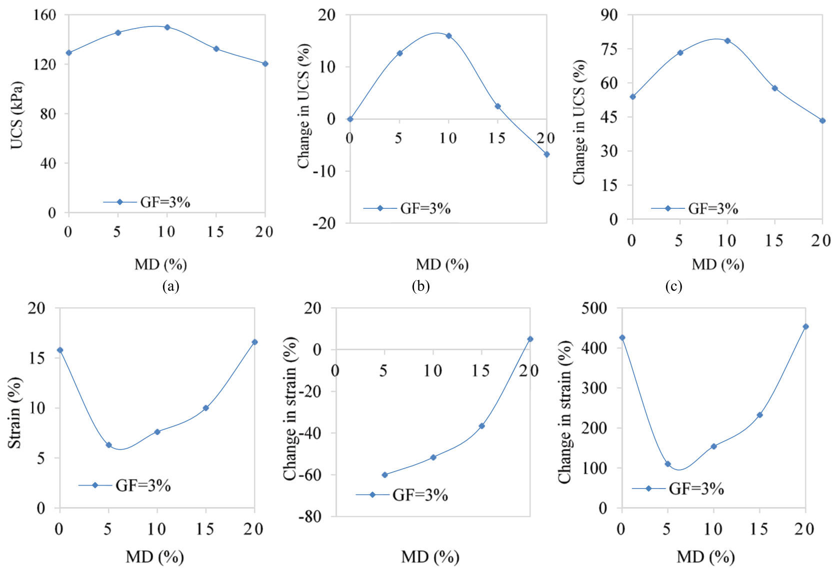

Fig. 9. Effect of marble dust on expansive soil: (a) variation in UCS; (b) % change in UCS in comparison to fiber reinforced soil; (c) % change in UCS in comparison to untreated soil; (d) variation in strain; (e) % change in strains in comparison to fiber reinforced soil; (f) % change in stain in comparison to untreated soil
Rys. 9. Wpływ pyłu marmurowego na ekspansywny grunt: (a) zmienność UCS; b) procentowa zmiana UCS w porównaniu z gruntem zbrojonym włóknem; (c)% zmiany w UCS w porównaniu z nieoczyszczoną glebą; d) zmienność naprężenia; e) procentowa zmiana odkształceń w porównaniu z glebą zbrojoną włóknem; (f)% zmiany zabarwienia w porównanie z nietraktowaną glebą

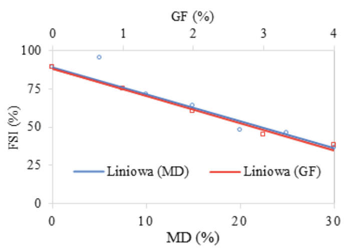

Fig. 10 Effect of marble dust on free swelling index
Rys. 10. Wpływ pyłu marmurowego na wskaźnik swobodnego pęcznienia

shown in Fig 10. The free swelling index (FSI) of soil initially increases with an increase in marble dust, and after a certain amount of marble dust, FSI is found to decrease. The tests have been repeated many times as the observation is contrary to earlier study results. However, every time the same results have been observed.

The free swelling decreases with any marble content greater than 5%. It is similar to earlier study results. For a marble content of 25%, the FSI reduces to less than 50 % of untreated soil. The characteristics of marble dust change with change in the characteristics of parent marbles. This can be a reason for different swell behaviour of soil with marble dust.

The addition of glass fiber linearly reduces the free selling index of soil. More is the fiber content; more is the reduction in soil swelling, which does not match with variation in shear strength, where strength enhancement ceases after 3% fiber content. Al-Akhras (2008) also observed a reduction in soil swelling with fiber content.

The maximum reduction was observed at 5% fiber content, which is significantly higher than earlier other studies, where optimum fiber was 0.75 to 1%.

Conclusion

The glass fiber and marble duct were mixed with highly plastic expansive clay. The denhacement in soil properties with the addition of marble dust is mainly contributed to the change in soil gradation. Glass fiber enhances not only pre-peak behaviour but post-peak behaviour also. The enhancement in strain corresponding to peak stress is relatively significant as compared to change in soil strength. In general, the ductility of reinforcement soil enhances continuously with an increase in the glass fiber. The unconfined compressive strength of fiber-reinforced soil increases initially with an increase in the marble dust in fiber-reinforced soil, to a certain extent, but beyond 10% of marble dust, it starts decreasing. However, the change in strain corresponding to peak stress of fiber-reinforced soil is almost opposite to the change in peak stress with the addition of marble dust. The addition of marble dust and glass fiber linearly reduces the free swelling index. The reduction is almost identical. The long-term performance of glass fibers and the effect of marble dust on glass fiber reinforced soil needs further research. The release of calcium ions under different temperatures and time intervals needs to be explored in future studies.

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Wpływ pyłu marmurowego i włókna szklanego na ekspansywną glebę

Gleby ekspansywne to gleby, które mają zdolność kurczenia się i / lub pęcznienia, a tym samym zmiany objętości, w zależności od zmian wilgotności. Utylizacja odpadów przemysłowych to duży problem w Indiach. Obecnie wiele produktów odpadowych stało się popularnymi materiałami konstrukcyjnymi. W niniejszej pracy oceniano przydatność zbrojenia włóknem szklanym do poprawy wytrzymałości gruntu ekspansywnego. Ponadto określa się również wpływ pyłu marmurowego na grunt wzmocniony włóknami. Limity Atterberga i wskaźnik plastyczności poprawiają się poprzez mieszanie pyłu marmurowego z glebą. Natomiast wpływ włókna szklanego na granicę Atterberga nie jest zachęcający. Wytrzymałość na ścinanie wzrasta wraz z dodatkiem pyłu marmurowego oraz włókien szklanych. Jednak wpływ włókna szklanego jest relatywnie bardziej zauważalny w porównaniu z pyłem marmurowym. Stwierdzono, że optymalna ilość pyłu marmurowego i włókna szklanego wynosi odpowiednio 15% i 3%. W przypadku włókna szklanego wytrzymałość na ściskanie i odpowiednie odkształcenie wzrastają odpowiednio o 55–58% i 700%. W gruncie zbrojonym włóknem wytrzymałość początkowo wzrasta wraz z dodatkiem pyłu marmurowego, do pewnego stopnia, po przekroczeniu której maleje. Stwierdzono, że wpływ pyłu marmurowego na zmienność szczytowych naprężeń i odpowiadających im odkształceń gleby wzmocnionej włóknami jest prawie przeciwny.

Słowa kluczowe: *depozycja na czynniki atmosferyczne, huta miedzi, emisje, metale*

A New Classification of Open Pits and their Remaining Gaps in Terms of Hydrogeological Conditions

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Abstract

As open-pits occupy the land only temporarily, post-mining planning for sustainable land reuse represents an important stage and it can be done since the pre-exploitation stage.
There are more possibilities to reuse former open pits depending on the nature and location of ore deposits. Coal open-pits are often reused as artificial lakes. Depending on local hydrology and hydrogeology the flooding process of former open-pits may be done naturally or artificially (combined). Reuse of the remaining gaps of open-pits requires a good evaluation of possibilities and limitations specific to the area.
The classification of open pits and their remaining gaps in terms of hydrogeological conditions is necessary for a better post-mining planning of the area. This paper proposes a multicriterial classification of open pits and their remaining gaps taking into account the hydrogeological conditions and the action of some hydrogeological parameters that have an important contribution in establishing the approach to their flooding process. The most important hydrogeological conditions of the region are investigated (the hydrogeological structure, types and number of aquifers, nature of aquifer rocks, hydrodynamic characteristics of the region) and the results are processed for the development of a multicriteria classification. Depending on the results of hydrogeological classification of open pits and their remaining gaps, the possibility of natural and/or artificial flooding can be established or, contrary, the need to consider a different reuse direction, other than flooding.
The proposed classification is useful as in literature no multicriteria classification exist, most of them being focused on single criterion classification. In this paper, more open-pits and their remaining gaps were analyzed from a hydrogeological point of view and classified based on the proposed classification which takes into account more evaluation criteria.

Keywords: *open pits, remaining gaps, hydrogeological conditions, hydrogeological classes, groundwater, inflow*

1. Introduction

Open-pit mining activity temporarily occupies the land, being an efficient method for exploitation of superficial ore deposits, but unfortunately it has negative impacts on environment (Walker and Willing, 1999). After the cessation of the mining activity results degraded land, usually as a result of the depletion of the useful minerals (Cooke and Johnson, 2002) and sometimes as a result of unfavorable technical or economical conditions. Reclamation of the land is needed in order to reintegrate and reuse it in a sustainable way (Laurence, 2011; Shen et al., 2015; McCullough and Lund, 2006).

The operating project includes planning of all stages of mining activity, taking into account the local conditions, offers the possibility to choose the most efficient exploitation and dumping methods and, subsequent, the type of reuse of the degraded land. Early planning allows applying the best practices of exploitation and dumping with regards on the future reuse of the land (Bangian et al., 2012; Miller, 2008; Maczkowiack et al., 2012; Donovan and Perry, 2019; Zhang et al., 2017). The possibility of executing the exploitation - dumping works in open-pits depending on the future land use, in at least acceptable technical and economical conditions, ensuring the necessary stability reserves of slopes, brings benefits such as reducing the costs of remodeling and reintegration into the landscape, reducing the geotechnical risks which may occur under the influence of new factors and faster takeover of the future function.

Classification of open pits and their remaining gaps according to the hydrogeological conditions is very important for establishing the approach to their flooding process after the exploitation activity is stopped.

Remaining gaps resulting from the exploitation of lignite in open pits are sometimes used to form lakes, by natural, artificial or combined flooding processes. These lakes can take on various uses, such as water sources for agriculture, horticulture and viticulture, for social and industrial activities in the surrounding areas or as leisure facilities (Mborah et al., 2016).

Natural flooding of the remaining gaps is specific to lignite deposits with complex hydrogeological structures, on the depths of which there are aquifers that extend over large areas and thicknesses and in the adjacent areas to the exploitation perimeters, with important static and dynamic groundwater resources. Artificial flooding of the remaining gaps is applied

Tab. 1. Multicriteria classification of open pits according to their hydrogeological conditions. * meter width of layer/aquifer horizon
Tab. 1. Wielokryterialna klasyfikacja wyrobisk odkrywkowych ze względu na ich warunki hydrogeologiczne. *metrowa szerokość warstwy/poziomu wodonośnego

	Classification / Specification	Hydrogeological conditions			
		I Simple	II Moderate	III Difficult	IV Complex
1	Hydrogeological structures	Open structures, with natural supplying and drainage conditions	Mixed open and closed structures, located above and below the local erosion base	Closed structures located under the regional erosion base	Complex structures with infinite aquifer horizons and inexhaustible water resources
2	Type of aquifers	Phreatic and captive with free level and limited water resources	Phreatic and captive with free or ascending groundwater level	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	Homogeneous or inhomogeneous multilayer aquifers with very large extension and with or without hydrodynamic connections between them
3	Type of aquifer rocks	Medium and coarse sands or mixtures of sands and gravels	Medium sands (Φ = 0.25÷0.5 mm)	Fine or dusty sands (Φ<0.25 mm) and medium sands	Fine sands, dusty or clayey sands and sometimes medium or coarse sands (Φ≥0.25 mm)
4	Number of aquifers	Two or more aquifers layers with limited extension	Two or more aquifers layers with large extension	Two or more aquifers layers with variable extension	Two or more aquifers layers with very large extension
5	Aquifer thicknesses	Under 15÷20 m	20÷40 m	30÷50 m	Over 40÷50 m
6	Piezometric pressure P [m H_2O]	10÷15	20÷50	40÷60	Over 60
7	Permeability of aquifer rocks, k_f [m/day]	Over 10	2÷10	0.5÷2.0	0.1÷0.5
8	Transmissivity T [m^3/m*·day]	100÷500	100÷250	50÷100	50÷200
9	Water inflow per ton extracted q [m^3/ton]	≤ 3	3÷5	5÷10	Over 10

in cases where groundwater resources are reduced, and involves supplementing the water supply by adductions, in order to reduce the flooding period of the remaining gap and, with it, the risk of landslides. An important role in the process of flooding the remaining gaps is played by the zonal or regional rainfall regime and the amplitude of the characteristic evapotranspiration.

2. Multicriteria classification of open pits

Formation of groundwater inflow towards the remaining gaps of the open pits depends on the presence and nature of aquifer formations, rock's aquiferity and hydrodynamic parameters of groundwater flow and occurs after the dewatering works are stopped.

The size of the inflows is dependent on several factors, including:

- type and size of groundwater resources;
- the hydrogeological characteristics of the rocks;
- the structure of aquifers currents and the hydrodynamics of groundwater;
- the contour of the aquifer supply domain;
- the size of the drained surfaces.

Of the three types of groundwater resources (static, dynamic and elastic), the dynamic resources have a great influence on the flooding process of the remaining gaps (including the stability of their final slopes), as they represent the inflow of groundwater provided by the natural supply of aquifers, which makes them virtually inexhaustible.

The evaluation of dynamic resources takes into account the precipitation modulus, the surface and groundwater flow modulus, the flows of the surface runoff, the groundwater drainage possibilities, the size of the active surfaces and the groundwater flow gradients.

Static resources are exhaustible under the conditions of the existence of natural or artificial drainage areas and can be regenerated only under the influence of the existence of sources and areas of natural supply.

Elastic resources, even if they exist in the lignite deposit conditions, become without influence by the de-stressing of aquifers when creating drainage conditions due to mining excavations that intersect closed type aquifers, with pressurized water.

Among the hydrogeological characteristics of the rocks, essential for the formation and volume of water inflows are:

- rock's permeability defined by the hydraulic conductivity, expressed by the filtration or permeability coefficient;
- rock's storage and release capacity, depending on the particle size composition and the porosity of the rocks.

The aquifer currents that form towards the remaining gaps evolve from unilaterally plane parallel currents on each side of the remaining gap, in non-permanent regime, to symmetrical or asymmetric radial currents with permanent flow regime.

The structure of aquifers currents is dependent on the geological structure of the region, the configuration of the works system, the geomorphological characteristics of the land surface, the existence of surface water sources and the contour of the aquifer supply domain. From this point of view, the contour can be linear when the supply is made in one direction, rectangular when the supply is made in two directions, circular or elliptical, when the supply is made in several directions and of surface when the supply is made by drainage or infiltration of precipitation into groundwater phreatic (surface) formations.

The size of the drained surfaces directly influences the inflow of water into the remaining gaps as the flow (inflow) is

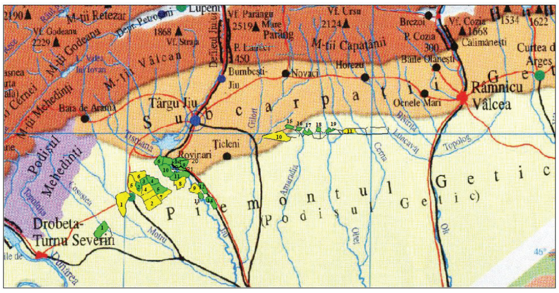

Fig. 1. Oltenia coal basin; Open-pit mining perimeters (green color; 1. Husnicioara; 2. Lupoaia; 3. Roşiuţa; 4. North Jilţ; 5. South Jilţ; 6. Tismana II; 7. Tismana I; 8. Gârla; 9. Rovinari Est; 10. Pinoasa; 11. Roşia de Jiu; 12. North Peşteana; 13. Urdari; 14. South Peşteana; 15. Seciuri; 16. Ruget; 17. Olteţ - Alunu; 18. Berbeşti; 19. Panga; 20. Balta Unchiaşului; 21. Beterega; 22. Cicani); Underground mining perimeters (yellow color)

Rys. 1. Zagłębie węglowe Oltenia; Granice kopalni odkrywkowych (kolor zielony; 1. Husnicioara; 2. Lupoaia; 3. Roşiuţa; 4. Północne Jilţ; 5. Południowe Jilţ; 6. Tismana II; 7. Tismana I; 8. Gârla; 9. Rovinari Est; 10. Pinoasa; 11. Roşia de Jiu; 12. North Peşteana; 13. Urdari; 14. South Peşteana; 15. Seciuri; 16. Ruget; 17. Olteh - Alunu; 18. Berbeşti; 19. Panga; 20. Balta Unchiaşului; 21. Beterega; 22. Cicani); Podziemne granice górnictwa (kolor żółty)

dependent on the underground flow rate and the size of the open surfaces at the level where the aquifers are intercepted by the final slopes of the remaining gap. From this point of view, it is estimated that the size of these drainage surfaces is very large, especially in the case of open pits with multilayer aquifers, which contributes to an accelerated dynamics of flooding the remaining gaps. In turn, this dynamic can influence the stability of slopes.

In the literature there are several hydrogeological classifications (Salako and Adepelumi, 2018; Hunkeler, 2010; ***, 2003; Rotunjanu and Lazăr, 2014; Gheorghe and Bomboe, 1963; Enache, 1985) of useful mineral deposits, most of them taking into account a single criterion, such as the degree of flooding of the deposit (characterized by the position of the deposit relative to the local erosion base); the presence or absence in the vicinity of the deposit of superficial aquifer sources; lithological composition of rocks within the boundaries of the deposit; rock's aquiferity; the degree and intensity of the tectonics of the deposit; the size of the water inflow, etc.

In this context, a multicriteria classification of open pits (remaining gaps) according to their hydrogeological conditions is proposed. The criteria taken into account, individually and as a whole, define the hydrogeological conditions that may affect the flooding process. In this manner, the methods and technologies used within the flooding process can be conditioned so as not to have a major influence on the stability of the final slopes (Table 1).

Observations

Class I – Open pits with simple hydrogeological conditions

There are no problems with the stability of the slopes during the flooding process. Due to the reduced groundwater resources, the flooding duration of the remaining gap is long, so water inputs from nearby surface sources are recommended.

Class II – Open pits with average hydrogeological conditions

Slope instability phenomena may occur as a result of suffosion holes caused by water seepage from the slopes, which exerts a hydrodynamic action. Under these conditions, after the dewatering works are stopped, the groundwater resources can be partially or totally restored, which can ensure to some extent the flooding of the remaining gap.

Class III – Open pits with difficult hydrogeological conditions

In the absence of dewatering works and the existence of open slopes, there are risks of landslides occurrence in the final slopes of the remaining gap due to the appearance of suffosion holes, of hydrodynamic pressure and changes in the structure and properties of fine-grained rocks. On the other hand, the flooding (almost total flooding) of the remaining gaps is ensured.

Class IV - Quarries with complex hydrogeological conditions

Constructive and maintenance works (measures) are needed to ensure the stability of the slopes of the remaining gaps before and during their flooding (reduction of slope angles, consolidation of dumped rocks by dynamic surface or in depth compaction, reinforcements etc.). Flooding of the remaining gaps is ensured by the large water inflows due to groundwater resources and flow conditions.

As the hydrogeological parameters vary from one deposit to another and even within the same deposit, depending on its hydrogeological structure, the classification of open pits in one class or another is difficult and for this reason a qualitative and quantitative assessment of the weight in which the analyzed parameters influences the dewatering and flooding processes must be made.

Practical experience has proved that special problems, when flooding the remaining gaps, occur when in the exploitation perimeters there are horizons with water under pressure, in conditions of a large influx of water. For this reason, an open pit or a remaining gap must be included in the class corresponding to the most unfavorable values of these parameters. Another principle of framing the remaining gaps, according to the presented classification, is the one according to which a deposit belongs to the class indicated by the values of most of the studied hydrogeological parameters.

3. Classification of coal open-pits and their remaining gaps from Romania

On Romanian territory, Oltenia's Coal Basin develop in the area of the Getic Subcarpathians and the Getic Plateau, between the Danube and Olt rivers, within the counties of Mehedinţi, Gorj, and Vâlcea. The basin covers an area of approximately 4500 km2 and stores over 95% of the country's lignite reserves (Fodor et al., 2003). It includes 5 mining basins: Rovinari, Motru, Jilţ, Berbeşti, and Husnicioara, being divided according to geographical, geological (rock nature

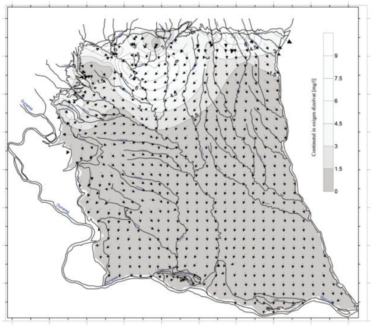

Fig. 2. The Dacian aquifer complex and the groundwater flow direction (vectors represent normal flow rates) (Palcu et al., 2008)
Rys. 2. Dacki kompleks wodonośny i kierunek przepływu wód podziemnych (wektory przedstawiają normalne natężenia przepływu) (Palcu et al., 2008)

and thickness of rock layers, depth of exploitation, degree of tectonization), hydrogeological, and economic criteria, and a total of 22 open-pit mining perimeters (Figure 1).

The lignite exploitation activity has ceased for 7 of the 22 perimeters, 2 of the remaining gaps resulting from the exploitation being currently flooded naturally (Urdari, which is located in the hilly area and South Peşteana, which is located in the meadow area of the Jiu river).

In order to verify the utility of the proposed classification and if the results confirm the real situation, the hydrogeological framing of the former South Pesteana and Urdari open-pits was carried out, which now form pit lakes. In addition, depending on the available data, some of the open-pits in the Rovinari mining basin and their remaining gaps were included in the proposed classes, as the exploitation is coming to an end (in maximum 5 years), being necessary to establish the direction of reuse and evaluate the potential risks, respectively the available water needed for flooding.

The hydrogeological research works have highlighted several groundwater horizons which, depending on the local erosion base, can be:

- groundwater with free level (phreatic aquifer);
- groundwater under pressure with ascending or artesian levels. Most of the aquifer structures in the southern part of Romania are located below or above the local erosion base, constituting hydrostructures with regional extension. (Palcu et al., 2008).

In the perimeter of the Getic Piedmont, the Dacian aquifer complex (consisting of sands with rare gravel elements and frequent sandstone concretions that pass to the top to fine sands with clay intercalations; Figure 2) is found at shallow depths in the western half of the perimeter, depths that gradually increase to the east. Also, there was a continuous increase in the thickness of the Dacian deposits from south to north (the aquifers reaching values of over 70 m). The bed of the Dacian aquifer complex consists of Pontic marls and clays or Meotian marls and sands, and the roof of Romanian clays and marls. The aquifer horizons in the coal complex do not have a continuous spread, the research boreholes highlighting their lens-like character. The variation of the hydrogeological facies takes place both vertically and horizontally, passing almost directly from permeable horizons to impermeable horizons. This situation is found especially in the upper part of the Dacian, in base the deposits being uniform. Therefore, in Oltenia, there is a strong artesian basin, which develops well below the Getic Plateau and the Oltenia Plain and which has important variations due to the granulometric constitution of the sands (ICSITPML, sb.810-537, 2012; ICSITPML, sb.820-710, 2012; MMAP, 2015).

The main exploitable lignite layers are the layers V to XII. The lower layers can not be exploited as a result of heavy and very heavy hydrogeological condition and high discovery reports (Fodor and Baican, 2011).

In the case of some mining perimeters located in the meadow area (North Peşteana, Roșia de Jiu), in order to exploit the V lignite layer, detensioning of artesian aquifer horizon was needed. This was made through free eruption boreholes. In meadow areas, generally, lignite layers V – VIII, and sometimes layers IX – X (except for South Peşteana perimeter were layers X – XII were exploited as to the south of the basin the upper layers have higher thicknesses and favorable discovery reports), are developed and can be exploited, while the upper layers (X – XII) can be found and exploited at higher levels, usually in hilly areas. Depending on mining perimeters, the exploitable lignite layers are as it follows (ICSITPML, sb.810-537, 2012; ICSITPML, sb.820-710, 2012; MMAP, 2015; ***, CEO, 2020):

- in South Peşteana mining perimeter – lignite layers X – XII;
- in Urdari mining perimeter – lignite layers X – XI;
- in North Peşteana mining perimeter – lignite layers V – VIII;
- in Roșia de Jiu mining perimeter - lignite layers V – XII;
- in Pinoasa mining perimeter – lignite layers V – XII;
- in Rovinari mining perimeter –lignite layers V – VIII.

The mixed (hilly and meadow) and hilly relief predominate in most of the mining perimeters in Rovinari. The development of deposits in the meadow area of the Jiu River, respectively in a region with aquifer horizons of impressive dimensions, has a positive influence in the conditions of restoring aquifer resources and flooding the remaining gaps, as it ensures the development of these processes naturally, without involving major financial investments. However, the presence of water in rocks is felt on the stability reserve of the slopes by increasing the volumetric weight of the rocks, reducing the resistance characteristics of the rocks (cohesion and internal friction angle), manifestation of pore water pressure and hydrodynamic pressure.

Tab. 2. Classification of open-pits and their remaining gaps in term of hydrogeological conditions
Tab. 2. Klasyfikacja wykopów i ich pozostałych luk pod względem warunków hydrogeologicznych

Classification criteria	South Pesteana		Urdari		North Pesteana		Rosia de Jiu		Pinoasa		Rovinari	
	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]	Values[1]	Class[2]
1	2	3	4	5	6	7	8	9	10	11	12	13
Hydrogeological structures	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II	Mixed open and closed structures, located above and below the local erosion base	II
Type of aquifers	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III	Deep with variable extension, with hydrodynamic connections between them and large water resources	III	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III	Deep with variable extension, with hydrodynamic connections between them and large water resources	III	Phreatic and deep with variable extension, with hydrodynamic connections between them and large water resources	III
Type of aquifer rocks	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I	Coarse to fine sands with rare elements of gravel	I
Number of aquifers	> 3 aquifers with variable extension with hydrodynamic connections between them important; inflow from Jiu river	III	> 3 aquifers with limited extension	I	> 3 multilayer aquifers with large extension, with/without hydrodynamic connections between them; inflow from Jiu river	IV	> 3 multilayer aquifers with large extension, with/without hydrodynamic connections between them; inflow from Jiu river	IV	> 3 aquifers with limited extension	I	> 3 aquifers with variable extension with hydrodynamic connections between them	III
Aquifer thicknesses	> 15 m	I	> 15 m	I	> 40 m	IV	> 40 m	IV	15 - 30	II	30	II
Piezometric pressure P [m H_2O]	50 - 150	IV	-	-	50 - 150	IV	10 - 200	IV	3.7 – 170.8	IV	50 - 150	IV
Permeability of aquifer rocks, k_f [m/day]	0.1 – 4.8	IV	0.46	IV	0.3 - 15	IV	0.1 - 10	IV	0.009 - 1	IV	0.3 - 3	IV
Transmissivity[3] T [$m^3/m^* \cdot day$]	-	IV	-	IV	-	IV	-	IV	-	IV	-	IV
Water inflow per ton extracted q [m^3/ton]	12.87	IV	-	-	12.87	IV	16.32	IV	3.7	II	5.41	III
Class[2]	III/IV		II		IV		IV		III/IV		III/IV	

1 varies on vertical and horizontal and the most unfavorable values were taken into account;
2 Class I – Open pits with simple hydrogeological conditions; Class II – Open pits with average hydrogeological conditions; Class III – Open pits with difficult hydrogeological conditions; Class IV - Quarries with complex hydrogeological conditions;
3 The calculated values of the transmissivity are dependent on the filtration coefficient and the thickness of the aquifer layers, so they indicate high/low values depending on the values of the two parameters (ICSITPML, sb. 810-537, 2012; ICSITPML, sb. 820-710, 2012).

The supply of the aquifer horizons is made with the inflow of water from the atmospheric precipitations, from the superficial waters and from the neighboring aquifer horizons where there is a hydraulic connection between them. The Rovinari mining basin is located between the Jiu (to the east) and Jilţ (to the west) rivers. The discharge of aquifers is made by natural drainage, in the southern area of Oltenia, by artificial drainage, in the dewatering systems of the exploitations, in the catchment fronts for water supply or by the ascending drainage, through the semipermeable formations. The physical-geographical conditions of the mining basins are favorable for the accumulation of significant groundwater reserves and their permanent renewal. (Vladimirescu, 1978; ***, CEO, 2020).

From one mining perimeter to another, depending on the extension of each aquifer, the number of aquifer varies. Three or more aquifers layers with variable extension and thicknesses are located in the studied areas. The main aquifers (in the region of Rovinari mining basin) are located as it follows (ICSITPML, sb.810-537, 2012; ICSITPML, sb.820-710, 2012; MMAP, 2015; ***, CEO, 2020; Nyari Apostu, 2019):

- in the bed of the lignite layer no. V with thicknesses between 21 ÷ 40 m which increases from north to south up to 70 m or even more;
- between V – VI lignite layers with thicknesses between 15 ÷ 28 m;
- between VI – VII lignite layers with thicknesses between 3,5 ÷ 31 m;
- between VII – VIII lignite layers with thicknesses between 0,3 ÷ 30 m;
- between VIII – IX lignite layers with thicknesses between 3 ÷ 15,5 m;
- between X – XII lignite layers with thicknesses between 3 ÷ 16,6 m.

Groundwater aquifers generally have thicknesses of the order of meters (with maximum thicknesses around 10 m).

Analyzing from a quantitative and qualitative point of view all the known data, the remaining gaps of the open-pits in the Rovinari mining basin were included in the proposed hydrogeological classes (Table 2). In the case of the Urdari remaining gap, the classification in the hydrogeological classes was made only on the basis of the criteria that could be defined according to the available data.

Overall, the remaining gaps of open-pits located in the Rovinari mining basin generally face difficult or complex hydrogeological conditions. Difficult and complex hydrogeological conditions are unfavorable in terms of stability during the flooding process, but are favorable in terms of water availability for natural flooding.

South Peşteana lake is flooded in a proportion of 80% (after its closure at the end of the 2015), the actual water level being maintained through dewatering boreholes and a discharge channel to protect the IInd step of the inner dump (on which are deposited the mining machineries and equipments) from submergence. The remaining gap of the South Peşteana open-pit is framed into the IIIrd/IVth class, meeting difficult and complex conditions from a hydrogeological point of view. During the flooding only the water level in the lake was monitored. During these monitoring activities, the manifestation of geotechnical phenomena was not reported, but it is possible that they occurred either underwater or above it, were not of large dimensions, so they were not taken into account. The aquifer horizon located between the lignite layers X – XII consists of sands with relatively low thickness (2–6 m, sometimes up to 10–12 m) that arise south of Cocoreni and Toporăști localities, coming in direct contact with the alluvial formations from Jiu meadow, which favors the supply of the aquifer horizon directly from the phreatic aquifers (***, CEO, 2020). The result partially confirms the real situation. Indeed, the flooding occurred naturally and in a short period of time (in about 3–4 years the gap was flooded to the current level), but geotechnical problems were not observed and several scenarios can be taken into account:

- there was no system for monitoring the stability of slopes or changes that may predict the occurrence of negative geotechnical phenomena, so that any problems observed were not recorded on any support (paper, electronic);
- no changes were observed because they appeared below water level or above it, but were insignificant, small in size;
- there were no stability problems due to the relatively rapid submergence of the slopes knowing that this situation is favorable for stability due to the manifestation of hydrostatic water pressure on the slopes (water on the slope behaves like a support prism increasing the stability reserve).

The Urdari open-pit was definitively closed in 2003. After the closure, its natural flooding began, today being 100% flooded. A discharge channel was built to take over the surplus of water in the lake, this being the main way to discharge the lake. According to the proposed classification, the remaining gap of the Urdari open-pit belongs to the II class, meeting average conditions from a hydrogeological point of view. Considering the development of the aquifer horizons in the Urdari perimeter, the supply and discharge conditions, and taking into account the fact that in this open-pit only layers X and XI, located above the local erosion base, were exploited, it appears that the flooding process can be done naturally, but it can be lasting. The conditions are favorable in terms of stability and it is unlikely that problems will occur at the final slopes during the flood. The result confirms the real situation. Before, during, and after the flooding of the remaining gap of the Urdari open-pit, no geotechnical phenomena such as landslides, suffusions, etc. were observed and the flooding produced 100% naturally.

North Peșteana and Roșia de Jiu open-pits and their remaining gaps present complex hydrogeological conditions (IV class), meaning there are needed stability works in order to increase the stability reserve of the final slopes considering the flooding of the remaining gaps. On the other hand, the hydrogeological conditions are favorable for the restoration of the aquifers resources, respectively for the natural flooding of the remaining gaps. In the case of Roșia de Jiu open-pit, at the cessation of the activity it is possible that the inner dump occupies the entire remaining gap so may not result in a pit lake.

Pinoasa and Rovinari open-pits and their remaining gaps present difficult to complex hydrogeological conditions (III/IV class), meaning that geotechnical risks may occur such as landslides as a result of manifestation of hydrodynamic pressure and occurrence of suffosion holes or of changes in the structure of fine-grained rocks. On the other hand, due to these conditions the natural flooding of the remaining gap may be ensured.

As we can see, according to the proposed classification and to the results, when favorable flooding conditions exist there may occur geotechnical problems. The classification is useful as it offers indications regarding the interventions needed to reduce or even eliminate the possible risks and the available water resources to create a pit lake.

4. Conclusions

The hydrogeologcal conditions specific to an area influence the type of restoration and reuse of the degraded mining land. To determine the hydrogeologcal conditions of an area, exploration of local geology and hydrogeology is needed consisting in studying the aquifer formations, their extension, the way of supplying and discharging them, the hydrogeological characteristics of the rocks.

Based on the proposed classification which takes into account several criteria a better classification of open pits and their remaining gaps can be made. Therefore, the flooding possibilities can be evaluated as these are the most common types of reuse of the remaining gaps of former open pits. The costs of restoration of the former open pits can be estimated in a more rigorous mode.

Generally, the open-pits and their remaining gaps located in the Rovinari mining basin are characterized by difficult to complex hydrogeological conditions which means there are needed works to increase the stability reserve of the final slopes in order to reduce the geotechnical risks that may arise, but on the other hand these conditions are favorable to natural flooding and creation of pit lakes.

As the classification is based on qualitative and quantitative analyses it ensure a rapid and quite precise response (depending on the existing data and informations and their accuracy) and indications regarding the geotechnical problems that may arise during the restoration of aquifer resources and/or during and after the flooding process, available water resources and the possibilities of flooding.

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Nowa klasyfikacja kopalń odkrywkowych i powstałych wyrobisk pod względem warunków hydrogeologicznych

Ponieważ odkrywki zajmują teren tylko tymczasowo, planowanie prac po zakońzceniu eksploatacji w celu zrównoważonego ponownego wykorzystania gruntów stanowi ważny etap i można to zrobić już na etapie przedeksploatacyjnym.

W zależności od charakteru i lokalizacji złóż rudy istnieje więcej możliwości ponownego wykorzystania dawnych wyrobisk odkrywkowych. Odkrywki węgla są często ponownie wykorzystywane jako sztuczne jeziora. W zależności od lokalnej hydrologii i hydrogeologii proces zalewania byłych odkrywek może odbywać się w sposób naturalny lub sztuczny (łączony). Ponowne wykorzystanie pozostałych odkrywek wymaga dobrej oceny możliwości i ograniczeń specyficznych dla tego obszaru.

Klasyfikacja odkrywek i pozostałych wyrobisk pod względem warunków hydrogeologicznych jest niezbędna dla lepszego planowania terenu po zakończeniu eksploatacji.

W artykule zaproponowano wielokryterialną klasyfikację odkrywek i pozostałych wyrobisk z uwzględnieniem warunków hydrogeologicznych i oddziaływania niektórych parametrów hydrogeologicznych, które mają istotny wpływ na zapełnianie wyrobiska wodą. Badane są najważniejsze warunki hydrogeologiczne regionu (budowa hydrogeologiczna, rodzaje i liczba warstw wodonośnych, charakter skał wodonośnych, charakterystyka hydrodynamiczna regionu), a wyniki są przetwarzane w celu opracowania wielokryterialnej klasyfikacji. W zależności od wyników klasyfikacji hydrogeologicznej odkrywek i pozostałych wyrobisk, można ustalić możliwość naturalnego i / lub sztucznego zalania lub przeciwnie, konieczność rozważenia innego kierunku ponownego wykorzystania. Zaproponowana klasyfikacja jest innowacyjna, ponieważ w literaturze opisano do tej pory klasyfikacji wielokryterialnej, a większość publikacji skupia się na klasyfikacji jednokryterialnej. W niniejszej pracy więcej odkrywek i wyrobisk poeksploatacyjnych przeanalizowano z hydrogeologicznego punktu widzenia i sklasyfikowano w oparciu o zaproponowaną klasyfikację uwzględniającą ocenę wielokryterialną.

Słowa kluczowe: *odkrywkowe, wyrobiska poeksploatacyjne, warunki hydrogeologiczne, klasy hydrogeologiczne, wody podziemne, dopływ*

Atmospheric Dust Pollution of the Cracow Agglomeration in the Light of Empirical Research

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Abstract

The paper presents the problem of dust pollution in the atmosphere of a typical urban agglomeration. The influence of natural and anthropogenic factors on airborne dust concentration is described. The results of air pollution tests with PM2.5 and PM10 particulate matter at five measurement points in the Cracow agglomeration are presented. The use of statistical methods has shown the relationship between airborne dust concentration and the season of the year. The highest levels of PM2,5 and PM10 dusts are recorded during the autumn and winter months. During the heating season, the municipal and household sector is mainly responsible for dust emissions. Measures to reduce emissions of air pollution from industrial sources and transportation are proposed.

Keywords: *dust, air pollution, monitoring*

Introduction

Air pollution is a growing national and global issue. The pollutants emitted into the atmosphere include dust, i.e. a mixture of suspended solids which form a dispersed phase. Aerosol particles refer to dust particles smaller than 50 µm. Dust can be classified using a number of criteria. Due to particle sizes, the following are identified: total suspended particulates TSP, fine particulate matter with particle diameter less than 10 µm PM10 and very fine particulate matter with particle diameter less than 2.5 µm PM2.5 [1].

Emission of particulates from combustion of solid fuels in central heating boilers makes Cracow one of the most polluted cities in Poland. The city is surrounded by communes where the main source of heating is domestic furnaces. Another reason for the high dust concentration is communication. The high traffic volume on narrow roads without ventilation causes exhaust emissions. Dense urban core and high-rise buildings on the suburbs also hinder the ventilation of the city. The accumulation of pollution in the Cracow agglomeration is influenced by the natural morphology of the area. Cracow is located in the Vistula valley, and the hills surrounding the city block the movement of masses of air, which makes the ventilation conditions extremely poor.

Influence of weather conditions on dust concentration in the air

The dust concentration in the air depends on the interaction of two factors: the emission of pollutants and weather conditions. Emissions are the factor that determines the occurrence of dusts in the atmosphere, while the concentration of dusts depends on weather conditions determining the transport of harmful compounds in the atmosphere [2, 3]. Atmospheric factors may affect the diversity of pollutant concentrations in the air by controlling emissions (e.g. influence of temperature on the length and intensity of the heating season, the intensity of traffic) and by influencing their distribution [4, 5]. Important meteorological parameters are the direction and speed of the wind in the lowest layer of the atmosphere. They determine the movement of air masses from neighbouring areas. The highest dust concentrations are found in the ground level of the atmosphere. During windless weather, pollutants accumulate at the place of their origin. For most substances, the higher the wind speed, the lower the concentration in the air due to the dilution of pollutants. Ventilation is particularly important during the heating season, when increased emissions from fuel combustion in domestic furnaces and motor vehicles result in dust accumulation in the city centre. The disruption of ventilation conditions specific to highly urbanised areas is a major problem, as dense number of urban buildings block natural ventilation corridors, resulting in the accumulation of dust [6–9].

An important weather factor in the Krakow agglomeration is the rain, especially rainfall. Sometimes the temperature distribution is reversed (thermal inversion phenomenon leading to accumulation of dust substances in the troposphere). It occurs during frosty and cloudless nights, which leads to a much lower temperature at the ground surface than in higher air layers. Harmful substances are retained and accumulated in the atmosphere as a result of air sedimentation.

Methods for measuring particulate matter in the air

PM2.5 and PM10 particulate matter are measured as part of the State Environmental Monitoring. The Inspection of Environmental Protection shall use two complementary methods to test the particulate matter content of air:

– the gravimetric (reference) method, considered worldwide to be the most precise;

Tab. 1. Permissible levels for particulate pollutants present in the air [11]
Tab. 1. Poziomy dopuszczalne dla zanieczyszczeń pyłowych obecnych w powietrzu [11]

Name of substance	Averaging period	Permissible level in the air in 2020 [μg/m³]	Permissible annual frequency of exceeding the level
particulate matter PM 2.5	Calendar year	20	-
particulate matter PM10	24 hours	50	35 times
	Calendar year	40	-

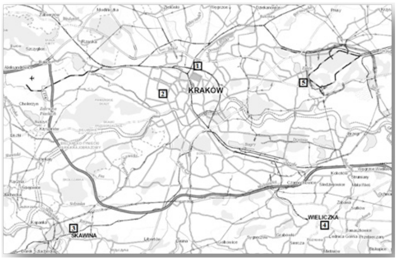

Fig. 1. The location of the test stations [13]: 1. 29 Avenue Listopada, 2. AGH University of Science and Technology, 3. Nowa Huta, 4. Skawina, 5. Wieliczka
Rys. 1. Lokalizacja stanowisk badawczych [13]: 1. aleja 29 Listopada, 2. Akademia Górniczo-Hutnicza, 3. Nowa Huta, 4. Skawina, 5. Wieliczka

– the automatic method, equivalent to the reference method.

The gravimetric method involves the use of aerosol samplers to which air is sucked in. Every 14 days, 14 disposable filters are placed in the sampler, which are changed automatically every 24 hours. Each of these filters is weighted before and after the measurement. The differences between the initial and final masses, related to the volume of air in the device, illustrate the particulate concentrations expressed in micrograms per cubic metre (μg/m³). The gravimetric method shows great accuracy. The only disadvantage of this method is that it takes about weeks to obtain results. At present, in Poland, measurements are performed with this method on 70 PM2.5 and 180 PM10 particle matter monitoring stations.

The automatic meters indicate the dust concentration in real-time so that the measurement results are displayed at the websites of the Inspection of Environmental Protection (Chief Inspectorate of Environmental Protection (GIOŚ) and Voivodeship Inspectorate for Environmental Protection (WIOŚ)). The data is updated on an hourly basis and translated into 24-hour average values for comparison with the permissible level. Measurements using the automatic method are carried out in Poland on 45 PM2.5 and 135 PM10 particle matter monitoring stations.

Particulate matter concentration standards

The permissible level, or air quality standard [10], is the concentration of a substance that can be reached in a given period of time and should not be exceeded after that time.

The information level is the level of the substance in the air above which there is a risk to human health from brief exposure to pollutants of vulnerable population groups. The information level for PM2.5 is 150 μg/m³, the averaging period is 24 hours, the information level for PM10 is 100 μg/m³, the averaging period is 24 hours [11]. The alarm level is the concentration of a substance in the air which, if exceeded in the short term, could cause a hazard to human health [12].

Research section

Methodology and research procedures

The research aimed to determine the concentration of particulate matter in selected strategic points of the urban agglomeration and to indicate whether there are relationships between the season of the year and the concentration of PM2.5 and PM10 in the air. The research was carried out at five measurement points in the Cracow agglomeration:

- 29 Avenue Listopada (one of the most important communication routes in Kraków),
- AGH University of Science and Technology (proximity of the thoroughfare),
- Nowa Huta, T. Ptaszyckiego street (proximity of industrial plants),
- Skawina (a commune included in the agglomeration),
- Wieliczka (a commune included in the agglomeration).

Figure 1 shows the location of the test stations.

The research was carried out in one month of each season: September 2019, November 2019, February 2020 and April 2020. They were performed for 15 days each month, twice a day: in the morning and in the evening. To measure the level of PM2,5 and PM10 particulate matter, a dust measurement device WP 6130 was used, additionally equipped with air temperature and humidity detectors.

Test results and discussion

Table 2 shows the minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on 29 Avenue Listopada.

At the measurement point located on 29 Avenue Listopada (Table 2), the highest PM2.5 level, amounting to 113 μg/m³, occurred on 28 November at 8:40 pm. The lowest value of PM2.5, equal to 1 μg/m³, occurred on 10 September and 14 September in the morning. The highest level of PM10 was also recorded on this station on 28 November at 8:40 pm: it amounted to 120 μg/m³. The lowest level of PM10 of 2 μg/m³ occurred on 10 September and 14 September.

Tab. 2. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on 29 Avenue Listopada
Tab. 2. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego przy alei 29 Listopada

	maximum measured concentration values of PM2.5 [µg/m³]	**minimum measured concentration values of PM2.5 [µg/m³]**	**maximum measured concentration values of PM10 [µg/m³]**	**minimum measured concentration values of PM10 [µg/m³]**
29 Avenue Listopada	113 (28 XI 2019)	1 (10 IX i 14 IX 2019)	120 (28 XI 2019)	2 (10 IX i 14 IX 2019)

Tab. 3. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on AGH
Tab. 3. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego przy Akademii Górniczo-Hutniczej

	maximum measured concentration values of PM2.5 [µg/m³]	**minimum measured concentration values of PM2.5 [µg/m³]**	**maximum measured concentration values of PM10 [µg/m³]**	**minimum measured concentration values of PM10 [µg/m³]**
AGH University of Science and Technology	127 (28 XI 2019)	2 (14 IX 2019)	139 (28 XI 2019)	3 (14 IX 2019)

Tab. 4. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on Skawina
Tab. 4. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego Skawina

	maximum measured concentration values of PM2.5 [µg/m³]	**minimum measured concentration values of PM2.5 [µg/m³]**	**maximum measured concentration values of PM10 [µg/m³]**	**minimum measured concentration values of PM10 [µg/m³]**
Skawina	117 (15 II 2020)	6 (9 IX 2019)	120 (15 II 2020)	8 (9 IX 2019)

Tab. 5. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on Wieliczka
Tab. 5. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego Wieliczka

	maximum measured concentration values of PM2.5 [µg/m³]	**minimum measured concentration values of PM2.5 [µg/m³]**	**maximum measured concentration values of PM10 [µg/m³]**	**minimum measured concentration values of PM10 [µg/m³]**
Wieliczka	111 (15 II 2020)	2 (9 IX i 10 IX 2019)	127 (27 XI 2019)	3 (10 IX 2019)

Tab. 6. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on Nowa Huta
Tab. 6. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego Nowa Huta

	maximum measured concentration values of PM2.5 [µg/m³]	**minimum measured concentration values of PM2.5 [µg/m³]**	**maximum measured concentration values of PM10 [µg/m³]**	**minimum measured concentration values of PM10 [µg/m³]**
Nowa Huta	128 (28 XI 2019)	3 (2 IX i 14 IX 2019)	142 (28 XI 2019)	5 (6 IX 2019)

At the measurement point located on AGH University of Science and Technology (Table 3), the highest PM2.5 level, amounting to 127 µg/m³, occurred on 28 November at 9:00 pm. The lowest value of PM2.5, equal to 2 µg/m³, occurred on 14 September at 11:16. The highest level of PM10 was also recorded on this station on 28 November at 9:00 pm: it amounted to 139 µg/m³. The lowest level of PM10 of 3 µg/m³ occurred on 14 September.

At the measurement point located on Skawina (Table 4), the highest PM2.5 level, amounting to 117 µg/m³, occurred on 15 February at 10.21 pm. The lowest value of PM2.5, equal to 6 µg/m³, occurred on 9 September at 6:10 pm. The highest level of PM10 was also recorded on this station on 15 February at 9:51 pm: it amounted to 120 µg/m³. The lowest level of PM10 of 8 µg/m³ occurred on 9 September at 6:10 pm.

At the measurement point located on Wieliczka (Table 5), the highest PM2.5 level, amounting to 111 µg/m³, occurred on 15 February at 11.27 pm. The lowest value of PM2.5, equal to 2 µg/m³, occurred on 9 September and on 10 September. The highest level of PM10 was also recorded on this station on 27 November at 7:04 pm: it amounted to 127 µg/m³. The lowest level of PM10 of 3 µg/m³ occurred on 10 September at 1:42 pm.

At the measurement point located on Nowa Huta (Table 6), the highest PM2.5 level, amounting to 128 µg/m³, occurred on 22 November at 10:40 pm. The lowest value of PM2.5, equal to 3 µg/m³, occurred on 2 September and on 14 September. The highest level of PM10 was also recorded on this station on 28 November at 10:40: it amounted to 42 µg/m³. The lowest level of PM10 of 5 µg/m3 occurred on 6 September at 10:28 am.

The analysis of the test results shows that the highest concentrations of PM2.5 and PM10 occurred in the autumn month at AGH and Nowa Huta and in the winter month in

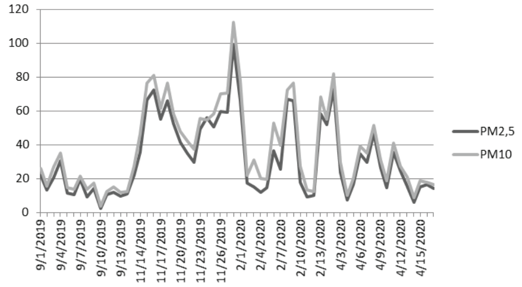

Fig. 2. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on 29 Avenue Listopada (in μg/m³)
Rys. 2. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: aleja 29 Listopada (w μg/m³)

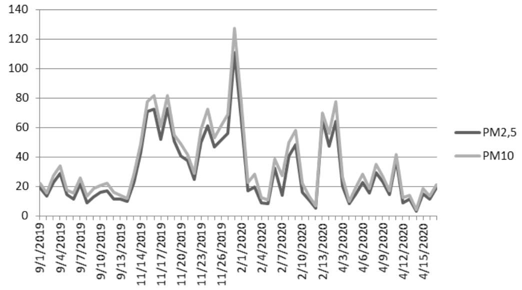

Fig. 3. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on AGH (in μg/m³)
Rys. 3. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: AGH (w μg/m³)

Skawina and Wieliczka. The heating season, which begins in the autumn, is a major contributor to dust emissions. The lowest dust concentrations occurred in the summer month when the air temperature does not require heating of buildings.

In order to determine the number of days on which the daily permissible, information and alarm level has been exceeded, the daily average concentration of particulate matter has been calculated (Figures 2-6).

The lowest concentrations of dust in the air occurred in September and April. The PM10 permissible level was exceeded 11 times in November, 7 times in February and one time in April. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 34 times. The information level was not exceeded.

The PM10 permissible level was exceeded 11 times in November and 5 times in February. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 30 times. The information level was not exceeded.

The PM10 permissible level was exceeded 5 times in November and 3 times in February. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 38 times. The information level was not exceeded.

The PM10 permissible level was exceeded 9 times in November, 3 times in February and one time in April. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 39 times. The information level was not exceeded.

The PM10 permissible level was exceeded 10 times in November, 2 times in February and one time in April. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 34 times. The information level was not exceeded.

The statistical analysis

For the statistical analysis of the PM2.5 and PM10 measurements, a non-parametric chi-square test was used to investigate the relationship between the variables [14]. The χ2 test consists of comparing the observed values with the theoretical values. The major differences between them means that there is a correlation between the parameters tested. The correlation between the level of particulate matter concentration in the air and the time of year at each test station was studied. The dust level was classified as low for the particulates <30 μg/m3, as average for the values in the range 30–60 μg/m³ and as high for the values above 60 μg/m³.

According to the measurement data from 29 Avenue Listopada station, the test results are as follows: $\chi^2_{PM2,5} = 80,6$, $\chi^2_{PM10} = 59,1$. For the six degrees of freedom, the critical value for the significance level α = 0.05 shall be: $\chi^2_{teor.} = 12,6$ (Figure 7).

A comparison of the calculated value for PM2.5 and PM10: 80.6>12.6; 9.1>12,6, allowed for the rejection of the hypothesis that there is no correlation between the season and the level of dust: $\chi^2_{PM2,5} > \chi^2_{teor.}$ $\chi^2_{PM10} > \chi^2_{teor.}$. The probability of making the type I error is p = 0.000 (p < α). The hypothesis that there is no difference between the variables must be rejected. At a significance level of α= 0.05 it is assumed that there is a statistical relationship between the season and the dust concentration in the air. It was found that the concentrations of particulate matter in autumn and winter are statistically significantly higher than those in the summer. The calculated test value for each measurement point (AGH University of Science and Technology, Skawina, Wieliczka, Nowa Huta) is greater than the critical value, there-

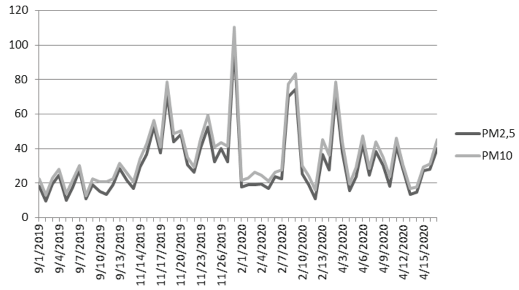

Fig. 4. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on Skawina (in μg/m³)
Rys. 4. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: Skawina (w μg/m³)

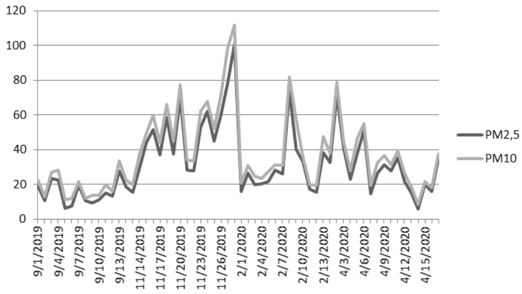

Fig. 5. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on Wieliczka (in μg/m³)
Rys. 5. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: Wieliczka (w μg/m³)

fore the hypothesis of no correlation between variables was rejected.

The analysis of the test results shows that the highest concentrations of particulate matter occurred in the autumn and winter months at each measuring point and the lowest in summer. The highest particulate concentration was recorded on 28 November 2019 in Nowa Huta in ulica Tadeusz Ptaszycki. The concentration of PM2.5 was 128 μg/m³ and PM10 amounted to 142 μg/m³. The lowest value of particulate matter was recorded on 10 September 2019 and 14 September 2019 on 29 Avenue Listopada. The concentration of PM2.5 was 1 μg/m³ and PM10 amounted to 3 μg/m³. After conducting a statistical test and comparing the observed values with the theoretical values, it was found that there are close correlations between the dust concentration in the air and the season of the year.

The research part also includes calculation of the daily average concentration of particulate matter by means of an arithmetic mean of the two measurements per day in order to determine the number of days when the 24-hour average permissible, information and alert levels were exceeded. At each of the stations, the permissible level for PM10 and PM2.5 has been exceeded several times, and the alarm level for PM10 has not been exceeded at any of them.

Discussion and summary

The heating season responsible for dust emissions begins in autumn and winter due to low air temperatures. Single-family and multi-apartment residential buildings lack high chimneys, which results in the emission of pollutants at low heights. As a result, instead of diluting in the atmosphere, local concentrations of pollution in the air increase. One of the main sources of air pollution are individual households and local boiler houses. Coal fired furnaces are characterized by low efficiency and significant dust emissions. In order to reduce the emission of harmful pollution into the atmosphere, it is necessary to modernize the heating system. Attention should be paid to the type and quality of fuel: coal-fired boilers should be replaced by gas, oil or electric ones. Pellet-fired boilers also provide a good solution [15]. However, the aforementioned measures are very expensive, and numerous people cannot afford them. Increasing public awareness and influencing the change of habits regarding the use of fuels in furnaces is extremely important. Financial support is needed for the municipal and household sector (e.g. subsidies for the replacement of furnaces), as well as the imposition of severe penalties for household waste incineration (plastic bottles, tyres, old furniture).

Motor vehicles are to a great extent responsible for particulate emissions [16, 17]. They emit exhaust fumes and wear road surfaces, tyres and brake pads. To reduce traffic, it is worth encouraging city residents to use public transport by introducing cheaper tickets or free journeys. Separate lanes for public transport constitute a useful solution. Another possibility is the development of the cycling infrastructure and investment in bike rentals.

In the industrial sector, the best available technologies should be identified in order to reduce dust emissions [18, 19]. Air protection should be implemented by taking measures to reduce dust emissions at source or by capturing them. One of the solutions allowing for the minimisation of particulate emissions is the air-tightening of processes consisting in the use of covers and seals on technological equipment. In order to reduce emissions, industrial plants should also deploy efficient electrostatic precipitators and chimney filters. The construction of insulating green belts around industrial plants will allow for a partial reduction in the dust dispersion [20].

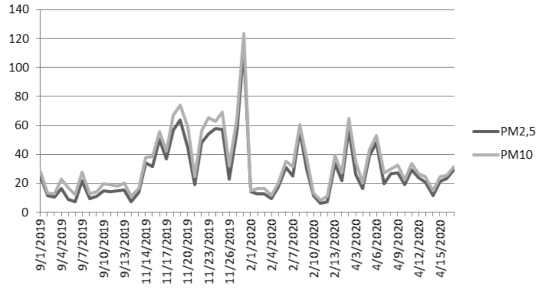

Fig. 6. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on Nowa Huta (in μg/m³)
Rys. 6. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: Nowa Huta (w μg/m³)

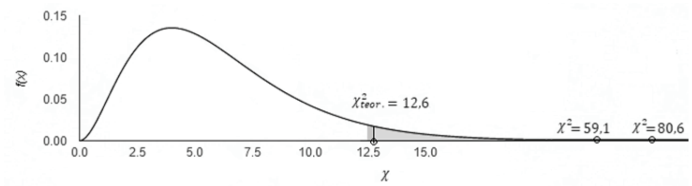

Fig. 7. Chi-square test for PM2,5 i PM10. The measurement point on 29 Avenue Listopada
Rys. 7. Test Chi-kwadrat dla PM2,5 i PM10. Punkt pomiarowy: aleja 29 Listopada

Poland has the highest level of dust in the atmosphere among European countries. Both ordinary citizens and public officials should be aware of the scale of the problem. The impact of polluted air affects all of us, so minimising emissions should become our joint responsibility.

Author Contributions

Karolina Skotnicka (K.S.) did the data collection and result analysis. Wiktoria Sobczyk (W.S.) conceived, designed the search, wrote the paper and result analysis. Both authors have read and approved the final manuscript.

Conflict of interest statement

The authors declare no conflict of interest.

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Zanieczyszczenia pyłowe atmosfery aglomeracji krakowskiej w świetle badań empirycznych

Artykuł prezentuje problem zanieczyszczenia pyłowego atmosfery typowej aglomeracji miejskiej. Opisano wpływ czynników naturalnych i antropogenicznych na stężenie pyłów w powietrzu. Przedstawiono wyniki badań zapylenia powietrza cząstkami PM2,5 i PM10 w pięciu punktach pomiarowych aglomeracji krakowskiej. Przy zastosowaniu metod statystycznych wykazano zależność między stężeniem pyłu w powietrzu a porą roku. Największe stężenia pyłów PM2,5 i PM10 obserwuje się w miesiącach jesiennych i zimowych. W sezonie grzewczym za emisję pyłów odpowiedzialny jest głównie sektor komunalno-bytowy. Zaproponowano sposoby ograniczenia emisji zanieczyszczeń atmosfery ze źródeł przemysłowych i transportu.

Słowa kluczowe: *pyły, zanieczyszczenie powietrza, monitoring*

Application of Control Automation and Energy Management Programs in the Energy Audit of the Company

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Abstract

The Energy Efficiency Act and the resulting notice of the Minister of Energy of 23 November 2016. "on a detailed list of energy efficiency improvement projects predicts "installation of measuring and control equipment, teletransmission equipment and automation in the implementation of energy management systems" as one of the methods of improving energy efficiency. Using specific examples of energy audits carried out by the author, this article demonstrates how such a solution can improve energy efficiency in the buildings of companies from various industries and what conditions must be met by such a system in order to operate efficiently.

Keywords: *energy efficiency, energy auditing, energy management programs*

Introduction

The Energy Efficiency Act of 20.05.2016 [5] imposes an obligation for large companies to carry out an energy audit once every 4 years. Since this obligation was first required from 30.09.2017, companies should perform the audit again next year. Experience from previous audits shows that auditors most often recommended to companies basic upgrades, such as: thermomodernization of buildings (e.g. office buildings, factory halls), replacement of lighting with LED, replacement of district heating or heat sources, use of RES (e.g. photovoltaics). In the current audit period, there are two possible cases:

1. If a company has implemented the recommendations, new, energy-efficient and economically justified methods of saving energy should be identified.

2. If the recommendations have not been implemented, it is worth taking a second look at them and take into account further factors that will lead to the proposed actions leading to the most optimal use of energy in the new audit.

Energy savings in buildings

Let's start by considering how one can reduce energy consumption in buildings. Many companies have buildings: offices, production, service, warehouses, stores. There are also, hotels, holiday homes, etc. The essential condition is that the building is large, with a large area and volume and, consequently, a sufficiently high energy consumption for heating, cooling, lighting. Applying these recommendations to a small building such as a gatehouse, a small shop or a detached house would not produce the expected results.

Application of weather-based regulation

Weather-based regulation of a heat source e.g. gas boiler, heat pump or heat node is well known, although seldom used. An obvious advantage is the ability to set the temperature of the heating circuit to the current outside temperature. The first benefit of this approach is to reduce overheating of rooms due to the use of too much heating power. For example, if the controller detects an increase in the outside temperature, it will begin to reduce the heating power. This saves energy while maintaining full thermal comfort. Otherwise, overheating the room as a result of not accounting for the increase in the outside temperature will cause, in addition to increasing energy consumption, discomfort to the user of the overheated room. Another important advantage of this method is that users can pay less attention to the heating, and it is very important. Adjusting the heating curve to your current needs allows the heating device to run longer at lower inlet and return temperatures of the space heating installation. In the case of heat pumps, working with a lower supply temperature increases the COP of the heat pump and thus reduces the consumption of electricity or gas (in the case of gas-powered heat pumps) to provide the same amount of heat. Table 1 shows the differences:

As you can see from the examples cited in the table, skilful control of the heat pump can produce savings of several percent energy. A similar example for more commonly used (than heat pumps) condensing gas boilers is given in Table 2.

Improving efficiency by a few percent may seem insignificant compared to Table 1 data, but for large energy values produced during the heating season, an improvement by a few percent can mean big savings in both energy and its cost. However, it is worth noting here that most weather controllers produced and sold with heating devices operate on the principle of fixed heating curve settings usually introduced by the service installing another heating device e.g. boiler. Installation companies usually set high heating parameters, because then they have no problems with the complaint that the device does not heat up.

The efficiency of the heating device is reduced, because by implementing such a poorly selected heating curve, the controller quickly forces the heating device to obtain high temperatures outside the range of optimal efficiency. It is rare for a user who engages in self-selected parameters of the heating curve. This is not easy, as it also depends on a few factors such as the thermal capacity of the building, internal and so-

Tab. 1. Efficiency of heat pumps according to the Regulation[3]
Tab. 1. Sprawność pomp ciepła zgodnie z rozporządzeniem [3]

Type of heat pump	COP		Efficiency improvement
	55/45°C	35/28°C	%
glycol/water heat pump type, compressor, electrically powered	3,5	4,0	14,3
air/water, compressor, electrically powered	2,6	3,0	15,4
glycol/water, absorption , gas-powered	1,4	1,6	14,3
air/water, absorption, gas-powered	1,3	1,4	7,7

Tab. 2. Average efficiency of condensing gas boilers according to the Regulation [3]
Tab. 2. Średnia sprawność gazowych kotłów kondensacyjnych zgodnie z rozporządzeniem [3]

Condensing gas boiler power	Efficiency		Efficiency improvement
kW	70/55°C	55/45°C	%
less then50	0,9	0,9	3,3
from 50 upto120	0,9	1,0	3,3
from 120 upto 1200	0,95	0,98	3,2

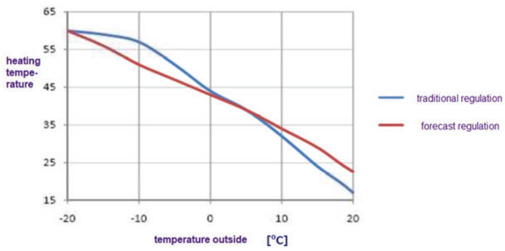

Fig. 1. Comparison of traditional and forecast adjustment [6]
Rys. 1. Porównanie korekty tradycyjnej i prognozy [6]

lar profits. Therefore, this often needs to be corrected several times before optimal operating parameters are set. However, since most users do not do this, one of the energy audit recommendations that can be implemented without investment costs is to adjust the weather controller settings.

Implementing of forecast regulation

Forecast regulation is a method of regulating heating more efficiently than the previously described weather regulation. Additional savings are achieved by predicting weather changes based on its 5-day forecast. This allows one to better adjust the heating level to weather changes. At the same time, so-called climate regulators are installed in the building, whose task is to record changes in temperature and humidity in heated rooms. This makes it possible to estimate some of the building's parameters, such as thermal capacity and take it into account in further calculations of the amount of energy and heating power required by the building. An example of such a solution is E-Gain.

Savings are achieved both during the period when the outside temperature rises and when it decreases. During the period of increase in external temperature, the heat demand of the building decreases. The weather controller will only react once the change has been recorded by the weather controller. By having this information, the forecast controller can limit the heating in advance so that, using the thermal capacity of the building, the temperature of the heated rooms is kept constant. As a result, the weather controller will first lead to a slight overheating of the room, and then significantly and quickly reduce the heating when a change is detected. The forecast controller will smoothly and slowly reduce the temperature of the heating circuit, having a longer time to change parameters (the forecast is ahead of the measurement data from the temperature sensor). In the case of condensing gas boilers and heat pumps, this control will allow them to work in conditions close to optimal conditions and thus increase their efficiency.

When the outside temperature drops, the mechanism is similar. The weather controller will react when the outdoor temperature sensor is changed. If it cools down rapidly to prevent the building from cooling down quickly, the controller will raise the inlet temperature of the space heating installation. This in turn, will ensure that the efficiency parameters of condensing gas boilers and heat pumps are again outside the optimal range. The forecast regulation will result in the possibility of early accumulation of energy, using the thermal capacity of the building (and energy in the space heating buffer, if any) and thus, will again last longer the possibility of operation of condensing gas boilers and heat pumps under conditions of optimal efficiency.

Examples of practical implementations of the aforementioned mechanism presented at [8] show that the actual measured reductions in energy consumption through the use of forecast regulation ranged from 10% to around 17% of previous energy consumption. The practice of the author of energy audits of buildings and enterprises shows that the use of heating control automation based on forecast regulation is an action that bring short payback times.

Example: An office building in Warsaw consisting of 8 storeys above ground and 1 underground is powered by urban

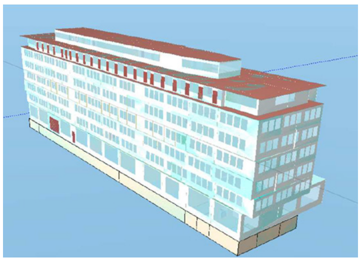

Fig. 2. Office building in Warsaw
Rys. 2. Budynek biurowy w Warszawie

Tab. 3. Examples of calculations of options for upgrading space heating installations including forecast regulation and precise indoor temperature control
Tab. 3. Przykłady obliczeń opcji modernizacji instalacji ogrzewania pomieszczeń, w tym regulacji prognozowanej i precyzyjnej regulacji temperatury wewnętrznej

Pos.	Type of improvement	Efficiency factors							
		Existing state	New variant						
			W1	W2	W3	W4	W5	W6	W7
1	heat generation	$\eta_{H,g}$ = 0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99
2	heat transmission	$\eta_{H,d}$ = 0,90	0,90	0,90	0,90	0,95	0,91	0,95	0,91
3	regulation and use of heat	$\eta_{H,e}$ = 0,88	0,88	0,93	0,89	0,93	0,89	0,93	0,89
4	heat accumulation	$\eta_{H,s}$ = 1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
5	total efficiency of the system	$\eta_{H,tot}$ = 0,78	0,78	0,83	0,79	0,87	0,80	0,87	0,80
6	taking into account heating breaks during the week	w_t = 1,00	1,00	0,93	0,93	0,93	0,93	0,93	0,93
7	taking into account the heating breaks during the day	w_d = 1,00	1,00	0,95	0,95	0,95	0,95	0,95	0,95

Evaluation of the proposed project

Pos.	Description	jedn.	Existing state	New variant						
				W1	W2	W3	W4	W5	W6	W7
1	Total efficiency of the heating system η_{tot}	-	0,78	0,78	0,83	0,79	0,87	0,80	0,87	0,80
2	taking into account heating breaks during the week w_t	-	1,00	1,00	0,93	0,93	0,93	0,93	0,93	0,93
3	taking into account the heating breaks during the day w_d	-	1,00	1,00	0,95	0,95	0,95	0,95	0,95	0,95
4	Cost savings	Plz/rok		2 151,95	23 030,97	16 172,55	29 258,72	17 951,46	29 258,72	17 951,46
5	Cost of the project N_H	PLz		12 201,00	945 324,78	220 701,49	3 359 887,34	453 390,29	3 342 601,37	451 724,46
6	SPBT	years		5,7	41,0	13,6	114,8	25,3	114,2	25,2

network heat. Building area is 6,915.0 m2, volume – 30,942.0 m3. Heat demand is approx. 0.9 MW and the energy demand for heating in heating season is 3,244.6 GJ.

Analysis of options for modernization of the heating system shows that in this operation the shortest return time gives the preservation of the existing heat node, while using forecast automation of the control of the work of thespace heating installation. The following table shows the variant W1, demonstrating a simple return on investment of 5.1 years:

The aforementioned Regulation (Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej) shows the effect of the way in which indoor temperatures are regulated on the efficiency of heating regulation:

The efficiency values shown Table 4 refer to the most popular water heating system.

Energy management program referring the space heating

Maximum efficiency of using internal heat sources

By using the right algorithms and obtaining data from multiple sources, the energy management program can combine the advantages of forecast regulation and precise regulation of room temperature to achieve maximum savings. An important feature of the enterprise's energy management program is access to extensive data from different areas of the company's operations at the same time, allowing for further savings.

Normally programs calculating the space heat of buildings assume average value of internal heat sources. Adaptive controllers with a proportional-integrating calculators operate in the similar way. Therefore, such solutions work well in large buildings whose internal profits do not appear to be subject to significant fluctuations. Such buildings can be exemplified by houses in multiple occupancy, schools during their working periods, nursing homes, offices etc. Even in buildings such as schools or offices the level of internal profits is subject to daily fluctuations. However, the working hours of a school or office are set and can be easily taken into account to create a suitable hourly and weekly schedule.

This method will not work in the case of e.g. production buildings where internal profits from production facilities can make a significant contribution to covering the losses of ventilation heat and through building partitions. At the same time, due to the variable load on the production plant, and since each part of the production cycle requires the involvement of a different energy, the value can vary considerably.

The author performed energy audits in companies where the share of internal profits was at 50%, or even close to 100% of the thermal losses of the building. Each reduction in the level of production significantly affected the demand for power for heating the building. In this case, setting the heating power parameters based only on the outside temperature will not work. This will cause the heating equipment to work frequently for short periods of time, but with too much power, losing the efficiency opportunities shown in Tables 1 and 2.

Some heating devices have adaptive controllers, which eliminates the problem, because the controllers "learn" the parameters of the building e.g. thermal capacity, on the basis of conversion, what temperature increases were achieved in previous periods, at a given outside temperature. This allows

Tab. 4. Improvement of efficiency due to precise adjustment of the installation of space heating [3]
Tab. 4. Poprawa wydajności dzięki precyzyjnej regulacji instalacji ogrzewania pomieszczeń [3]

Water heating with member or plate heaters in case of adjustment	Regulatory efficiency	Efficiency improvement %
Central without automatic local adjustment	0,77	0
Automatic local	0,82	6,49
Central and local with thermostatic valve with proportional action with proportional range P - 2K	0,88	14,29
Central and local with proportional and integrating valve with proportional action with proportional range P - 1K central and local with pi proportional-integrating valve with adaptive and optimization functions	0,89	15,58
Central and local with PI proportional-integrating valve with adaptive and optimization functions	0,93	20,78

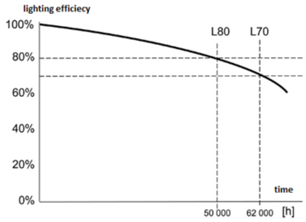

Fig. 3. Decrease in LED performance during operation [9]
Rys.3. Spadek wydajności diod LED podczas pracy [9]

the user to be relieved of the need to adjust the heating curve and works well in buildings with stable parameters mentioned earlier. In production buildings, calculating the average of previous periods does not always work, because current production may increase or fall significantly, as had happened during the pandemic.

In production buildings, only a well-configured energy management system, which has power readings of the currently operating equipment in the building, and not only the outside temperature, will allow for the correct selection of heating power and thus the inlet temperature to the space heating system. So as not to lose thermal comfort, ensure the longest possible operation of heating equipment in optimal thermal efficiency parameters.

The power management program, by knowing how many devices work on production and at what power, can know the level of internal profits immediately after turning them on. This information allows it to react before the heat from the production machines starts to be felt, as in the case of forecast regulation, the regulator is prepared for conditions that are yet to occur. This will allow one to increase the heating capacity with a decrease in the power currently used in production and a decrease when this power increases. The adaptive heating controller does not have this information and will only react to the change in room temperature when it is noticeable. Thanks to this, the energy management program will be better able to use the possibilities of improving the efficiency of heating devices than with the above-described control systems depending on the inlet temperature to the space heating system presented in Tables 1 and 2.

Lighting control

In most of the cases under consideration, the modernisation of lighting amounts to the replacement of luminaires or light sources with LEDs. On the other hand, Regulation [2] (in paragraph 3(1) requires "indication of the technically acceptable and economically justified types and variants of the energy efficiency improvement project, taking into account the use of different technologies". One of the alternative solutions for the use of LED luminaires is the selection of LED light sources, but with the possibility of controlling the light intensity e.g. by regulating the current flowing through the light source and applying automatic lighting regulation in the energy management program.

In order to be able to dynamically control the lighting level, light level sensors must be installed at the workstations and combined with an energy management programme which can dynamically adjust the level of the artificial light flux according to the amount of natural light in order to maintain the required level of illumination but limit its overrun. The energy management program also eliminates energy losses due to aging of the light source. Typically, new luminaires have a higher light flue within the range of light than is required to ensure the right level of illumination, as the efficiency of light emission decreases over many years of operation and the lighting must meet the standards throughout its working life. This is illustrated by the chart below. Limiting the power of the luminaires so that the light flue is at the required level, and no more will save energy during most of the time from the expected service life.

If the decrease in efficiency of up to 80% is taken as the lifetime (graph is 50,000h), it means that to ensure that the standard is met throughout its life, a light source must be chosen so that 80% of its effectiveness is sufficient for this purpose. The consequence of this, in turn, is the fact that most of the working time the source gives a higher beam of light than is required. It can therefore be reduced to the level of the norm, thereby reducing its power, and thus saving energy. An additional condition is the use of light sources, the intensity of which can be adjusted. Such solutions occur among LED light sources, but this must be taken into account when buying.

Savings can be estimated from standard PN-EN 15193:2010P: "Energy performance of buildings – Energy requirements for lighting. The standard contains an array in

Tab. 6. Maximum values of electricity consumption indicators for lighting (according to PN-EN 15193:2010P)[10]
Tab. 6. Spadek wydajności diod LED podczas pracy [9]

Comparative values and criteria for the design of lighting in buildings								
Type of building	lighting level	Pem [kWh/m2·rok]	Ppc [kWh/m2·rok]	PN [W/m2]	No cte illuminance		With cte illuminance	
					LENI	LENI	LENI	LENI
					Limit value		Limit value	
					Manual	Auto	Manual	Auto
					[kWh/m2×rok]		[kWh/m2×rok]	
office	*	1	5	15	42,1	35,3	38,3	32,2
	**	1	5	20	54,6	45,5	49,6	41,4
	***	1	5	25	67,1	55,8	60,8	50,6
school	*	1	5	15	34,9	27,0	31,9	24,8
	**	1	5	20	44,9	34,4	40,9	31,4
	***	1	5	25	54,9	41,8	49,9	38,1
hospital	*	1	5	15	70,6	55,9	63,9	50,7
	**	1	5	25	115,6	91,1	104,4	82,3
	***	1	5	35	160,6	126,3	144,9	114,0

Tab. 7. Return time of lighting upgrades in two variants
Tab. 7. Czas zwrotu ulepszeń oświetlenia w dwóch wariantach

Pos.	Description	Units	Existing sate	Variant 1	Variant 2
1.	Unit power of primary lighting fixtures in building P_N	W/m^2	5,63	2,32	2,32
2.	Time of use of primary lighting during the day t_D	h	4 468	4 468	4 468
3.	Time of use of primary lighting during the night t_N	h	1 372	1 372	1 372
4.	Factor that takes into account the reduction in illuminance to the level required F_c	----	1,00	1,00	0,93
5.	Factor taking into account the absence of users in the workplace F_o	----	1,00	1,00	0,80
6.	Współczynnik uwzględniający wykorzystanie światła dziennego F_D	-----	1,0	1,0	0,80
7.	Leni numerical light energy indicator LENI	kWh/m^2*year	32,9	13,6	8,6
8.	Annual demand for final energy supplied to the building for the built-in lighting system $Q_{kL} = A_f \cdot$ LENI	kWh/year	139 178,9	57 465,6	36 213,0
9.	Annual final energy savings after ΔQ_{kL} lighting system upgrade	kWh/year		81 713,3	102 965,9
10.	Cunit Unit Electricity Charges C_{unit}	Plz/kWh	0,25154		
11.	Annual variable costs of electricity consumption for built-in lighting K	Plz/year	35 009,06	14 454,90	9 109,01
12.	Annual savings in electricity consumption costs for lighting Δ_{QK}	Plz/year		20 554,16	25 900,04
13.	Cost of upgrading the lighting system N_U	Plz		20 842,36	132 775,96
14.	Simple pay back time SPBT	years		1,0	5,1

which indicators are placed for the lighting of particular types of buildings"[10].

For example, for a good level of lighting in the office (in Table 3), using automation, one can reduce the LENI factor, i.e. the annual amount of kWh of energy per lighting 1 m^2 from 67.1 to 50.6 . This represents (67.1-50.6) 67.1 = 24.59%, or about a quarter of the additional electricity savings for lighting. There is no doubt that in the future, as electricity prices rise, systems using automation will become more common. Currently, due to the high cost of controlled LED and

Fig. 4. Principle of operation of the light-emitable tube [11]
Rys. 4. Zasada działania rurki emitującej światło [11]

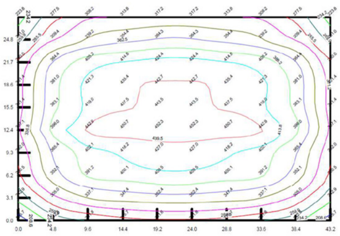

Fig. 5. Results of the simulation of the light intensity from light pipes in a sports hall[7]
Rys. 5. Wyniki symulacji natężenia światła światłowodów w hali sportowej [7]

the implementing elements of the energy management program, the payback times of such an investment are most often longer than standard solutions.

An example is show in Table 7:

Variant W1 is standard LED luminaires without control, W2- with the automatic control described above. Further increasing energy savings would combine automatic lighting adjustment technology with skylights or light pipes. Light pipes are a better option because, thanks to the lens at the top of the roof, concentrated solar radiation enters the tube. The high reflectivity allows one to transfer this light up to several meters, limiting losses to a minimum. At the same time, small dimensions in relation to the skylight reduce heat loss, as always the coefficient of heat transfer through the window or skylight is greater than through the ceiling insituated in accordance with the requirements of the Regulation.

An example of the use of light pipes in the hall is shown in the figure below. These are the results of simulation of the level of lighting of the hall in autumn-winter conditions. During the summer, the projected results will be about 2 times higher.

The introduction of solar energy into the lighting of the hall using light pipes is an example of the use of renewable energy, which is the sun. As you can see from the example, the use of solar energy to save electricity does not always have to be based on photovoltaics. However, maximum savings can only be achieved when we apply automatic lighting adjustment in the energy management program, as no attempt at manual adjustment can be just as effective with varying levels of sunlight.

Recapitulation

The use of an energy management program will allow for the best management of energy for heating. The solution proposed by the author to control the heating not only on the basis of the forecast method and reading of the regulators in the premises, but the pledging of information from production equipment to calculate internal profits in advance, will bring additional energy savings compared to the best systems currently in use. Real automatic control of heating, lighting is a guarantee of return on investment in the energy management program. This control also offers significant energy savings. Further in-depth analysis of energy consumption on the basis of data from the energy-managed programme can lead to further significant savings.

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Zastosowanie automatyki sterowania i programów do zarządzania energią w audycie energetycznym przedsiębiorstwa

Ustawa o efektywności energetycznej i wynikające z niej obwieszczenie Ministra Energii z dnia 23 listopada 2016 r. "w sprawie szczegółowego wykazu przedsięwzięć służących poprawie efektywności energetycznej" przewidują jako jedną z metod poprawy efektywności energetycznej „instalację urządzeń pomiarowo-kontrolnych, teletransmisyjnych oraz automatyki w ramach wdrażania systemów zarządzania energią" Artykuł przedstawia na konkretnych przykładach audytów energetycznych wykonanych przez autora, jak takie rozwiązanie może wpłynąć na poprawę efektywności energetycznej przedsiębiorstw różnych branż i jakie warunki musi spełnić taki system, by działać efektywnie.

Słowa kluczowe: *efektywność energetyczna , audyty energetyczne, programy do zarzadzania energią*

Wybrane zagadnienia z zagospodarowania i utylizacji odpadów poeksploatacyjnych pochodzących z górnictwa i przeróbki soli kamiennej

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Abstrakt

W artykule przedstawiono możliwość gospodarczego wykorzystania odpadów powstałych w trakcie eksploatacji złoża solnego oraz zagospodarowania słonych wód dołowych na przykładzie procesu warzenia soli. Przedstawiono w ogólnym zarysie procesy technologiczne warzelni soli, które generują znane jakościowo odpady. Wskazano możliwość dalszego ich zagospodarowania, względnie sposoby ich utylizacji.

Słowa kluczowe: *utylizacja odpadów solnych, warzelnia soli, sucha eksploatacja soli*

Wstęp

Górnictwo solne w Polsce ma blisko tysiącletnią historię. Najstarsze kopalnie – Bochnia i Wieliczka – są dziś obiektami muzealnymi. Obecnie jedyną czynną kopalnią soli jest Kopalnia Soli „Kłodawa", natomiast kolejnym miejscem, gdzie sól jest wydobywana jako kopalina towarzysząca jest kopalnia ZG „Polkowice-Sieroszowice" wchodząca w skład KGHM „Polska Miedź" S.A. Obie wspomniane kopalnie prowadzą tzw. eksploatację suchą. Prócz nich sól pozyskują Inowrocławskie Kopalnie Soli „Solino" (wchodzące w skład PKN „Orlen") w postaci solanki – jest to tzw. eksploatacja otworowa mokra. Pozyskana solanka jest przekazywana do odbiorców w celu dalszej jej obróbki. W jej wyniku otrzymuje się m in. sól warzoną, chlor, wodór. Przeróbka solanki powinna odbywać się w oparciu o najlepsze dostępne techniki BAT (Best Available Techniques) [Najlepsze… 2005].

Eksploatacja metodą suchą

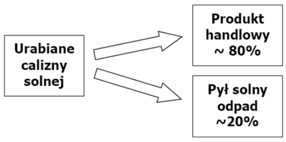
Eksploatacja soli kamiennej metodą suchą prowadzona jest w dwóch kopalniach, lecz w diametralnie różny sposób. Kopalnia Soli „Kłodawa" S.A. prowadzi górnicze roboty eksploatacyjne z wykorzystaniem techniki strzelniczej, natomiast ZG „Polkowice-Sieroszowice" pozyskuje sól metodą mechaniczną z wykorzystaniem kombajnów chodnikowych. Obie kopalnie wydobyły w 2019a r. łącznie 873 tys. Mg NaCl, co stanowi ok. 21,5% wydobycia krajowego [Bilans… 2020].

Istotne różnice w technologii urabiania górotworu solnego bardzo wyraźnie przekładają się na frakcje uzyskiwanego urobku. Zdecydowanie grubszy sortyment uzyskuje się wskutek urabiania skał solnych za pomocą materiałów wybuchowych. W przypadku stosowania kombajnów uzyskiwany wychód jest skutkiem skrawania skał, tak więc urobek stanowią głównie frakcje o mniejszym uziarnieniu. W obu przypadkach uzyskuje się frakcję pyłową, czyli ziarna poniżej 1 mm, która na etapie urabiania nie jest frakcją pożądaną. Jednak w przypadku pierwszym (urabianie techniką strzelniczą) frakcja ta nie przekracza kilku procent urobku, natomiast w przypadku urabiania mechanicznego frakcja pyłowa stanowi około 20% pozyskanej soli (Andrusikiewicz 2012).

Problem pyłów solnych w Kopalni Soli „Kłodawa" S.A. jest w pełni rozwiązany na etapie przeróbki soli, która polega na przesiewaniu urobku i rozsortowaniu na poszczególne frakcje. Wychód ilościowy poszczególnych frakcji jest regulowany w procesie mielenia kruchów solnych (nadawy) pod kątem ich przyszłego wykorzystania. Kopalnia we własnym zakresie wykorzystuje najdrobniejsze frakcje urobku do produkcji soli spożywczej bądź tzw. galanterii solnej w postaci dodatków paszowych bądź lizawek dla zwierząt. W związku z tym można uznać, że frakcja pyłowa uzyskana w wyniku robót eksploatacyjnych nie stanowi problemu i jest w całości zagospodarowana.

ZG „Polkowice-Sieroszowice" jest kopalnią rud miedzi, natomiast sól kamienna jest kopaliną towarzyszącą. Od ponad 20 lat w złożu soli prowadzone są roboty górnicze, których efektem jest wydobycie soli kamiennej. Przyjęta technologia urabiania górotworu solnego (kombajny górnicze) powoduje, że w wyniku ich prowadzenia powstaje frakcja pyłowa, która stanowi do 20% całości wydobycia. O ile z zagospodarowaniem grubszych frakcji nie ma większych problemów, gdyż jest to produkt handlowy (np. sól drogowa), to frakcja pyłowa stanowi w chwili obecnej odpad – rys. 1. Pył solny zagospodarowany poprzez wypełnianie nim nieczynnych wyrobisk solnych.

Z technicznego punktu widzenia sam proces przetransportowania pyłu solnego do nieczynnych wyrobisk nie stanowi dziś większego problemu, natomiast ma to swoją drugą stronę – stronę ekonomiczną. Udział frakcji poniżej 1 mm jest dość znaczący w całej masie pozyskiwanej soli, w istotny sposób podnosi koszt wydobycia, a także znacząco obniża ilość pozyskanego surowca handlowego. Jak widać, zagospodarowanie odpadowego pyłu solnego od strony technicznej w warunkach dołowych nie stanowi problemu, ale istnieje też inna możliwość jego zagospodarowania, która jednak wymaga pewnych inwestycji dołowych w postaci odpowiedniej instalacji, oraz na powierzchni – budowy warzelni soli.



Rys. 1. Podział urobku solnego pozyskiwanego w sposób mechaniczny
Fig. 1. Division of the saline excavated material

Potencjalnym rozwiązaniem jest wykorzystanie pyłu solnego do produkcji solanki, czy to na bazie wody słodkiej, czy słonych wód dołowych (solanka nienasycona) występujących w kopalni. Potencjał tkwi w ilości słonych wód dołowych – ok. 2 mln m^3/rok, których nasycenie oscyluje wokół 50% (ok. 150-160 kg NaCl/m^3).

Nasycenie solanki, aby mogła być wykorzystana jako surowiec dla warzelni soli, musi wynieść min. 308 kg/m^3 roztworu. Przy zastosowaniu odpowiednich procesów technologicznych istnieje możliwość uzyskania solanki o wymaganym stopniu zatężenia w wyrobiskach podziemnych, w obrębie złoża soli. Pozwoli to na niemal całkowite zagospodarowanie frakcji pyłowej urobionej soli. W celu uzyskania 1 m^3 solanki pełnonasyconej na bazie tych wód możliwe będzie wykorzystanie ok. 150-160 kg pyłu solnego.

Aktualna polityka wydobywcza KGHM Polska Miedź S.A. idzie w kierunku ograniczenia wydobycia soli kamiennej. Z planowanego kilka lat temu wydobycia ok. 1 mln Mg NaCl/rok aktualne wydobycie oscyluje wokół wielkości 300 tys. Mg NaCl/rok. W tej sytuacji rozwiązanie związane z wykorzystaniem pyłów solnych do produkcji solanki może być nieuzasadnione ekonomicznie.

Eksploatacja metodą mokrą

Eksploatacja soli kamiennej metodą mokrą jest aktualnie realizowana przez Inowrocławskie Kopalnie Soli „Solino" S.A. w Inowrocławiu, a dokładniej rzecz biorąc w Kopalni Soli Mogilno i Kopalni Soli i Podziemnym Magazynie Ropy i Paliw Góra. Są to kopalnie zlokalizowane na wysadach solnych i prowadzące eksploatację otworową. Polega ona na zatłaczaniu do złoża wody słodkiej, która rozpuszcza skały solne, w wyniku czego powstaje solanka. Ta z kolei jest wypompowywana na powierzchnię i w zależności od stopnia nasycenia kierowana jest do kolejnego otworu, a w przypadku pełnego nasycenia – do odbiorcy, jako produkt finalny. Głównymi odbiorcami solanki są zakłady chemiczne z Grupy Ciech S.A. w Inowrocławiu i Janikowie, oraz grupy Orlen S.A. we Włocławku.

W 2019 r. IKS „Solino" pozyskały metodą mokrą 2,819 mln Mg NaCl, co stanowi 69,4% wydobycia krajowego [Bilans… 2020].

Powstawanie odpadów w procesie warzenia soli

Uzyskana solanka może stanowić doskonałe zaplecze surowcowe dla warzelni soli. Ogólnie rzecz ujmując, po odparowaniu wody można uzyskać czystą sól, czyli NaCl. Jednak wytworzona solanka jest tzw. solanką surową, wymagającą szeregu procesów przygotowawczych (oczyszczenia), które umożliwią wytrącenie z niej związków niepożądanych w procesie ważenia soli To z kolei wskazuje na powstanie związków, będących odpadami procesu oczyszczania.

Również sam proces warzenia nie jest wolny od odpadów – w jego trakcie powstaje szereg ścieków technologicznych. W ogólnym zarysie miejsca powstawania tych odpadów przedstawiono na rys. 2.

Oczyszczanie solanki

Każda solanka surowa zawiera w swoim składzie związki wapnia i magnezu, które w procesie warzenia soli są związkami niepożądanymi – powodują „zarastanie" instalacji i aparatów procesowych.

Proces oczyszczania polega na wytrąceniu z solanki zanieczyszczeń w postaci związków wapnia i magnezu [Iwański et al. 2017]. W oczyszczalni solanka podawana jest do dozatora, gdzie równolegle podawany jest odpowiednio dozowany roztwór solankowy sody amoniakalnej Na_2CO_3 oraz sody kaustycznej NaOH (tzw. mikstury). Zużycie mikstury uzależnione jest od zawartości wapnia i magnezu w solance surowej. Z dozatora solanka i mikstura kierowane są do mieszalnika, gdzie następuje ich dokładne wymieszanie. Następnie media te spływają do reaktora, w którym zachodzą następujące reakcje:

$$CaSO_4 + Na_2CO_3 = Na_2SO_4 + CaCO_3$$
$$MgCl_2 + 2NaOH = Mg[OH]_2 + 2NaCl$$

Solanka po przejściu przez reaktor rozprowadzana jest do klarownic, gdzie osadzają się szlamy poreakcyjne, w tym nierozpuszczalne związki wapnia i magnezu. Szlamy te mają następujące parametry fizyko-chemiczne:

- gęstość ~1250 kg/m^3;
- skład chemiczny (średnio)

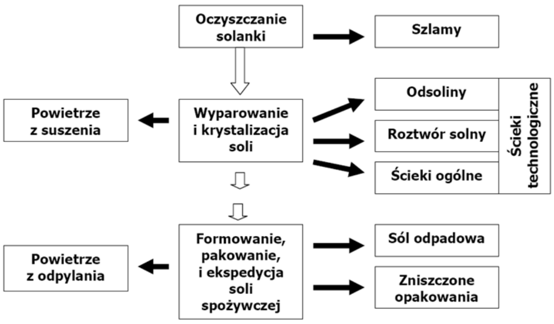
$CaCO_3$ – 7,3 %,
$Mg(OH)_2$ – 5,0 %,
NaCl – 22 %,
H_2O – 65,7 %.

Faza stała, wydzielona z roztworu, znajduje zastosowanie jako wapno nawozowe, wzbogacone z magnez.

Oprócz wapnia i magnezu w solance mogą pojawić się inne zanieczyszczenia mineralne, których obecność stwierdzono we frakcji pylastej soli. Mogą to być następujące minerały: anhydryt, gips, bassanit, kwarc (detrytyczny i autogeniczny), dolomit, tlenki żelaza, skaleń potasowy, plagioklaz, glaukonit, fosforan oraz cała grupa minerałów ilastych (chloryt, illit, kaolinit, montmorillonit, smektyt, talk, wermikulit oraz minerały mieszanopakietowe: chloryt pęczniejący, chloryt – smektyt, illit – smektyt, kaolinit – smektyt oraz rektoryt). W procesie warzenia soli zanieczyszczenia te nie wpływają na przebieg procesu, a także nie przechodzą do produktu (sól warzona). Zanieczyszczenia mineralne pozostają w ściekach technologicznych powstających na etapie wyparowania i krystalizacji soli.

Proces wyparowania i krystalizacji soli

Pozbawiona zanieczyszczeń mineralnych solanka jest podgrzewana, a następnie kierowana aparatów wyparnych.



Rys. 2. Powstawanie odpadów w procesie warzenia soli oraz jej przygotowania do sprzedaży
Fig. 2. Waste formation in the salt brewing process and its preparation for sale

Proces warzenia soli polega, najogólniej rzecz ujmując, na odparowaniu wody i krystalizacji soli. Na tym etapie powstają ścieki technologiczne, na które składają się: odsoliny, roztwór solny oraz ścieki ogólne. Poniżej przedstawiono przybliżone parametry fizyko-chemiczne każdego z trzech rodzajów odpadów (ścieków):

1. odsoliny
- gęstość: 1280 kg/m³;
- skład chemiczny:

NaCl – 20 %,
Na_2SO_4 – 8 %,
H_2O – 72 %.

2. roztwór solny
- gęstość: 1050 kg/m³
- skład chemiczny:

NaCl – 10 %,
H_2O – 90 %.

3. ścieki ogólne
- gęstość: 1020 kg/m³;
- skład chemiczny:

NaCl – 5 %,
H_2O – 95 %.

Odpady z warzelni kieruje się do stawów osadowych. Woda nadosadowa – o ile spełnia odpowiednie parametry – może być zrzucana do cieków powierzchniowych, natomiast osad kierowany jest na składowiska odpadów. Należy zaznaczyć, że nie każde składowisko takie odpady przyjmuje, w związku z czym zachodzi konieczność opracowania bezpiecznej metody składowania tego typu odpadów. Wydaje się, że możliwości takie mogą stwarzać nieczynne kawerny solne lub podziemne składowiska odpadów w kopalniach soli [por. Andrusikiewicz 2016;, Andrusikiewicz, Wrzosek, Zeljaś 2019].

Na etapie wyparowania i krystalizacji soli uzyskuje się znaczące ilości wody zdemineralizowanej, którą jednak trudno uznać za odpad – jest raczej produktem ubocznym procesu [Andrusikiewicz, Tora 2012]. Zagospodarowanie jej jest odrębnym zagadnieniem.

Formowanie i pakowanie soli

Jednym z kierunków wykorzystania soli warzonej jest produkcja soli tabletkowanej stosowanej m. in. do regeneracji wymienników jonitowych (zmiękczacze wody). Sól stosowana do produkcji tabletek solnych wytwarzana jest zgodnie z:
- PN-EN ISO 9001: 2015-10 – Systemy zarządzania jakością. Wymagania;
- PN-EN ISO 14001: 2015-09 – Systemy zarządzania środowiskowego. Wymagania i wytyczne stosowania;
- wymaganiami HACCP (Hazard Analysis and Critical Control Point System – System Analizy Zagrożeń i Krytycznych Punktów Kontroli);
- Atestem Higienicznym PZH wystawiony przez Narodowy Instytut Zdrowia Publicznego – Państwowy Zakład Higieny (NIZP-PZH).
- Tabletki solne do zmiękczaczy wody są zgodne z normami:
- PN-EN 973:2009 – Chemikalia do uzdatniania wody przeznaczonej do spożycia. Chlorek sodu do regeneracji jonitów;
- PN-EN 14805:2008 – Chemikalia do uzdatniania wody przeznaczonej do spożycia. Chlorek sodu do elektrochemicznego wytwarzania chloru;

Charakterystyka fizykochemiczna tabletek:
- NaCl – min. 99,9 %;
- Ca – max. 50 ppm;
- H_2O – max. 0,1 %;
- $K_4Fe(CN)_6$ – max. 3 mg/kg;
- średnica – ok. 25 mm lub 22 mm +/- 0,2 mm;
- grubość – ok. 14 mm lub 14,4 mm +/- 1 mm;
- masa – ok. 12 g lub 9 g +/- 1 g.

Technologia produkcji tabletek solnych w swoim zamierzeniu jest całkowicie bezodpadowa. Jednak stwierdzenie to nie do końca jest prawdziwe. W tym procesie można spodziewać się cyklicznie nieznacznej ilości ścieków pochodzących z mycia maszyny (tabletkarki), które usuwane są razem ze ściekami technologicznymi. Jednak w ogólnej ilości produkowanych ścieków są to ilości pomijalne, które nie wpływają na jakość ścieków.

Sporadycznie można spodziewać się także śladowej ilości odpadów stałych w postaci niepełnowartościowych tabletek, tzn. takich, które nie spełniają kryteriów handlowych. Są to tabletki, które nie w pełni zostały uformowane, najczęściej przy rozruchu tabletkarki lub na skutek uszkodzenia stempla w maszynie. Ilość tego typu odpadów nie będzie przekraczała kilku, kilkunastu kilogramów w skali roku, w związku z czym śmiało może być utylizowana z innymi odpadami technologicznymi.

Potencjalnym problemem, choć równie marginalnym, są odpady powstałe ze zniszczonych/uszkodzonych opakowań, np. big-bagów. Odpady te są utylizowane wg standardowych procedur, czyli po prostu są wywożone na składowisko odpadów bądź zagospodarowywane w inny sposób.

Podsumowanie

Kopanie soli mogą wydobywać sól kamienną praktycznie bezodpadowo, pod warunkiem zastosowania odpowiedniej technologii jej pozyskiwania. Dopiero przetwórstwo soli, jak np. przedstawiono powyżej na przykładzie warzelni soli, generuje odpady, których zagospodarowanie czy utylizacja może stwarzać określone problemy. Jednak zaprezentowaną propozycję zagospodarowania słonych wód dołowych oraz pyłów solnych można uznać za działanie proekologiczne i uzasadnione ekonomicznie, pod warunkiem, zapewnienia odpowiedniej ilości pyłów solnych lub uzupełnienia ich braków bieżącym wydobyciem soli. Mimo iż w procesie warzenia soli powstają szlamy solne oraz zasolone ścieki technologiczne, ich ilość oraz zawartość ładunku chemicznego jest zdecydowanie mniejsza, niż ilość i jakość zasolonych wód dołowych wypompowywanych na powierzchnię Przykładowo, produkcja 100 tys. Mg soli warzonej umożliwia zagospodarowanie ok. 330 tys. m^3 słonych wód dołowych o nasyceniu ok. 50% oraz ok. 50 tys. Mg pyłu solnego. Efektem ubocznym, poza wymienionymi wyżej odpadami, będzie ok. 250 tys. m^3 wody zdemineralizowanej, którą można wykorzystać przemysłowo (zakład ciepłowniczy, zakład przeróbki rud itp.), a w ostateczności odprowadzić do cieków powierzchniowych.

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Selected Issues in the Management and Disposal of Post-Mining Waste From Mining and Rock Salt Processing

The article presents the possibility of economic use of waste generated during the exploitation of the salt deposit and the management of salt mine waters on the example of the salt brewing process. The technological processes of the salt works, which generate wastes known in quality, are outlined in general. The possibility of their further development and methods of their utilization were indicated.

Keywords: *utilization of salt waste, salt works, salt mining*

Operating Opencast Mines of Selected Groups in the Silesian Voivodeship Against a Background of Water Environment and Possibilities of Waste Placing

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Abstract

The paper is aimed at location identification of operating opencast mines against a background of main groundwater basins (MGB) and in relation to surface waters. The scope of analysis covered the Silesian Voivodeship, as the area in which many operating and closed opencast mines are situated. On the other hand this is a voivodeship, where great amounts of mining waste are generated, potentially placeable in mine workings. The analysis comprised the mines, where raw materials are mined, classified in the Balance of Mineral Deposits Resources in Poland as of 31 December 2017 to the following groups: crushed and block stone, sands and gravels, filling sands, quartz sands for cellular concrete and sand-lime brick production, sands with heavy metals, and moulding sands.

The work resulted in a developed map of mined aforementioned opencast mines arrangement in the Silesian Voivodeship, taking into account their location in relation to groundwater basins boundaries and in relation to surface watercourses. Two distances of mined opencast workings from surface watercourses were taken, 500 m and 1000 m. Such a recognition provides an approximate picture of possibilities for various waste types placing in the process of technical reclamation after the end of mining.

The use of various waste types for technical reclamation is a complex issue, both in the field of regulations applicable to the ground and water environment, in the field of mine location determination, and in the field of the quality of the waste material determination. The applied legal regulations, frequently changing over time, indicate the right process of decision making and handling of individual waste types. It is most important, that raw materials and waste intended to fill the mines would not create a hazard for the environment, including the environment of surface waters and ground waters.

Keywords: *opencast mines, MGB area, surface waters, reclamation, waste*

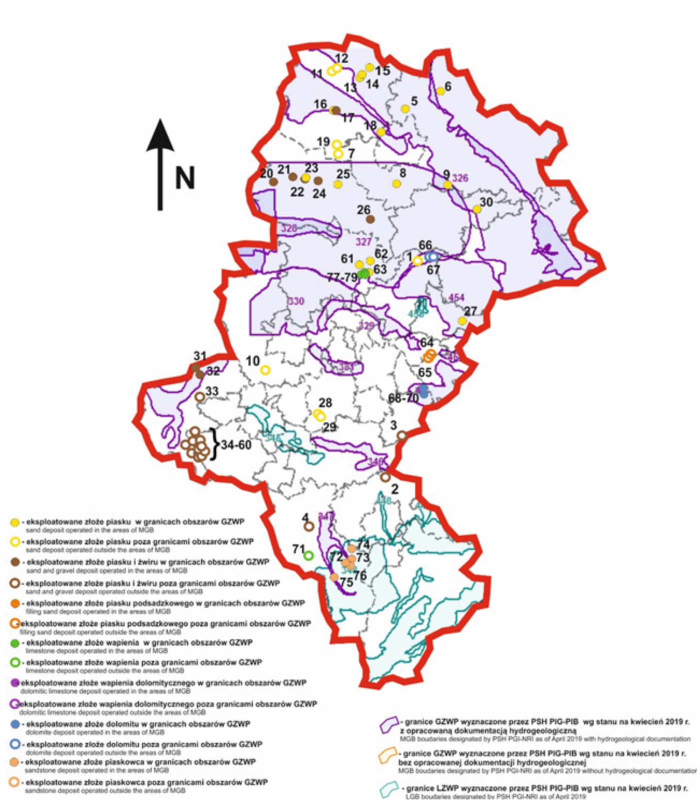
Introduction

The paper is aimed at identification of active opencast mines location against a background of main groundwater basins (MGB) and in relation to surface waters. The scope of analysis covered the Silesian Voivodeship, as the area in which many operating and closed opencast mines are situated. On the other hand this is a voivodeship, where great amounts of mining waste are generated, potentially placeable in mine workings. The paper is a continuation of previous papers with the author's involvement 'Active opencast mines of carbonate raw materials against a background of MGB boundaries and possibilities of their reclamation by filling with waste' (Klojzy-Karczmarczyk, Staszczak, 2017) and 'Recognition of sand and gravel pits in relation to MGB boundaries and surface watercourses in the area of Silesian Voivodeship' (Klojzy-Karczmarczyk, Staszczak, 2019).

The analysis comprised the mines, where raw materials are mined, classified in the Balance of Mineral Deposits Resources in Poland as of 31 December 2017 (Szuflicki et al (ed.) 2018) to the following groups: crushed and block stone, sands and gravels, filling sands, quartz sands for cellular concrete and sand-lime brick production, sands with heavy metals, and moulding sands. Not all raw materials from the mentioned groups are mined in the Silesian Voivodeship. Only crushed and block stone (limestone, dolomite, dolomitic limestone, and sandstone), sands and gravels, and also filling sands were mined in 2017. No quartz sands for cellular concrete and sand-lime brick production, sands with heavy metals, and moulding sands were mined.

The work resulted in a developed map of mined aforementioned opencast mines arrangement in the Silesian Voivodeship, taking into account their location in relation to groundwater basins boundaries and in relation to surface watercourses. Such an identification provides an approximate picture of possibilities for various waste types placing in the mine. It is necessary to note here that the waste placement in mines, considered in the paper, can be carried out in the process of technical reclamation after the end of mining. The original intention of the paper consisted in locating operating opencast mines against a background of MGP protection area boundaries. However, because of the lack of published sufficient and topical materials the mines in question were situated only against a background of MGP boundaries.

The use of various waste types for technical reclamation is a complex issue, both in the field of regulations applicable to the ground and water environment, in the field of mine location determination, and in the field of the quality of the waste material determination. The applied legal regulations, frequently changing over time, indicate the right process of decision making and handling of individual waste types (e.g. Góralczyk, Baic, 2009; Góralczyk, 2011; Kukulska-Zając, Dobrzańska, 2012; Klojzy-Karczmarczyk, Mazurek, 2015; Kicki, Sobczyk, 2016, Klojzy-Karczmarczyk, Staszczak 2019). The provisions of the Act of 14 December 2012 on Waste are applied to reclamation and management of opencast mines with the use of waste in the process of recovery. The filling of a post-mining working with external materials is the basic stage of technical phase of reclamation in rock mines (Ostrę-



Rys. 1. Lokalizacja złóż surowców badanych grup w województwach południowej Polski (Szuflicki i in., 2018) na tle granic zbiorników wód podziemnych (stan na kwiecień 2019 r., wykorzystano mapę GZWP wykonaną przez PSH PIG-PIB; http://epsh.pgi.gov.pl/epsh/)

Fig. 1. Location of raw materials deposits of the studied groups in the voivodeships of southern Poland (Szuflicki et al, 2016) in relation to the boundaries of groundwater basins (as of April 2019, with the use of the MGB map developed by PHS PGI-NRI; http://epsh.pgi.gov.pl/epsh/)

ga, Uberman, 2010; Strzałkowski, Kaźmierczak, 2014; Czekaj, Sobczyk, 2015) and the use of materials for mines filling is limited to certain waste groups or types.

Previous analyses show that selected mining waste fractions with codes 01 01 02 and 01 04 12 can be widely used in technical reclamation by opencast mines filling. This material frequently has no waste status and is a raw material (Klojzy-Karczmarczyk et al, 2016a, b. Klojzy-Karczmarczyk, Staszczak 2019). It is most important, that raw materials and waste intended to fill the mines would not create a hazard for the environment, including the environment of surface waters and ground waters.

Methodology adopted in the analysis

Based on the data contained in the Balance of Mineral Deposits Resources in Poland (Szuflicki et al (ed.) 2018) a list was prepared of all operated in 2017 opencast mines of crushed and block stone (dolomites, limestones, dolomitic limestones, and sandstones), sands and gravels, filling sands, quartz sands for cellular concrete and sand-lime brick production, sands with heavy metals, and moulding sands deposits in the area of Silesian Voivodeship. The opencast mines were next situated on an orthophotomap (http://www.geoportal.gov.pl), from which geographical coordinates of facilities were read, which were then imposed on the map of MGB boundaries in the area of Poland, produced by the National Hydrogeological Service of the National Geological Institute – National Research Institute (PSH PIG-PIB) as of April 2019 (http://epsh.pgi.gov.pl/epsh/, 2019). As a result a map of all mined opencast mines was obtained for deposits of aforementioned groups in the Silesian Voivodeship. The carried out analysis did not include mines not operated in 2017.

The map produced by the PSH PIG-PIB comprises all documented, not documented main and local groundwater basis (http://epsh.pgi.gov.pl/epsh/, 2019) and their range was marked out on the basis of determined uniform qualitative and quantitative parameters of basins (Mikołajków & Węglarz 2011).

To estimate distances of opencast mines analysed in the paper from watercourses the generally available base maps were used of the Google portal (https://www.google.com/maps) and of the geoportal (https://www.geoportal.gov.pl). River channels are not straight lines therefore in certain cases doubts appeared, whether a specific mine is situated at a distance of less than 500 m, or not. Finally, a decision was made to classify mines to the group of less than 500 m, if only a minimal their part was situated closer than 500 m from the river channel boundary.

Results of carried out analysis

The management of opencast mines after the end of mining is a still observed problem. However, there are more and more methods of reclamation and management, proving the dynamics of this research area development. The prepared map (Fig. 1) presents only opencast mines of the above groups mined now within the Silesian Voivodeship. Altogether 79 mined deposits (as of 2017 end) of sands and gravels, filling sands, sandstones, limestones, dolomites, and dolomitic limestones are situated within the voivodeship area. The total number of such deposits is much higher. The total number of all deposits of discussed groups in the Silesian Voivodeship,

Tab. 1. Lokalizacja wyrobisk odkrywkowych badanych grup złóż w powiatach województwa śląskiego w odniesieniu do granic GZWP
Tab. 1. Location of opencast mines of studied deposit groups in the districts of the Silesian Voivodeship in relation to MGB boundaries

Powiat *District*	Ilość wyrobisk / Ilość na obszarze GZWP *Number of opencast mines / number in the MGB area*	***[Nr wyrobiska odkrywkowego - zgodnie z ryc. 1]***, Nr GZWP, wiek utworów*, typ ośrodka** (wg A.S. Kleczkowski, 1990), status udokumentowania*** ***[No. of opencast mines** - according to Fig. 1**]**, No. of MGB, age of aquifer*, type of aquifer (according to A.S. Kleczkowski, 1990)**, documentation status****
Sands and gravels, filling sands		
Będzin	1/0	-
Bielsko-Biała	1/0	-
Bieruń-Lędziny	1/0	-
Cieszyn	1/0	-
Częstochowa	5/4	**[5]** 326, J_3, s-k, U; **[6]** 408, Cr_3, s, U; **[8]** 327, T_1, T_2, s-k, U; **[9]** 326, J_3, s-k, U; 327, T_1, T_2, s-k, U;
Gliwice	1/0	-
Kłobuck	9/6	**[13]** 326, J_3, s-k, U; **[14]** 326, J_3, s-k, U; **[15]** 326, J_3, s-k, U; **[16]** 325, J_2, s-k, U; **[17]** 325, J_2, s-k, U; **[18]** 325, J_2, s-k, U;
Lubliniec	7/7	**[20]** 327, T_1, T_2, s-k, U; **[21]** 327, T_1, T_2, s-k, U; **[22]** 327, T_1, T_2, s-k, U; **[23]** 327, T_1, T_2, s-k, U; **[24]** 327, T_1, T_2, s-k, U; **[25]** 327, T_1, T_2, s-k, U; **[26]** 327, T_1, T_2, s-k, U;
city of Dąbrowa Górnicza	1/1	**[27]** 454, T_1,T_2, s-k, U;
city of Jaworzno and city of Sosnowiec	2/0	-
Mikołów	2/0	-
Myszków	1/1	**[30]** 326, J_3, s-k, U;
Racibórz	7/2	**[31]** 332, Tr, Q_K, p, U; **[32]** 332, Tr, Q_K, p, U;
Tarnowskie Góry	3/3	**[61]** 327, T_1, T_2, s-k, U; **[62]** 327, T_1, T_2, s-k, U; **[63]** 327, T_1, T_2, s-k, U;
Wodzisław	17/0	-
Wodzisław and Racibórz ****	6/0	-
other districts	0/0	-
Total voivodeship	**65/24**	
Crushed and block stone		
Będzin	2/0	-
Bieruń-Lędziny	3/3	**[68]** 452, T1, T2, s-k, U; **[69]** 452, T1, T2, s-k, U; **[70]** 452, T1, T2, s-k, U;
Cieszyn	6/5	**[72]** 348, Cr_f, s-p, L; **[73]** 348, Cr_f, s-p, L; **[74]** 348, Cr_f, s-p, L; **[75]** 347, Q_D, p, U; **[76]** 348, Cr_f, s-p, L;
Tarnowskie Góry	3/3	**[77]** 327, T_1, T_2, s-k, U; **[78]** 327, T_1, T_2, s-k, U; **[79]** 327, T_1, T_2, s-k, U;
other districts	0/0	-
Total voiodeship	**14/11**	
TOTAL	**79/35**	

** – Aquifer age based on the Regulation of the Council of Ministers (Dz.U. Of 2006, No 126, item 878)*
*** – Aquifer types: s – fissured, p – porous, s–k – fissured-karstic, s–p – fissured-porous*
**** – Degree of MGB documentation: U – MGB with prepared of hydrogeological documentation,*
N – MGB without prepared hydrogeological documentation (as of April 2019, http://epsh.pgi.gov.pl/epsh)
***** – deposits in the area of both districts.*

Tab. 2. Lokalizacja wyrobisk odkrywkowych badanych grup złóż w odniesieniu do cieków powierzchniowych na obszarze województwa śląskiego
Tab. 2. Location of opencast mines of studied deposit groups in relation to the watercourses in the Silesian Voivodeship

Województwo *Voivodeship*	Ilość wyrobisk / Ilość w odległości **do 500 m** od cieków *Number of opencast mines / up to 500 m from watercourses*		Ilość wyrobisk / Ilość w odległości **do 1000 m** od cieków *Number of opencast mines / up to 1000 m from watercourses*	
Sands and gravels, filling sands				
Total voivodeship	**65/24**		**65/48**	
	watercourse name	number of mines	watercourse name	number of mines
	Oder	14	Oder	25
	Biała Przemsza	2	Biała Przemsza	3
	Other	8	Liswarta	3
			Biała Oksza	3
			tributary of Gostynka	2
			Vistula	2
			Other	10
Crushed and block stone				
Total voivodeship	**14/4**		**14/12**	
	watercourse name	number of mines	watercourse name	number of mines
	Brennica	2	Brennica	3
	Gahura	1	tributary of Brynica	3
	Leśnica	1	tributary of Przemsza	3
			Other	3

comprising the mined deposits, deposits with preliminary explored resources (in cat. C2 + D), deposits with resources explored in detail (in cat. A + B + C1), deposits which mining was already abandoned, deposits cancelled from the balance of resources in the reporting year, and managed deposits, mined periodically, is 395. Sands and gravels are the largest group (288 deposits), moulding sands are the next group (45 deposits), crushed and block stone (44 deposits), filling sands (17 deposits), and quartz sands (1 deposit) (Szuflicki et al, (ed.) 2018). After the end of mining each mine should be technically reclaimed. The application of external raw materials or various types of waste to fill the mines is possible for all basic target reclamation directions (agriculture, forest, recreation, and construction). The choice of reclamation direction depends mainly on hydrogeological and location conditions, area development situation, conditions of zoning plans, or financial capabilities.

The location conditions of operating opencast mines in the area of the Silesian Voivodeship were identified, for which in the future there is a potential possibility of carrying out technical reclamation (by filling and shaping the surface) using the waste from hard coal mining or other waste or raw materials. The discussed mined deposits (Szuflicki et al (ed.) 2018) are situated in the area of 16 districts (Table 1). The largest number of them is in the Wodzisław district (17 deposits), Kłobuck district (9 deposits), and also in Cieszyn, Lubliniec, and Racibórz districts (7 deposits each). In addition, mined deposits of the aforementioned raw materials are situated in the Tarnowskie Góry (6 deposits), Częstochowa (5 deposits), Bieruń-Lędziny (4 deposits), Będzin (3 deposits), Mikołów (2 deposits), and Bielsko-Biała, Gliwice, Myszków districts and in the city of Dąbrowa Górnicza (1 deposit each). The remaining deposits are situated at boundaries of two districts. In the areas of Wodzisław and Racibórz dis-

Tab. 3. Zestawienie wyrobisk odkrywkowych badanych grup złóż w powiatach województwa śląskiego z uwzględnieniem ich lokalizacji na tle granic GZWP oraz w odległości od cieków powierzchniowych

Tab. 3. Summary of opencast mines of studied deposit groups in the districts of the Silesian Voivodeship in relation to MGB boundaries and at a distance from surface watercourses

Powiat *Dictrict*	Ilość wyrobisk *Number of opencast mines*				
	ogółem *Total*	na obszarze GZWP *within MGB area*	do 500 / 1000 m od cieków *up to 500 / 1000 m from watercourses*	poza GZWP i ponad 500 m od cieków *outside the MGB and above 500 m*	poza GZWP i ponad 1000 m od cieków *outside the MGB and above 1000 m*
Sands and gravels, filling sands					
Będzin	1	0	0/1	1	0
Bielsko-Biała	1	0	0/1	1	0
Bieruń-Lędziny	1	0	1/1	0	0
Cieszyn	1	0	1/1	0	0
Częstochowa	5	4	0/1	1	0
Gliwice	1	0	1/1	0	0
Kłobuck	9	6	1/5	3	1
Lubliniec	7	7	0/2	0	0
city of Dąbrowa Górnicza	1	1	1/1	0	0
city of Jaworzno and city of Sosnowiec	2	0	2/2	0	0
Mikołów	2	0	1/2	1	0
Myszków	1	1	0/0	0	0
Racibórz	7	2	5/5	1	1
Tarnowskie Góry	3	3	0/1	0	0
Wodzisław	17	0	10/17	6	0
Wodzisław and Racibórz ****	6	0	1/6	5	0
other districts	0	0	0/0	0	0
Total voivodeship	**65**	**24**	**24/47**	**19**	**2**
Crushed and block stone					
Będzin	2	0	0/1	2	1
Bieruń-Lędziny	3	3	0/3	0	0
Cieszyn	6	5	4/5	1	0
Tarnowskie Góry	3	3	0/3	0	0
other districts	0	0	0/0	0	0
Total voivodeship	**14**	**11**	**4/12**	**3**	**1**
TOTAL	**79**	**35**	**28/59**	**22**	**3**

***** – deposits in the area of both districts.*

tricts (6 deposits), and in the area of cities of Jaworzno and Sosnowiec (2 deposits).

In the other districts there are no mined deposits of described raw material groups (Table 1, Fig. 1). As many as 35 out of 79 mined deposits are situated within boundaries of main groundwater basins (MGB). The largest group of mined deposits are those of sand and gravel – 37, of which 7 are situated within MGB boundaries. In addition, 26 mined sand deposits were located (16 in MGB area), 5 sandstone deposits (all within MGB), 4 dolomite deposits (2 in MGB areas), 4 limestone deposits (2 within MGB), 2 filling sand deposits (all outside MGB area), and 1 dolomitic limestone deposits (in the MGB area). No sand and moulding sand pits were located in the area of Silesian Voivodeship. Groundwater basins within boundaries, in which opencast mines are mined, are situated in geological structures varying in terms of age (Table 1).

Overall, at a distance below 500 m from surface watercourses there are 28 mined opencast mines, and at a distance of less than 1000 m – already 60 out of 79 mined opencast mines of raw material groups analysed in this paper (Table 2) in the area of Silesian Voivodeship. However, if we consider the intersection of opencast mines location outside the MGB area and situated at least 500 m from the nearest watercourse, the number of facilities satisfying this criterion will be only 22 out of 79 mined opencast mines, and if the criterion of distance from rivers to 1000 m, then only 3 out of 79 (Table 3).

Summary and conclusions

The mined opencast mines of groups: crushed and block stone (limestones, dolomites, dolomitic limestones, sandstones), sands and gravels, filling sands, quartz sands, and moulding sands in the Silesian Voivodeship are situated in 16 districts. They were arranged on the map of MGB boundaries of Poland produced by the National Hydrogeological Service, National Geological Institute – National Research Institute (http://epsh.pgi.gov.pl/epsh/, 2019). As a result of carried out analysis of operating opencast mines location for deposits of studied groups against a background of MGB boundaries it was found, that out of 35 facilities among 79 opencast mines are situated within boundaries of determined MGB areas, which is approx. 44% of the total. In the crushed and block stone group 11 out of 14 opencast mines are situated in the MGB area, which is as much as 78%. In turn, in the group of filling sands and gravels this percentage is much smaller – 37%. 24 out of 65 opencast mines are situated in MGB areas in this group.

Because of the scale of sands and gravels output, and also of crushed and block stones, and the necessity of post-mining sites reclamation, the possibility to manage various waste types in the process of workings filling is an interesting development direction. However, it is necessary to emphasise that nearly a half of them are situated within the range of main groundwater basins areas. In the protection areas of groundwater basins, being a part of aquifer feeding, bans, orders, and limitations in the land use are being applied.

If we add the second criterion, such as the distance from watercourses equal to 500 metres, these requirements will be met by only 22 out of 79 mined opencast mines, which is less than 28%, and if we increase the criterion of distance from rivers to 1000 metres, only 3 opencast mines will remain and less than 4% of all mined ones. Only 3 facilities, out of 14 opencast mines of the crushed and block stone group, are situated outside the MGB area and at a distance of more than 500 m from surface watercourses. If we extend the criterion from 500 to 1000 metres, the conditions will be met by only 1 opencast mine, which is 7% of the total. In turn, 19 facilities, out of 65 opencast mines of the filling sands as well as sands and gravels group, are situated outside the MGB area and at a distance of more than 500 m from surface watercourses. If we extend the criterion from 500 to 1000 metres, the conditions will be met by only 2 opencast mines, which is 3% of the total.

Although in the presented paper the opencast mines of described deposit groups are situated against a background of MBG boundaries, and not boundaries of their protection zones, the developed map provides an approximate picture of possibilities of placing various waste types in the mines. It should be emphasised, that the process of opencast mines reclamation by filling with waste or with another external material each time should be preceded by a detailed recognition of hydrogeological conditions and hydrological conditions of the analysed area. In addition, in sensitive areas a proper choice of waste, from the point of view of their quality and potential transformation of the chemical composition over time, is particularly important.

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Eksploatacja kopalni odkrywkowych wybranych grup w województwie śląskim na tle środowiska wodnego i możliwości składowania odpadów

Celem pracy jest rozpoznanie lokalizacji czynnych wyrobisk odkrywkowych na tle granic głównych zbiorników wód podziemnych (GZWP) oraz w pobliżu cieków wodnych. Obszarem badań zostało wybrane województwo śląskie jako obszar, na którym znajduje się wiele czynnych oraz nieczynnych wyrobisk, a także bardzo duża ilość potencjalnych możliwych do ulokowania w wyrobiskach odpadów górniczych. Analizie poddano wyrobiska, w których eksploatowane są surowce zaklasyfikowane w Bilansie zasobów złóż kopalin w Polsce wg stanu na 31 XII 2017r., do grup: kamienie łamane i bloczne, piaski i żwiry, piaski podsadzkowe, piaski kwarcowe do produkcji betonów komórkowych i cegły wapienno-piaskowej, piaski z metalami ciężkimi oraz piaski formierskie.

Efektem pracy jest opracowana mapa rozmieszczenia eksploatowanych w/w wyrobisk w województwie śląskim z uwzględnieniem ich lokalizacji w stosunku do granic zbiorników wód podziemnych oraz w stosunku do cieków powierzchniowych. Przyjęto dwie odległości eksploatowanych wyrobisk odkrywkowych od cieków powierzchniowych, które odpowiednio wynoszą 500 m. oraz 1000 m. Takie rozpoznanie daje przybliżony obraz możliwości lokowania różnych rodzajów odpadów w procesie rekultywacji technicznej po zakończeniu eksploatacji.

Zastosowanie różnego rodzaju odpadów w celu rekultywacji technicznej jest zagadnieniem złożonym zarówno w sferze przepisów odnoszących się do jakości środowiska gruntowo-wodnego, jak i w zakresie określenia lokalizacji. Surowce oraz odpady przeznaczone do wypełniania wyrobisk nie powinny stanowić zagrożenia dla środowiska.

Zakłady górnicze posiadające poeksploatacyjne wyrobiska odkrywkowe, które w przyszłości będą przeznaczone do rekultywacji, mogą stanowić poważną grupę odbiorców kruszyw lub odpadów produkowanych nie tylko w sektorze górnictwa węgla kamiennego. Głównymi kryteriami decydującymi o możliwości rekultywacji wyrobisk odpadami są opłacalność i założenia środowiskowe.

Słowa kluczowe: *kopalnie odkrywkowe, obszar GZWP, wody powierzchniowe, rekultywacja, odpady*

Alternative Ways of Financing in the Global Mining: ECA Export Credit Agencies

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Abstract

Nowadays, mining enterprises are perceived through the prism of "the black PR, what causes the general reluctance of the financial market and the withdrawal of the traditional financial institutions from providing capital in the form of debt for the mining industry. "While spending from national budgets on coal fell, as did tax breaks for it, other forms of support - from development finance institutions, export-credit agencies – soared." [1] This article analyses the possibilities of using these sources depending on the life cycle phase of a geological and mining project. In the following part of the article, the main attention is paid to ECAs, which offer much more opportunities than traditional banks, among others: chipper credits, longer terms of credits and tax exemptions. The article presents the largest Export Credit Agencies in the world and indicates their characteristic features compared to conventional sources of financing. The largest financing countries, as well as acquiring such capital in relation to the mining industry, were identified.

Keywords: *alternative source of financing, ECA, mining financing*

1. Introduction

The mining industry is dynamically changing, it must constantly respond to constant changes, such as: business cycles and changing trends in commodity markets. It has to react to the pressure and preferences of shareholders and capital markets. It has to face with environmental restrictions, which require constant improvement of the technologies and processes of the entire life cycle of the geological and mining projects. All of that causes that costs are increasing at every stage of operation of mining companies. The mining industry must constantly search various sources of financing. This task is not easy because of mining industry "black PR" which comes from global climate policy which is aimed at achieving climate neutrality by reducing CO_2 emissions. The "black PR" of mining causes the general reluctance of the financial market and the withdrawal of the traditional financial institutions from providing capital in the form of debt for the mining industry. Therefore, mining enterprises, out of concern for their existence, are looking for innovative sources of financing, that will be an alternative to traditional sources.

This article presents the essence of the Export Credit Agency (ECA) operation with the current characteristics of the ECAs' market and the units operating on it. It shows the involvement of ECA financing in the mineral resources mining in the world and it indicates the advantages and disadvantages of such financing.

2. The problems of mining industry financing and the units operating on it

Mining enterprises are not able to function properly without adequate financing at the operating or investment level. Currently, one of the key challenges of the mining industry is to obtain the capital. They have to create an optimal structure of debts as well as appropriate financial leverage, which will allow for the effective implementation of geological and mining projects, and thus to generate value for the owner.

From the traditional capital donors point of view, the mining industry is unattractive, in opposition to enterprises operating in a stable market environment. This perception is influenced by: price instability, the inelastic structure of assets and general formal, legal or political conditions. Therefore, mining companies cannot take full advantage of financial market opportunities. High costs, lack of capital for development and problems related to maintaining current financial liquidity lead to the rejection of prospective projects, the slowing down of already implemented projects, their closure during implementation, or abandonment at the planning stage.

The financing of particular problems of the coal mining and conventional energy industries became stronger about 10 years ago, when the anti-carbon policy was introduced. In 2013, U.S. President Obama announced his Climate Action Plan that included a commitment to end US support for the public financing of new coal plants overseas. The same did governments of the UK, Denmark, Finland, Norway, Sweden and Iceland.

In the same year The World Bank announced that it would limit funding for new coal-fired power plants in developing countries. The European Investment Bank has introduced Emissions Performance Standard, where it has been declared that the EIB will finance low-emission projects that have a limited negative impact on the environment. All of this was sealed by the OECD Secretary General Angel-Gurría, who called "every government" to reform fossil fuel subsidies and to address incoherent and inconsistent policies, both of which encourage harmful fossil fuel production and consumption. [2]

In 2014, IPCC in a new report on Climate Change claimed that in the nearest future the global temperature will increase by 2°C if the world does not reduce CO_2 emissions. This resulted in further cuts in financing for the hard coal mining and conventional energy industries.

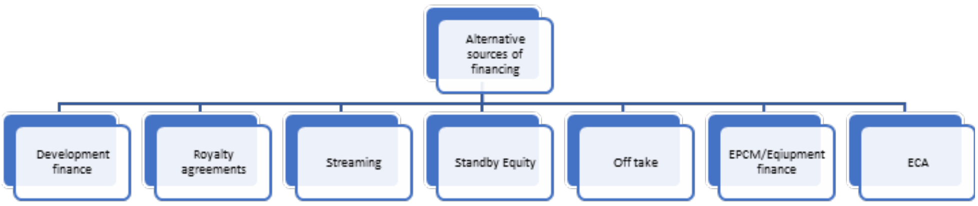

Fig. 1. Alternative forms of financing. Source: Own elaboration based on [5] [6]
Rys. 1 Alternatywne źródła finansowania. Źródło: Opracowanie własne na podstawie [5] [6]

In 2015, The ING Bank announced a funding reduction for coal mining entities and confirmed this non-involvement in new investments, the sales of which come at least in 50% from the coal mining segment. This policy is a complete change of the current strategy of ING Bank, under which it was one of the thirty largest and most committed entities financing the mining industry in the world. The financing was estimated at USD 4.5 billion in 2007-2015. Sixty percent of this amount was the bank's lending activity, and 40% was their equity involvement in shares or corporate securities of mining enterprises. [3]

Subsequently, the state-owned Norges Bank Investment Management, the largest investment fund in the world, withdrew from investments in mining and energy companies related to hard coal. The indicated financing limitations applied to over 50 companies in which over 30% of sales revenues came from coal mining or coal-based energy. However, Norges Bank did not withdraw from the largest three entities in the world that are coal producers, i.e. BHP Billiton, Rio Tinto and Glencore, because in their case the diversification and mass revenues from other mining business segments result in a lower share of revenues from coal sales. The funds cut concerned mainly American enterprises (e.g. Peabody Energy), Chinese (e.g. China Coal Energy), Indian (e.g., Tata Power), three Japanese and several European enterprises (e.g. Tauron, Bogdanka). [4]

The examples mentioned above, show the need of the alternative forms of financing implementation in mining enterprises, in that hard coal enterprises, which are strongly exposed to the lack of capital.

3. The alternative forms of mining financing

The facts indicated in the previous chapter resulted that mining enterprises have reached for alternative sources of financing, which were previously used as a form of monetization in geological and mining projects, but only for products which were accompanying the main mineral in the deposit.

The use of alternative sources ensures obtaining financing at specific stages of the life cycle of a geological and mining project, where the low value of the project results from the high risk of failure and financial losses for the capital donors.

A particular demand for such financing arises in the initial phases of the project life cycle, which are characterized by significant investment outlays and negative cash flows.

The Figure shows alternative forms of financing.

The sources of financing, which are shown above, due to their specificity, are used at specific phases of geological and mining projects' life cycle. The use of specific alternative financing is usually assigned to a specific phase during which specific works are performed with a specific credit risk as well as the perspective of a potential investor (Table 1).

The phase of research work (exploration) is carried out after concessions and appropriate rights are obtained(although this is not always the determining factor). The research work is focused on areas with the highest mineralization of the deposit. From an investor's point of view the financing of this phase is very risky. Entrepreneurs in that phase can reach for alternative sources of financing such as: development finance, royalty agreement and standby equity.

The phase of development work (deposit estimation) relies on the identification of the individual, characteristic parameters of the deposit. That kind of works have to focus on establishing of the technical feasibility and commercial viability of extracting the mineral resources, as well as on determining the expenditure incurred for the preparation and providing access to the deposit. This phase is completed when the mineral deposit is identified and the decision to build a mine is made. In that phase there still s a high risk for the investors. Mining entrepreneurs can reach for alternative sources such as: development finance, royalty agreement or off take financing.

The construction phase of geological and mining projects is one of the most capital-intensive phase. At that phase, the deposit is made available for exploitation. In that time the mining entrepreneur has to obtain many permits, which often extends this phase. From an investor's point of view it is still high risk to invest in that project. However, at this phase there appears to be more options of alternative forms of financing such as: development finance, streaming, off take, EPCM/equipment finance and ECA.

The last stage where alternative sources of mining financing are needed is production. This stage consists of two phases: production indication and production. The difference between them is that in the first phase we deal with setting up the production process and when this is done then follows full production (extraction). Extraction can last many years (depending on the deposit, resources owned and the extraction techniques and the technologies used). During this time, there may be changes in the estimation of resources from a technical and economic point of view. These changes are the primary assumptions of the geological and mining project. Other differences between the two phases are in the area of the risk. The phase of production initiation is medium risky for the investor and full production is low risky. In both phases mining entrepreneurs can reach for streaming financing as an alternative to traditional financing sources.

Summing up, the possibility of using alternative sources of financing is the most important in the early and initial phases

Tab. 1. The risk and investor's perspective at various phases of geological and mining projects depending on the source of alternative financing. Source: Own elaboration based on [5] [6]

Tab. 1. Ryzyko i perspektywa inwestora na różnych etapach cyklu życia projektów górniczych w zależności od alternatywnego źródła finansowania. Źródło: Opracowanie własne na podstawie [5] [6]

Phase	Research works-exploration	Development works – estimation	Construction	Production indication	Production
Risk class	No rating	No rating	No rating/high yield	high yield	Investment
Investor's perspective	High/ unacceptable risk	High risk	High risk	Medium risk	Low risk
Development finance	✓	✓	✓		
Royalty agreement	✓	✓			
Streaming			✓	✓	✓
Standby Equity	✓				
Off take		✓	✓		
EPCM/Equipment finance			✓		
ECA			✓		

of the life cycle of a geological and mining project, where the investor's perspective is associated with high investment and credit risks. When the project enters the next phases leading to the launch of production and achieving maximum production capacity, the mining corporation can reach for traditional forms of financing through external capital, such as loans, corporate bonds, convertible bonds, etc., which will be more achievable at this point.

4. Export credit agencies

The first export credit agency, the Export Credits Guarantee Department (ECGD) of the United Kingdom, was established in 1919. ECGD was established to support the export of domestic products (initially to Russia), as well as to support the labour market. The ECA has established British exporters in competition on foreign markets through loans, taking on cross-border risks, insurances and guarantees.

In 1933, another ECA Export-Import Bank of the United States (US Exim bank) was established. For few decades there was a stagnation period in the raising of export credits agencies, until after the Second World War. [7]

The ECAs were limited to the role of a lender of last resort, they were used only in the case of a lack of commercial appetite in the private financial sector [8]. In 1980s the ECAs began to decline, but it changed in 2008 in the time of the world financial crisis. During that time banks retreated from export financing and the ECAs provided the necessary liquidity to support the international trading system. [9] Official export credit agencies were critical 'shock absorbers', supporting the survival of the international trading system. [10]

The newest EXIM's report sum up that now exist more than 1 hounded of national ECAs, which deliver $215 billion in form of export support in loans, guarantees, and insurance to domestic firms' exports of goods, services, and investments. [11]

The ECAs are financed by state funds, which means that they are not affected by problems with market liquidity. At the same time, they constitute indirect support of the state in financing domestic enterprises on foreign markets, as part of their capital investments or sale of their products, services or intangible assets in the form of the technology. The ECAs also ensure coverage for political risks, which in emerging markets can be particularly high and costly in commercial banks. To reduce exposure to foreign exchange risk the export agencies provide financing in the local currency in which an entity generates revenues on the foreign market (Figure 2).

Export agencies are able to extend the debt repayment to around twelve years, while in developed countries, according to the OECD, this period usually does not exceed ten years. By offering longer payback periods, the ECAs are a serious competition for commercial banks. In addition, the financial costs of the financing granted under the ECAs are much lower than in the case of commercial banks.

ECAs have a much greater creditworthiness than banks and other financial institutions, which means that they can support the financing of projects up to several billion USD. The financing often reaches to 85% of an eligible contract value and covers the agency's risk and 30% of the local costs of the export value. As a result, the obtained financing may significantly exceed the equity of the project, and therefore it may be characterized by a high degree of financial leverage. That is impossible to achieve in terms of bank financing. ECAs also has tax advantages, this financing is exempt from withholding taxes. Thus, it is an attractive property that determines the profitability of projects in countries with restrictive tax policies.

The opponents of the ECA point to hidden mechanisms of supporting and financing activities, especially in developing countries, for economic entities from developed countries, which naturally strive to expand sales markets and ensure additional revenues for themselves. At the same time, it is believed that ECAs are state-owned vehicles that ensure the functioning of domestic entrepreneurs, who are allowed to expand internationally, outside their domestic markets, where they are unable to function effectively.

At present, the model of ECA functioning in the world has significantly changed and is evolving under the direction of China, Japan and Korea's agencies. The Asian model is characterized by a specialization, in one country operates two kinds of agencies. One of them acts as a lender and insurer in short-term transactions, while the other acts as a lender in medium and long-term projects, offering a wide range of additional services in addition to core financing. The second one does not necessarily offer services along a common value chain for a specific economic entity.

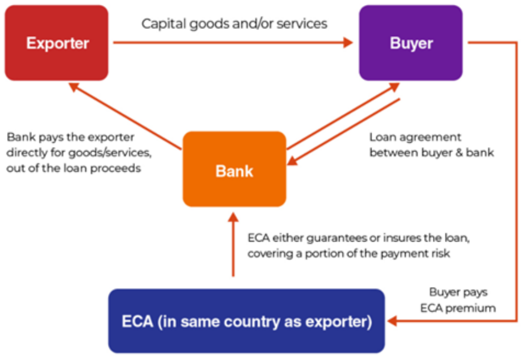

Fig. 2. How ECA works. Source: [12]
Rys. 2. Schemat działania ECA. Źródło: [12]

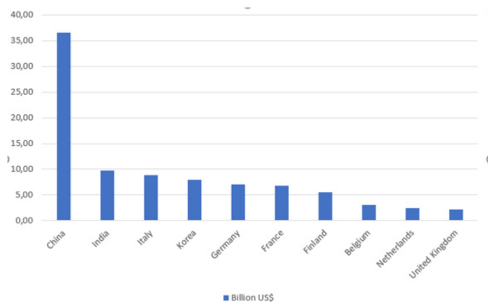

Fig. 3. Top 10 ECA providers 2017. Source: Own elaboration based on [14]
Rys. 3. 10 największych Agencji Kredytów Eksportowych. Źródło: Opracowanie własne na podstawie [14]

In the European market, short-term transactions are handled by private entities in the form of commercial banks or providers offering trade credit. In some European Union countries it is forbidden to involve ECA agencies as a support for short-term transactions.

In Table 2 is presented a list of the largest export credit agencies in the world, including their market specialization based on lending and financing insurance.

Short-term transactions are financed by Asian ECAs, as:Chinese Sinosure, Korean K-sure and Japanese NEXI. This is due to the previously described model of evolution and the resulting market specialization.

In the case of the medium and long-term market, financial involvement through the ECA agencies was shown by China, which in 2016 provided capital in the amount of USD 34 billion. Russia, South Africa and India have showed the highest dynamics of this type of financing. Overall, the BRICS countries involved USD 51 billion in the international financing of their entities in 2016.

In 2017 capital provided by China was more than USD 36 billion and the top ten ECAs all together have spent USD 90 billion for export transactions financing (Figure 3).

In the case of OECD countries, the total value of financing provided in 2016 was approximately USD 66 billion. The largest share in this financing was held by Italy (USD 10.3 billion), Germany (USD 9.7 billion), France (USD 9.4 billion) and Korea (USD 7.4 billion).

The share in financing export transactions of individual countries through the ECA agencies operating on their territory is shown in Figure 4.

In the chart above (Figure 4) it is visible that the highest level of export financing took place in 2012 (over 120 billion). Since this year, the value of transactions has been systematically declining, but still is at a level over USD 60 billion. The countries most involved in supporting exports are Germany, France, Italy, Korea, Japan and the USA. The chart shows also that US involvement in export financing has significantly decreased since 2012.

5. The possibilities of alternative financing in the mining industry

The figure below (Figure 5) shows outflows of ECAs' funds in OECD countries in years 2009-2018. As it is visible in OECD countries mining has only 9% the expenditure structure of ECAs' funds. That number would be higher if we took into account world data.

However, ECAs are an important source of financing for mining projects, sometimes even the only one possible, especially for projects in the construction phase, where there are high financial costs on loans granted for capital-intensive investments.

If hard coal mining was taken into consideration then the strongest involvement in mining financing would be as follows: Japan, South Korea, China and Germany (Figure 6).

In the case of Japan, the largest beneficiaries of mining financing are domestic companies related to the mining industry, such as Hitachi, Toshiba and Mitsubishi. For example, in 2014 Mitsubishi obtained financing in the amount of USD 1.4 billion from JBIC (Japan Bank for International Co-operation) for the purchase of shares of the Caval Ridge - coal project in Queensland, Australia.

Tab. 2. The largest ECAs operating in the world. Source: Own elaboration based on [13]
Tab. 2. Największe ECA, które istnieją na świecie. Źródło: Opracowanie własne na podstawie [13]

No.	Country	Name of ECA	Specialization
1	China	China Export and Credit Insurance Corporation **Sinosure**	I
		The Export-Import Bank of China **CHEXIM**	F
2	Italy	Servizi Assicurativi del Commercio Estero S.p.A. **SACE**	I+F
3	Germany	**Euler Hermes**	I+F
4	France	Compagnie Française d'Assurance pour le Commerce Extérieur **COFACE**	I
		Banque Publuquw d'Investissement **Bipfrance**	F
5	Korea	Korea Trade Insurance Corporation **K-sure**	I
		Export-Import Bank of Korea **KEXIM**	F
6	India	Export Credit Guarantee Corporation of India **ECGS**	I
		Export-Import Bank of India **India-Eximbank**	F
7	Russia	Export Insurance Agency of Russia **EXIAR**	I+F
8	United Kingdom	UK Export Finance **UKEF**	I+F
9	Canada	Export Development Canada **EDC**	I+F
10	Japan	Nippon Export and Investment Insurance **NEXI**	I
		Japan Bank for International Corporation **JBIC**	F
11	USA	Export Import Bank of U.S. **EXIM**	I+F

I – Insurance, F – Financing

The involvement of some countries in the financing of hard coal mining projects, may be surprising, especially in relation to the climate policy and global air protection they promote. The most surprising is the participation of Germany, which through companies related to the mining industry, engaged over USD 3 billion in years 2007-2015. So far, the USA and France have banned ECA financing of mining projects and coal-based energy.

Among developing countries that are the largest recipients of ECAs' (funds for coal mining) finds also Australia, which is one of the ten richest countries in the world and at the same time has accepted over USD 4 billion of financing involved in hard coal mining. This is not surprising, however, as Australia is considered a mining country, where gross domestic product and its growth largely depend on the mining industry. In turn, the energy industry is based on conventional energy sources, which are constantly being developed through systematic financing into new strategic projects.

Non-coal mining entities have much more easier access to traditional financing, but they also reach for ECAs funds (Tabele 3).

The first one on the list is the mine copper and gold mine Oyu Tolgoi in Mongolia. The Rio Tinto company is running that project. The value of that project is estimated at US$4.4bn. That investment will be financed by 20 lenders such as: commercial banks, ECAs and a range of development finance institutions. ECAs, which are in that project are as follow: Export Development Canada (EDC), the European Bank for Reconstruction and Development (EBRD), the International Finance Corporation (IFC), the Export-Import Bank of the United States (US Exim) and the Export Finance and Insurance Corporation of Australia (Efic). All together they will lend to Rio Tinto USD 1,3 billion. [17]

Another example is the financing of the copper mine Mina Justa in Peru. The whole project is estimated at USD 1,7 billion. The financing of that project is provided also by banks and the following ECAs: Export Development Canada (EDC), Export Finance and Insurance Corporation (EFIC), the Australian ECA) and Export Import Bank of Korea (Kexim). Only Kexim has financed USD 200 million.

Kexim has been growing its presence in Latin America in recent years in a bid to solidify South Korea's supply of raw minerals. In 2015, it signed on-lending deals worth US$3.2bn with five banks in Brazil, Chile and Peru.

This followed a state visit by former Korean president Park Geun-hye in the same year, which saw a range of investment deals signed. The most high-profile deal was a US$13bn agreement between the Peruvian energy ministry and Kexim to collaborate on a petrochemical complex. [18]

6. Summary

The global policy aims to achieve climate neutrality, which means the industry decarbonisation. Recently, this policy has a large impact on the shape of today's mining, especially mining related to conventional energy resources as well as to all undertakings indirectly related to coal mining. The economic climate around the fuel and conventional energy industry, causes that institutions of the traditional financial market are reluctant to get involved financially in all projects related to coal, or even they completely cut themselves off from such undertakings. Therefore, all investments related to hard coal mining have problems with obtaining financing from tradi-

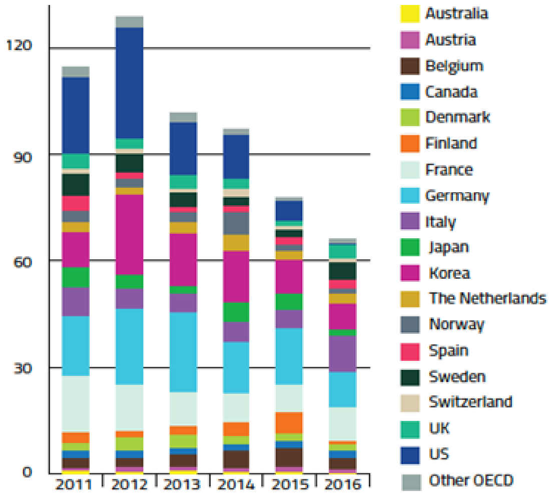

Fig. 4. The share of financing and its changes in 2011-2016 of individual countries in which operate ECAs [USD billion]. Source: [13]
Rys. 4. Udział finansowania poszczególnych państw w których funkcjonują ECA i jego zmiany w latach 2011-2016 [mld USD]. Źródło: [13]

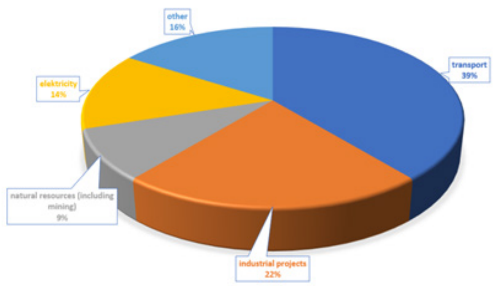

Fig. 5. Outflow in 2009-2018 of ECAs' funds in OECD countries. Source: Own elaboration based on [19]
Rys. 5. Kierunki finansowania przez ECA w krajach OECD. Źródło: Opracowanie własne na podstawie [19]

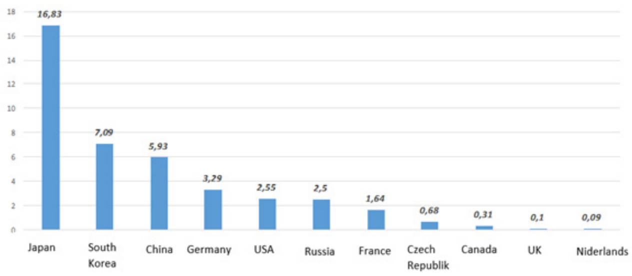

Fig. 6. The largest countries that finance coal mining activities through the ECAs [USD billion]. Source: Own elaboration based on [15]
Rys. 6. Wykaz państw z największym udziałem w finansowani górnictwa przez Agencje Kredytów Eksportowych [mln USD]. Źródło: Opracowanie włase na podstawie [15]

Tab. 3. Mines' projects financing by EXIM. Source: [16]
Tab. 3. Projekty finansowane przez EXIM. Źródło: [16]

	Project	Mineral	Country	EXIM Financing ($millions)
2013	Oyu Tolgoi LLC	Copper/Gold	Mongolia	$367
2013	Roy Hill Holdings Pty. Ltd.	Iron	Australia	$694
2011	Downer Edi Mining Pty Ltd.	Iron	Australia	$58
2010	Pueblo Viejo Dominicana Corp.	Gold	Dominican Republic	$375
2010	Minera y Metalurgica del Boleo	Copper-Cobalt-Zinc	Mexico	$420
2010	ANZ/Leighton Holdings Ltd.	Coal	Australia	$15
2004	Minera Argentina SA/Veladero	Gold	Argentina	$77
1997	PT Newmont Nusa Tengarra/Batu Hijau	Copper/Gold	Indonesia	$425
1996	Minera Alumbrera Ltd.	Copper/Gold	Argentina	$228
			TOTAL:	$2,658

tional sources. Mining and related enterprises have to look for alternative forms of financing. One of such forms are Export Credit Agencies.

Export credit agencies fill the gap in the financial market by providing capital for strategic development and creating long-term value of mining enterprises. This is especially important in emerging markets. At the same time, these agencies are a key tool for exports support and the promotion of capital expansion of economic entities from the same political area.

The largest beneficiaries of this market are Asian markets as Japanese, Korean and Chinese companies, where also the largest ECAs come from. The leader on the European ECAs' market is Germany, supporting mining-related entities in their foreign market expansion. In turn, countries that use such financing belong to a group of developing countries, e.g. Vietnam, South Africa, India, the Philippines and Indonesia. Surprising is that also Australia, one of the richest countries in the world, is heavily using ECAs as a source of mining industry financing.

The ECAs as a source of alternative financing may be an interesting option for the domestic mining industry and entities associated with it, but also for enterprises which are struggling with lack of capital.

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Alternatywne sposoby finansowania w globalnym górnictwie: Agencje Kredytów Eksportowych (ECA)

W dzisiejszych czasach przedsiębiorstwa górnicze spotykają się z trudnościami odnośnie możliwości uzyskania finansowania z tradycyjnych źródeł na realizację projektów geologiczno-górniczych. Rozwiązaniem problemów z finansowaniem takich projektów mogą być alternatywne źródła finansowania, tj. development finance, royalty agreements, streaming, standby equity, off take, EPCM/equipment finance lub ECA. W artykule przeanalizowano możliwości wykorzystania tych źródeł w zależności od fazy cyklu życia projektu geologiczno-górniczego. W dalszej części główną uwagę poświęcono Agencjom Kredytów Eksportowych (ECA), które dają dużo wiesze możliwości niż tradycyjne banki. W artykule przedstawiono największe Agencje Kredytów Eksportowych na świecie i wskazano ich cechy charakterystyczne na tle konwencjonalnych źródeł finansowania. Zidentyfikowano największe państwa finansujące, ale również pozyskujące takiego rodzaju kapitały w odniesieniu do branży górniczej.

Słowa kluczowe: *alternatywne źródła finansowania, Agencje Kredytów Eksportowych, finansowanie w górnictwie*

Bioleaching of Selected Metals from Waste Printed Circuit Boards by Fungs

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Abstract

The growing demand for non-ferrous metals over the last centuries has resulted in constant extraction of natural resources - in case of many crucial and most widely used raw materials, accessible and high-quality deposits are already close to being depleted. Waste electrical and electronic equipment (WEEE) constitutes a rich, secondary source of metals, the amount of which in the EU is increasing every year. In order to increase resource efficiency and contribute to a circular economy, it is necessary to improve the processing and recycling of waste electrical and electronic equipment at the end of an electronic lifetime. The choice of a suitable method of processing this waste is vital due to the complex and materially diverse composition of WEEE. Waste printed circuit boards (WPCBs) that constitute approx. 3-5% of WEEE by weight are of particular importance from both environmental and economic point of view.

The article investigates the recovery of Cu, Ag and Al from WPCBs using an industrial fungal strain of Aspergillus niger. The bioleaching process was carried out using 3 methods (one-step, two-step and spent medium) in an incubator with shake depending on the contact time and pulp density.

The research presented in the article aimed at assessing the usefulness of the biotechnological method for leaching of selected metals from e-waste. The results indicate that it is possible to mobilise metals from the WPCBs using microorganisms.

Keywords: *metals bioleaching, waste printed board, fungi*

Introduction

Metals are important in all aspects of our daily life. According to the OECD's global forecasts concerning material requirements by 2060, the global demand for non-ferrous metals will increase faster than demand for any other raw material – from 7 to 19 gigatonnes per year by 2060. This is due to social change, growing world population and, above all, new technologies – non-ferrous metals are vital for the transition to a low-carbon economy due to their use in breakthrough technologies such as electric vehicles, renewable energy sources and batteries. The growing demand for non-ferrous metals over the last centuries has resulted in constant extraction of natural resources - in case of many crucial and most widely used raw materials, accessible and high-quality deposits are already close to being depleted. What is more, the extraction and processing of non-renewable raw materials involves interference in the environment (Pollmann et al., 2018)

A relevant approach concerning saving resources seems to be recycling. It allows for reusing raw material that has already been exhausted. Waste produced becomes a renewable, secondary source of natural resources which limits its depletion. Moreover, effective recycling provides safe resources for industrialised countries and reduces dependence on resource-rich countries (Dodson et al., 2012; Woynarowska, Żukowski, 2012).

Waste electrical and electronic equipment (WEEE) constitutes a rich, secondary source of metals, the amount of which in the EU is increasing every year from about 9 million tonnes produced in 2005 to the expected more than 12 million tonnes in 2020. (https://ec.europa.eu/environment/waste/weee/index_en.htm). In order to increase resource efficiency and contribute to a circular economy, it is necessary to improve the processing and recycling of waste electrical and electronic equipment at the end of an electronic lifetime. The choice of a suitable method of processing this waste is vital due to the complex and materially diverse composition of WEEE. Waste printed circuit boards (WPCBs) that constitute approx. 3–5% of WEEE by weight are of particular importance from both environmental and economic point of view. They contain, on average, 30-40% of metals by weight, with higher purity than in minerals, including base metals (Cu, Zn), precious metals (Au, Ag, Pd) and heavy metals.

To recycle waste printed circuit boards (WPCBs), mechanical, chemical, and biological methods can be used. Traditional pyrometallurgical and physical separation methods are energy-intensive, while hydrometallurgical methods generate large amounts of chemical waste. (Zhang Y. et al., 2012; Hao J. et al., 2020; Kaya M., 2017; Li H. et al., 2018; Lu Y., Xu Z., 2016; Akcil A. et al., 2015, Cui J, Zhang L, 2018). Therefore, it seems that biohydrometallurgical methods which can be described as ecological, inexpensive, "low-tech" processes with low emission of hazardous substances, using naturally occurring microorganisms and their metabolic products to extract metals from the matrix, have a chance to be applied on an industrial scale. These methods have already been successful in the processing of low-quality ores and bioleaching of industrial solid waste (Xi M. et al., 2018; Pollmann et al., 2018).

The microorganisms involved in the process of bioleaching of WPCBs are mainly chemoautothrops Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans (Brandl H. et al., 2001; Hong Y., Valix M., 2014; Yang Y. et al., 2014), iron-oxidizing bacteria and sulfur bacteria (Wang S. et al., 2016; Kar-

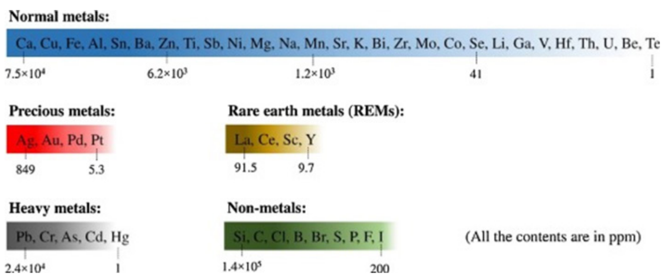

Fig. 1. Contents of metallic and non-metallic elements in typical WPCBs (metal contents decrease with the colour becoming light) (Li H. et al., 2018)
Rys. 1. Zawartość składników metalicznych i niemetalicznych w typowych WPCB (zawartość metali zmniejsza się wraz z rozjaśnianiem się koloru) (Li H. i inni, 2018)

wowska E. et al., 2014; Xia M.C. et al., 2017; Willscher S. et al., 2007; Shah M.B. et al., 2015; Ilyas S. et al., 2010; Xiang Y. et al., 2010; Zhu N. et al., 2011) heterotrophic bacteria Chromobacterium violaceum (Faramarzi M.A., et al., 2004; Chi T.D. et al., 2011) and mould fungus Aspergillus niger (Jadhav U. et al., 2016; Brandl H. et al., 2001; Faraji F. et al., 2017; Kolenčík M. et al., 2013), Penicillium sp. (Ilyas S., Lee J.C., 2013; Brandl H. et al., 2001) and Rhizopus sp. (Netpae T., Suckley S. et al., 2019)

The article investigates the recovery of Cu, Ag and Al from WPCBs using an industrial fungal strain of Aspergillus niger. The bioleaching process was carried out using 3 methods (one-step, two-step and spent medium) in an incubator with shake depending on the contact time and pulp density.

Materials and methods

Pretreatment of WPCBs

Printed circuit boards were separated from mobile phones manually and then crushed in a hammer mill. Three-stage shredding was performed. The first stage involved shredding using a 15mm sieve. The shredded material was classified on a 1mm sieve. Sieving resulted in obtaining a final product with a grain size of 0–1mm and retained with a grain size >1mm, which was put back to the mill. Before the second stage, the sieve was changed to a 5 mm one. The product was sieved, and the results were the same as in the previous stage – grain size 0-1mm. Grains larger than 1mm were put back to the mill. In the last stage, a 1mm sieve was used. Grain size was classified as 0–1mm. Shredding process using hammer mill made it possible to separate the grain size classes, which were subjected to further investigation. The process diagram is shown in Figure 2. During shredding, dust collectors collected dust, which, due to its low weight, constituted a ready product for examination using microorganisms. Shredded material with grain size >1mm was directed to a magnetic separator, where a magnetic and non-magnetic material were detached, which, when combined with the dust collected during the shredding process, was a source for further biological research. Next, in order to ensure sterility, the feed was cleansed using deionised water and placed in the dryer at a temperature of 80oC for 24h.

Chemical analysis

The WPCBs sample was dissolved using aqua regia and then the obtained solution was filtered and analysed for metal content using the Philips PU-9100x atomic absorption spectrophotometer. Obtained results are presented in Table 1.

To analyse the metal content of the bioleaching process, 5 ml of leaching solution was centrifuged at 10,000 RPM for 15 minutes in order to separate the mycelium and then filtered using syringe filters to completely remove solids. The supernatant obtained in such a way was analysed for the average metal content using Philips PU-9100x atomic absorption spectrophotometer.

The medium's pH change was monitored using WTW InoLab® Multi 9310.

Metal recovery at each step was calculated according to the following equation:

$$\textit{Bioleaching efficiency (\%)} = C_1/C_0 \cdot 100$$

where C_0 and C_1 are concentrations of metals in the solution before and after bioleaching, respectively.

Microorganisms and growth condition

The A. niger 419 strain used in the research was obtained from the Institute of Agriculture and Food Biotechnology's microbe culture collection. The strain was cultured on potato dextrose agar (PDA) BTL P-0134 at 28°C for 7 days. After the set incubation time, spores were collected by cleansing the surface with deionised water. The obtained suspension was diluted to 107 spores/ml (inoculum). The number of spores was counted using the microscope (magnification 400x) applying a haemocytometer.

Shake flask one-step bioleaching

Inoculum with a concentration of 1ml/100ml of medium was added to 500ml Erlenmeyer flasks containing 200ml of Sabouraud broth BTL P-0133 and various pulp densities of WPCBs 0.1; 0.5; 1; 2.5; 5% w/v, and incubated for 25 days. During a given period of the process, samples of the leaching solution were taken at selected intervals in order to analyse the metal content.

Shake flask two-step bioleaching

In two-step bioleaching, pre-cultivation was carried out by adding an inoculum at a concentration of 1ml/100ml of medium to a 500ml Erlenmeyer flask containing 200ml of Sabouraud broth BTL-P-0133 with no WPCBs. After 5 days, the WPCBs with the concentration of 2.5% w/v was added and the obtained suspension was incubated for 20 days. During a given period of the process, samples of the leaching solution were taken at selected intervals in order to analyse the metal content.

Shake flask spent medium bioleaching

Pre-cultivation involving adding an inoculum at a concentration of 1ml/100ml of feed to a 500ml Erlenmeyer flask

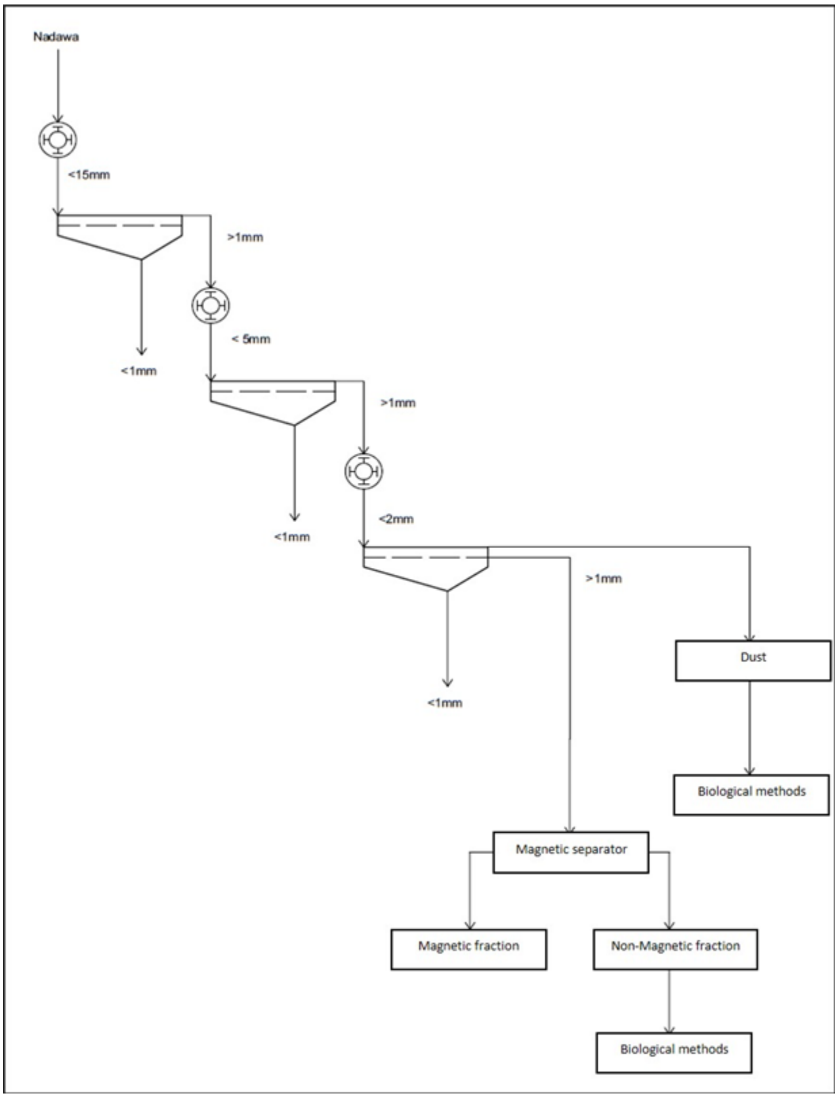

Fig. 2. Diagram of processing printed circuits board of a mobile phone
Rys. 2. Schemat przeróbki płytek drukowanych pochodzących z telefonów komórkowych

Tab. 1. Chemical analysis for metal content of WPCBs
Tab. 1. Patka. 1. Analiza chemiczna zawartości metali w WPCB

Metal type	Metal content (%w/w)
Al	0,36
Cu	14,76
Ag	0,0012

containing 200ml of Sabouraud broth BTL-P-0133 with no WPCBs was carried out. After 10 days of cultivation, the obtained mycelium was separated from the medium, then the medium was filtered in order to remove the remains of mycelium and spores. WPCBs with the concentration of 2.5% w/v was added to the obtained medium and the suspension obtained was left for 15 days. During a given period of the process, samples of the leaching solution were taken at selected intervals in order to analyse the metal content.

Results and discussion

Mechanism of fungal bioleaching

Bioleaching of metals by mould fungus usually involves indirect process consisting of bioproduction of organic acids, amino acids, and other metabolites. The metabolites produce dissolve (mobilise) metals in the two processes: the first is displacing metal ions from the solid matrix with hydrogen ions (acidolysis) and the second involves forming soluble metal and chelate complexes and their stabilisation in solution (complexolysis) (Xia M. et al., 2018; Işıldara A. et al., 2019). The dissociation and complexation reactions of organic acids that occur during the bioleaching process are presented below (Faraji F. et al., 2018):

Citric acid dissociation and complexation:

$$C_6H_8O_7 \rightarrow C_6H_7O_7^{\ -} + H^+ \quad (pK_{a1} = 3{,}09)$$
$$C_6H_7O_7^{\ -} \rightarrow C_6H_6O_7^{\ 2-} + H^+ \quad (pK_{a1} = 4{,}75)$$
$$C_6H_6O_7^{\ 2-} \rightarrow C_6H_5O_7^{\ 3-} + H^+ \quad (pK_{a1} = 6{,}40)$$
$$n[C_6H_7O_7^{\ -}] + M^{n+} \rightarrow M[C_6H_7O_7]_n$$
$$n[C_6H_6O_7^{\ 2-}] + 2M^{n+} \rightarrow M_2[C_6H_6O_7]_n$$
$$n[C_6H_5O_7^{\ 3-}] + 3M^{n+} \rightarrow M_3[C_6H_5O_7]_n$$

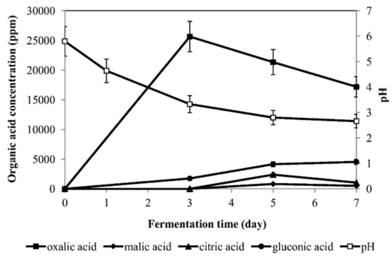

Fig. 3. Kinetics of production of organic acids. (Rasoulnia P., Mousavi S.M., 2016)
Rys. 3. Kinetyka tworzenia kwasów organicznych (Rasoulnia P., Mousavi S.M., 2016)

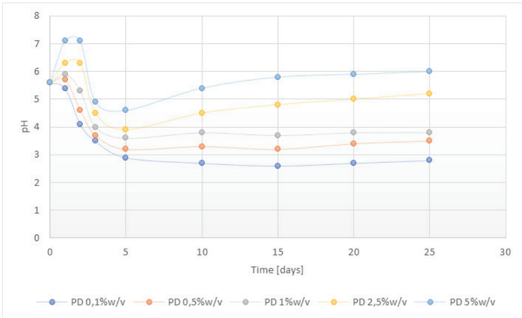

Fig. 4. Alteration in pH within the 25st days of one step bioleaching by A. niger (T=28°C; 120 rpm speed)
Rys. 4. Zmiany odczynu podczas 25 dni jednostopniowego procesu bioługowania z wykorzystaniem A. niger (T=28°C; 120 rpm speed)

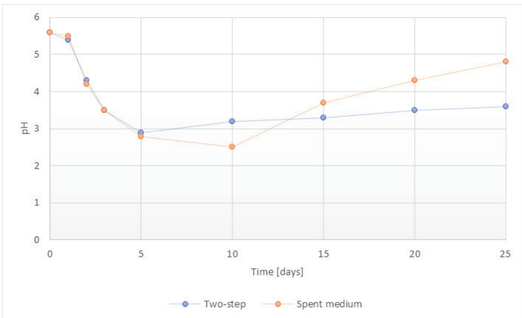

Fig. 5. Alteration in pH within the 25st days of two step/spent medium bioleaching by A. niger (T=28°C; 120 rpm speed; PD =2,5% w/w)
Rys. 5. Zmiany odczynu podczas 25 dni dwustopniowego/pośredniego procesu bioługowania z wykorzystaniem A. niger (T=28°C; 120 rpm speed; PD =2,5% w/w)

Oxalic acid dissociation and complexation:

$$C_2H_2O_4 \rightarrow C_2HO_4^{\ -} + H^+ \quad (pK_{a1} = 1{,}25)$$
$$C_2HO_4^{\ -} \rightarrow C_2O_4^{\ 2-} + H^+ \quad (pK_{a1} = 4{,}14)$$
$$n[C_2HO_4^{\ -}] + M^{n+} \rightarrow M[C_2HO_4]_n$$
$$n[C_2O_4^{\ 2-}] + 2M^{n+} \rightarrow M_2[C_2O_4]_n$$

Gluconic acid dissociation and complexation:

$$C_6H_{12}O_7 \rightarrow C_6H_{11}O_7^{\ -} + H^+ \quad (pK_a = 3{,}86)$$
$$n[C_6H_{12}O_7^{\ -}] + M^{n+} \rightarrow M[C_6H_{12}O_7]_n$$

Malic acid dissociation and complexation:

$$C_4H_6O_5 \rightarrow C_6H_5O_5^{\ -} + H^+ \quad (pK_{a1} = 3{,}40)$$
$$C_6H_5O_5^{\ -} \rightarrow C_6H_4O_5^{\ 2-} + H^+ \quad (pK_{a1} = 5{,}11)$$
$$n[C_6H_5O_5^{\ -}] + M^{n+} \rightarrow M[C_6H_5O_5]_n$$
$$n[C_6H_4O_5^{\ 2-}] + 2M^{n+} \rightarrow M_2[C_6H_4O_5]_n$$

All organic acids mentioned above play a key role in the process of leaching metals from PCBs. However, citric acid and oxalic acid are of the most importance. This is due to the fact that citric acid has the greatest ability for complexation while oxalic acid is one of the strongest acids. Hydrogen ions of acids release (mobilise) metal ions and metal chelation stabilise them in the solution.

It should be noted that compared to bacterial leaching, fungal bioleaching has several advantages, namely:

- ability to grow at higher pH, making it more suitable for biological leaching of alkaline material
- usually shorter bioleaching process time
- chelation of metal ions with metabolites (organic acids) reduced their toxicity (Xia M. et al., 2018).

Organic acids production kinetics

During the first three days of Aspergillus niger mycelium growth, accelerated production of oxalic acid occurs, which is gradually decreasing, but at the end of the seventh day there is still a significant amount of it in the medium. Such a relationship occurs because in the early days of fungal growth, the pH of the medium is higher and oxalic acid secretion occurs mainly when pH values are above 4.

As the concentration of oxalic acid in the medium decreases, gluconic acid production increases. Gluconic acid secretion occurs at pH values lower than values for oxalic acid

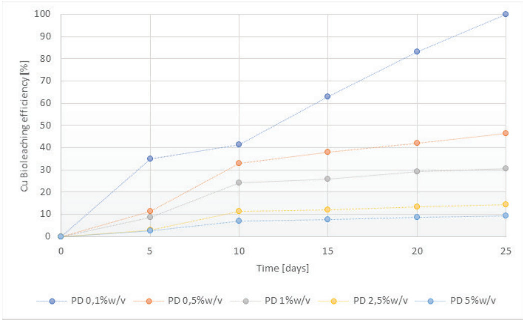

Fig. 6. Bioleaching efficiency of Cu as a function of time; one-step bioleaching, Aspergillus niger, T=28°C; 120 rpm speed
Rys. 6. Skuteczność biołogowania Cu w funkcji czasu; jednostopniowe biołogowanie, Aspergillus niger, T=28°C; 120 rpm speed

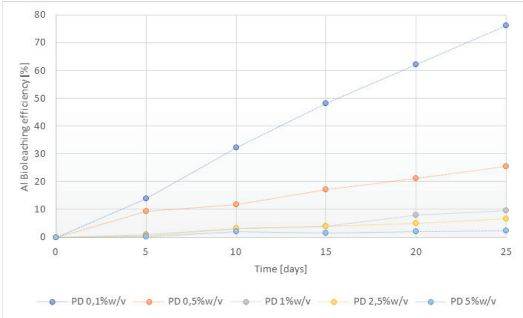

Fig. 7. Bioleaching efficiency of Al as a function of time; one-step bioleaching, Aspergillus niger, T=28°C; 120 rpm speed
Rys. 7. Skuteczność biołogowania Al w funkcji czasu; jednostopniowe biołogowanie, Aspergillus niger, T=28°C; 120 rpm speed

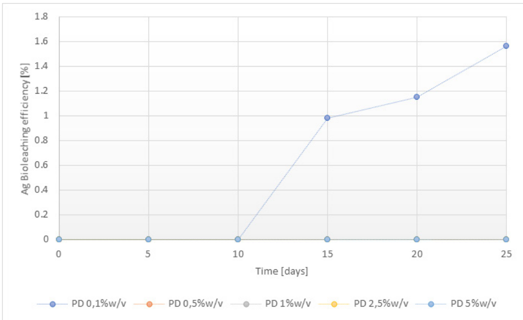

Fig. 8. Bioleaching efficiency of Ag as a function of time; one-step bioleaching, Aspergillus niger, T=28°C; 120 rpm speed
Rys. 8. Skuteczność biołogowania Ag w funkcji czasu; jednostopniowe biołogowanie, Aspergillus niger, T=28°C; 120 rpm speed

production but higher than those for citric acid production. Thus, as long as the pH of the medium is maintained within the acceptable range, gluconic acid will be produced to a sufficient degree and then its production will gradually be stopped.

Citric acid production carried out by Aspergillus niger does not occur in the exponential growth phase, but in secondary productivity, which is characterised by a reduced growth rate and low external pH. Therefore, taking into consideration the first days of mycelium growth, the production of citric acid is negligible compared to other organic acids. In case of the longer growth period and keeping the low pH of the medium, citric acid would probably be the main metabolite present in the medium as it reduces the concentration of oxalic acid present in the medium by using it in the Krebs cycle.

After three days of mycelium growth, the production of malic acid commences gradually, but its concentration is much lower compared to other present organic acids. (Rasoulnia P., Mousavi S.M., 2016).

However, it should be noted that the presence of metals in the medium may affect the kinetics of organic acid production. According to published research, in one and two-step bioleaching process, the presence of Cu ions can interrupt citric acid production, the existence of Mn ions in the medium can cause gluconic acid production (Wu H.Y., Ting, Y.P., 2006; Xu T.J. et al., 2014) while oxalic acid concentration may be higher in the presence of heavy metals (Santhiya D., Ting Y.P., 2005).

Changes in pH of culture medium during bioleaching

The aqueous solution is one of the most important factors in bioleaching process. It is related to the kinetics of organic acids production, which have a decisive influence on leaching of metals from WPCBs. The following Graphs 1–2 illustrate the changes in pH over time using different bioleaching methods.

The graphs show trends in pH changes depending on the bioleaching model. In all three cases, one might spot an initial

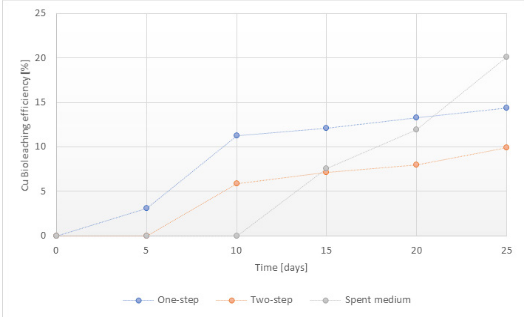

Fig. 9. Bioleaching efficiency of Cu as a function of time of a) one step at PD of 2%w/v, b) two step at PD of 2%w/v and c) spent medium at PD of 2%w/v (Aspergillus niger, T=28°C; 120 rpm speed)

Rys. 9. Skuteczność bioługowania Cu w funkcji czasu; a) jednostopniowe bioługowanie, b) dwustopniowe bioługowanie c) bioługowanie pośrednie (Aspergillus niger, T=28°C; 120 rpm speed)

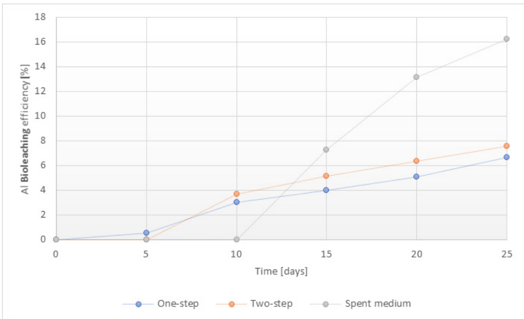

Fig. 10. Bioleaching efficiency of Al as a function of time a) one step at PD of 2%w/v, b) two step at PD of 2%w/v and c) spent medium at PD of 2%w/v (Aspergillus niger, T=28°C; 120 rpm speed)

Rys. 10. Skuteczność bioługowania Al w funkcji czasu; a) jednostopniowe bioługowanie, b) dwustopniowe bioługowanie c) bioługowanie pośrednie (Aspergillus niger, T=28°C; 120 rpm speed)

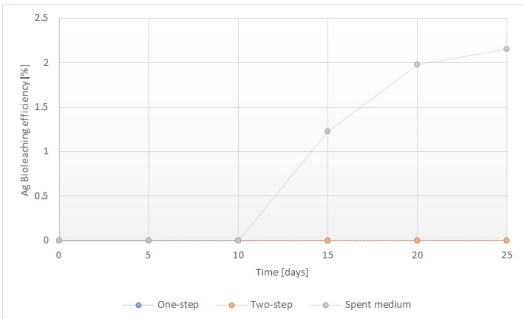

Fig. 11. Bioleaching efficiency of Ag as a function of time a) one step at PD of 2%w/v, b) two step at PD of 2%w/v and c) spent medium at PD of 2%w/v (Aspergillus niger, T=28°C; 120 rpm speed)

Rys. 11 Skuteczność bioługowania Ag w funkcji czasu; a) jednostopniowe bioługowanie, b) dwustopniowe bioługowanie c) bioługowanie „spent medium" (Aspergillus niger, T=28°C; 120 rpm speed)

sharp drop in pH over a period of 5 days, which corresponds to a phase of exponential growth of mycelium and production and dissociation of organic acids. (Faraji F. et al., 2017; Kolenčík M. et al., 2013). After that time, changes in pH were dependent on the presence and concentration of PD, but general trends were still visible. The downward trend is associated with the formation of organic acids. The upward trend, on the other hand, is caused either by the use of organic acids in the leaching process or by inhibition/disturbance of mycelium activity by metals (Horeh et al., 2016; Xia M. et al., 2018). What is more, according to Amiri et al. (2012), the 10th day of incubation is the end of the active growth phase and is followed by a decrease in the concentration of citric acid in the medium, which might be associated with the resorption of organic acids by mycelium.

Metals recovery at different fungal bioleaching approaches

Another crucial parameter affecting the efficiency of bioleaching is the concentration of metals in suspension (PD). It has been observed that a high content of WPCBs in the suspension has a negative effect on microorganisms and reduces the rate of bioleaching. This is due to the toxicity of metals and/or the insufficient amount of oxygen in the case of bacterial biomass, which inhibits the bioleaching rate (Zhu N. et al. 2011; Ilyas S. et al., 2010; Ilyas S. et al., 2013; Yang Y. et al., 2014). Graphs below illustrate the recovery of metals over time using different bioleaching methods.

The analysis of the results shows a clear relationship between metal recovery and PD and the chosen bioleaching method. Graphs 3–5 show that as the PD increases, metal recovery in the one-step bioleaching approach decreases. One might explain it by assuming that the presence of a high concentration of toxic metals has an inhibitory effect on organisms. The growth and activity of the inoculum can be delayed or even inhibited, which is limited to a one-step bioleaching process with low PD. In addition, concerning a one-step process, it is challenging to provide optimal conditions for both the growth of organisms and metal extraction, which may also contribute to lower metal recovery in this process (Faraji F. et al., 2018; Kolenčík M. et al., 2013; Ilyas S. et al., 2013).

The analysis of shows the highest metal recovery to occur in the spent medium bioleaching method. In this case, contact of mycelium with toxic metals is completely eliminated. This results in higher metal extraction over less amount of time and the possibility to carry out the process with higher PD. However, concerning this method, the content of organic acids in the used medium depends on the conditions in which the culture was carried out. This may result in effective leaching of only some metals, depending on the concentration of the relevant organic acid (Faraji F. et al., 2018).

In the case of two-step bioleaching process, the effect of toxic metals on mycelium in the initial growth phase is eliminated. Mycelium can grow in optimal conditions until the first metabolites are produces. This should result in higher metal extraction over less amount of time and the possibility to carry out the process with higher PD. The analysis of the graphs shows that in this method, the recovery is higher concerning Al, but lower concerning Cu. This might be due to the low concentration of oxalic acid, which is most effective concerning mobilisation and retaining of Cu in a solution, which is due to its ability to produce insoluble oxalates. (Cui, H., Anderson, C.G., 2016; Santhiya, D., Ting, Y.P.,2005; Faraji F. et al., 2018).

Conclusions

Technological innovations and increased demand for electronic devices resulted in production of more and more waste with high metal content. This means that e-waste recycling is not only beneficial for waste neutralisation but also for the recovery of metals, including precious and rare-earth metals. Traditional e-waste recycling techniques, namely pyrometallurgical and hydrometallurgical techniques, are eco-unfriendly, energy-intensive, and noneconomic. This posed a challenge of using biotechnology to process e-waste and recover metals in an economical and environmentally friendly way.

The research presented in the article aimed at assessing the usefulness of the biotechnological method for leaching of selected metals from e-waste. The results indicate that it is possible to mobilise metals from the WPCBs using microorganisms such as Aspergillus niger fungi. For some elements, complete solubilisation has been achieved. However, it can be noted that in order to recover as much metal as possible, one should carry out a two-step or spent medium bioleaching process. This reduces the inhibitory effect of metals on mycelium growth and the production of metabolites which provides greater control over the process. Nonetheless, the application of biotechnological methods on an industrial scale requires further research in order to eliminate discrepancies concerning process parameters present in the literature and optimise those parameters.

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Bioługowanie wybranych metali z odpadowych obwodów drukowanych z wykorzystaniem grzybów mikroskopowych

Rosnący popyt na metale nieżelazne w ciągu ostatnich stuleci wywierał stałą presję na zasoby naturalne. W przypadku wielu ważnych i najczęściej używanych surowców na wyczerpaniu są już złoża łatwo dostępne i wysokiej jakości. Bogate, wtórne źródło metali stanowią odpady elektryczne i elektroniczne, których ilość w UE corocznie wzrasta. W celu zwiększenia efektywności gospodarowania zasobami i przyczynienia się do gospodarki o obiegu zamkniętym niezbędne jest usprawnienie przetwarzania i recyklingu urządzeń elektronicznych (WEEE) pod koniec ich życia. Dobór odpowiedniej metody przetwarzania tych odpadów jest bardzo ważny ze względu na złożony i różnorodny, pod względem materiałowym, skład zużytego WEEE. Szczególne znaczenie zarówno pod kątem środowiskowym jak i gospodarczym mają odpadowe obwody drukowane (WPCBs) stanowiące 3-5% wagowych WEEE. W artykule badano odzysk Cu, Ag i Al z WPCBs z wykorzystaniem przemysłowego szczepu grzyba pleśniowego Aspergillus niger. Proces bioługowania prowadzono 3 metodami (jednoetapowy, dwuetapowy, z wykorzystaniem pożywki zawierającej metabolity w inkubatorze z wytrząsaniem w zależności od czasu kontaktu oraz różnych gęstości zawiesiny.
Badania przedstawione w artykule miały na celu ocenę przydatności metody biotechnologicznej do ługowania wybranych metali z odpadów elektronicznych. Wyniki wskazują, że jest możliwe mobilizowanie metali z WPCBs przy użyciu mikroorganizmów.

Słowa kluczowe: *bioługowanie metali, odpadowe płyty drukowane, grzyby*

Zastosowanie metody wartości wypracowanej (EVM) do oceny projektów górniczych – podejście krytyczne – część 2 – doświadczenia z stosowania

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Abstrakt

Cel artykułu: celem publikacji jest zaprezentowanie na praktycznych przykładach możliwości zastosowania oraz ograniczeń w zastosowaniu metody wartości wypracowanej (EV), jako narzędzia służącego ocenie postępu prac w projektach realizowanych w przedsiębiorstwach górniczych węgla kamiennego w Polsce.
Metoda badawcza/narzędzia: metodą badawczą będzie analiza wybranych, typowych przypadków projektów oraz możliwość ich oceny za pomocą metody wartości wypracowanej.
Oryginalne rezultaty: wynikami pracy będą referencje w zakresie skutecznego wykorzystania metody wartości wypracowanej w projektach realizowanych w górnictwie węgla kamiennego.

Słowa kluczowe: *zarządzanie projektami, górnictwo węgla kamiennego, metoda wartości wypracowanej*

1. Wprowadzenie

W pierwszej części artykułu [3] zaprezentowane zostały podstawy teoretyczne stosowania metody analizy wartości wypracowanej. Metoda ta, została zbudowana z założeniem możliwości stosowania jej w różnych projektach, niezależnie od obszaru ich realizacji – budownictwa, inżynierii, górnictwa czy przemysłu. W dostępnej literaturze można znaleźć liczne przykłady, w których zaprezentowane są szczegółowe rozważania w zakresie warunków stosowania metody. Są to zwykle przykłady dotyczące realizacji projektów w obszarze szeroko rozumianego budownictwa [1, 2, 5, 8]. Z kolei przykłady na wykorzystanie metody do oceny projektów górniczych są dość skąpe [6, 7]. A nawet można znaleźć materiały krytyczne [4], lecz są one jeszcze rzadsze.

W prezentowanej publikacji zaprezentowane zostaną dwa – mocno różniące się od siebie, ale charakterystyczne dla działalności górniczej przykłady, wykorzystania metody EV do oceny projektów górniczych. Na tych przykładach przeprowadzona zostanie dyskusja w odniesieniu do uzyskanych wyników i ich zgodności z obserwacją rzeczywistych rezultatów uzyskanych w tych projektach. Zaprezentowane przykłady stanowią odzwierciedlenie realnie zrealizowanych projektów i zaistniałych w nich zdarzeń, choć zostały nieco uproszczone, dla potrzeb zamieszczenia wszystkich informacji w niniejszej publikacji.

2. Ocena projektów z wykorzystaniem EVM

Prezentowany przykład projektu został opisany przez pryzmat możliwości jego praktycznego zastosowania do rzetelnej oceny stanu realizacji projektu oraz prognozowania wartości końcowych. Przykład ten jest typowy dla przedsięwzięć realizowanych w podziemnym górnictwie w Polsce. Należy jednak podkreślić, iż opisuje on projekt polegający na realizacji robót górniczych, przygotowawczych lub udostępniających, lecz nie eksploatacyjnych – związanych z procesem wydobycia węgla, gdyż te, w sposób znaczący różnią się pomiędzy sobą w zależności od eksploatowanego surowca. Równocześnie z punktu widzenia zakładów górniczych eksploatacja jest procesem operacyjnym nie podlegającym systemowi zarządzania projektami.

a. Przykład – wykonanie sieci wyrobisk korytarzowych.

Opisywany projekt obejmuje realizację 2390 mb. wyrobisk. Wyrobiska te charakteryzują się zróżnicowanymi parametrami gabarytowo-wymiarowymi, lokalizacją w różnych skałach oraz wykonaniem w różnej technologii. Wykonanie wyrobisk wiąże się z ponoszeniem kosztu stałego (m.in. kosztami pracy, energii) oraz kosztu zmiennego (np. materiały, koszty najmu). Rozliczanie projektu będzie następowało w cyklach miesięcznych zgodnie z obmiarem zrealizowanych prac. Podstawowe informacje o planowanym projekcie – harmonogramie prac oraz ich kosztach przedstawiono w tabeli nr 1.

Dla tak skonstruowanego planu projektu wyznaczono krzywą narastania kosztów S (rys. 1).

W trakcie realizacji projektu w trzecim miesiącu jego realizacji pojawiło się opóźnienie w realizacji prac. Zamiast zaplanowanych 80 mb. wykonano jedynie 20 mb. wyrobiska. W rezultacie cały harmonogram prac uległ zmianie (tabela 2)

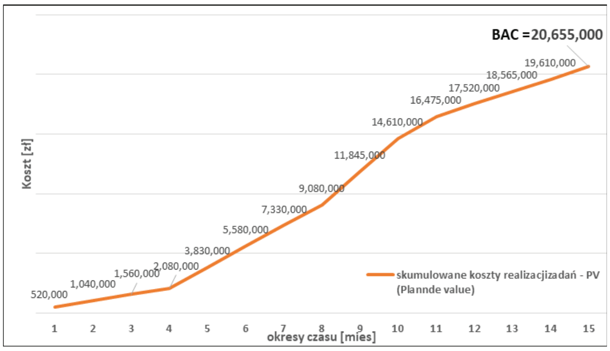
Efektem zaistniałej sytuacji jest pojawienie się od 3 miesiąca realizacji projektu, odchyleń wartości wskaźników SPI, CPI (rys 2 oraz 3).

Z danych zaprezentowanych w tablicy 2 oraz na rysunku 2 i 3 wynikają następujące wnioski związane bezpośrednio z ocenianym projektem:

1. Dane zaprezentowane w tablicy 2 oraz na rysunkach 2 i 3 wskazują na spójność uzyskanych informacji o stanie realizacji projektu, co w szczególności przedstawia wykres 3 – linia wskaźnika CPI (dolna) utrzymuje się w trakcie trwania projektu na poziomie <1, co oznacza, iż projekt zostanie

Tab. 1. Podstawowe parametry wyrobisk realizowanych w ramach projektu. Źródło: opracowanie własne
Tab. 1. Basic parameters of excavations realized in project

Wyrobisko			Okres 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Ilość [mb]	320	**80**	**80**	**80**	**80**											
	Ks [tys zł]	260 000 zł	520 000	520 000	520 000	520 000											
	Kz [zł/mb]	3 250 zł															
2	Ilość [mb]	400					**100**	**100**	**100**	**100**							
	Ks [tys zł]	425 000 zł					850 000	850 000	850 000	850 000							
	Kz [zł/mb]	4 250 zł															
3	Ilość [mb]	600					**100**	**100**	**100**	**100**	**100**	**100**					
	Ks [tys zł]	450 000 zł					900 000	900 000	900 000	900 000	900 000	900 000					
	Kz [zł/mb]	4 500 zł															
4	Ilość [mb]	770									**110**	**110**	**110**	**110**	**110**	**110**	**110**
	Ks [tys zł]	522 500 zł									1 045 000	1 045 000	1 045 000	1 045 000	1 045 000	1 045 000	1 045 000
	Kz [zł/mb]	4 750 zł															
5	Ilość [mb]	300									**100**	**100**	**100**				
	Ks [tys zł]	410 000 zł									820 000	820 000	820 000				
	Kz [zł/mb]	4 100 zł															
Metrów [mb]	w okresie		80	80	80	80	200	200	200	200	310	310	210	110	110	110	110
	skumulowane		80	160	240	320	520	720	920	1 120	1 430	1 740	1 950	2 060	2 170	2 280	2 390
	wykonano		3,3%	6,7%	10,0%	13,4%	21,8%	30,1%	38,5%	46,9%	59,8%	72,8%	81,6%	86,2%	90,8%	95,4%	100,0%
PV [zł]	w okresie		520 000	520 000	520 000	520 000	1 750 000	1 750 000	1 750 000	1 750 000	2 765 000	2 765 000	1 865 000	1 045 000	1 045 000	1 045 000	1 045 000
	skumulowane		520 000	1 040 000	1 560 000	2 080 000	3 830 000	5 580 000	7 330 000	9 080 000	11 845 000	14 610 000	16 475 000	17 520 000	18 565 000	19 610 000	20 655 000



Rys 1. Krzywa narastania kosztów planowanego projektu. Źródło: opracowanie własne
Fig. 1. Line of project cost distribution in time (actual costs – AC)

zrealizowany powyżej zaplanowanych pierwotnie kosztów; linia wskaźnika SPI, <1 w pierwszym okresie realizacji projektu oznacza opóźnienie w jego realizacji, zaś „przebicie" wartości „1" w okresie 10, a następnie wartość wskaźnika SPI>1 oznacza zwiększenie ilości prac w analizowanym okresie, co jest rezultatem opóźnienia we wcześniejszym okresie.

2. Bez szczegółowego rozpisania zakresu prac oraz związanego z każdym zadaniem budżetu nie byłoby możliwe poprawne wyznaczenie wartości służących do oceny projektu.

3. Niezbędne jest regularne wprowadzanie danych o realizowanym przedsięwzięciu. W przypadku prezentowanego projektu, liczącego ponad 12 miesięcy, standardowy układ okresu raportowania i rozliczania jest wystarczający, jednak w przypadku projektów trwających 2-3 miesiące (a czasami nawet krócej) konieczne jest określenie krótszych okresów raportowania. Nie zawsze jest to możliwe – wynika np. z zapisów umowy z dostawcą, gdzie rozliczenie realizacji projektu występuje, po zakończeniu prac lub jest zaliczkowane.

b. Innowacyjne wyposażenie dołowe

Przykład drugiego projektu jest w znaczący sposób odmienny od zaprezentowanego wcześniej, choć jest równie typowy. Jest to projekt polegający na zamówieniu innowacyjnego zestawu maszyn i urządzeń wraz z robotami górniczymi, jakie należy zrealizować dla skutecznego wdrożenia do stosowania zamówionego wyposażenia.

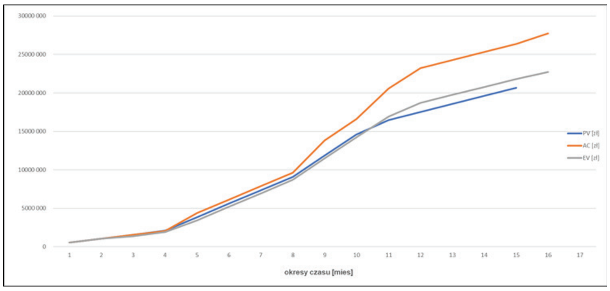
W przykładzie pierwszym mieliśmy umownie prostą sytuację, jednolity rodzaj zadań, pozwalający na jednolity sposób planowania i monitorowania postępów tych prac dla znanej technologii i procesów produkcyjnych. Prezentowany poniżej przykład to sytuacja, w której znacząca, zakresowo i finansowo, część prac jest zlecana podmiotom zewnętrznym, w związku z czym prace są rozliczane dopiero po dostarczeniu produktu klientowi. W związku z powyższym, na wykresie harmonogramu prac, ich wartość finansowa była planowana na ostatni okres rozliczeniowy danego zadania (tablica 3). Ponadto, na co należy bardzo wyraźnie zwrócić uwagę, wartość realizowanych w ten sposób prac stanowi prawie 95% planowanego budżetu projektu - dominują trzy zadania (numer 3, 6 oraz 7), odnoszące się do zakupu wyposażenia i jednocześnie.

Rezultatem przyjęcia poniższego sposobu planowania prac oraz budżetu projektu jest krzywa PV (rys 4), pokazująca skokowe przyrosty planowanych wartości kosztów projektu, zamiast linii bardziej wypłaszczonej, tak jak to miało miejsce w pierwszym przypadku.

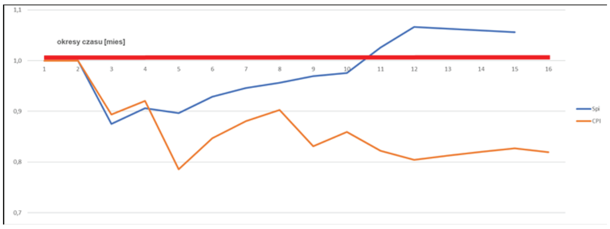
W trakcie realizacji projektu, pozyskiwane były informacje o jego postępach. Informację tę gromadził kierownik projektu, w oparciu o wewnętrzne odbiory kolejnych etapów po-

Tab. 2. Zmiana harmonogramu prac wywołana opóźnieniem w 3 miesiącu realizacji projektu. Źródło: opracowanie własne
Tab. 2. Change in the work schedule caused by the delay in the 3rd month of the project

Wyrobisko			Okres															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Ilość [mb]	320	80	80	20	80	60											
	Ks [tys zł]	260 000zł	520 000	520 000	325 000	520 000	455 000											
	Kz [zł/mb]	3 250zł																
2	Ilość [mb]	400					25	100	100	100	75							
	Ks [tys zł]	425 000zł					531 250	850 000	850 000	850 000	743 750							
	Kz [zł/mb]	4 250zł																
3	Ilość [mb]	600					25	100	100	100	100	100	75					
	Ks [tys zł]	450 000zł					562 500	900 000	900 000	900 000	900 000	900 000	787 500					
	Kz [zł/mb]	4 500zł																
4	Ilość [mb]	770									30	110	110	110	110	110	110	80
	Ks [tys zł]	522 500zł									665 000	1 045 000	1 045 000	1 045 000	1 045 000	1 045 000	1 045 000	902 500
	Kz [zł/mb]	4 750zł																
5	Ilość [mb]	300									20	100	100	80				
	Ks [tys zł]	410 000zł									492 000	820 000	820 000	738 000				
	Kz [zł/mb]	4 100zł																
Metrów [mb]	w okresie		80	80	20	80	110	200	200	200	225	310	285	190	110	110	110	80
	skumulowane		80	160	180	260	370	570	770	970	1 195	1 505	1 790	1 980	2 090	2 200	2 310	2 390
	wykonano		3,3%	6,7%	7,5%	10,9%	15,5%	23,8%	32,2%	40,6%	50,0%	63,0%	74,9%	82,8%	87,4%	92,1%	96,7%	100,0%
AC [zł]	w okresie		520 000	520 000	487 500	520 000	2 323 125	1 750 000	1 750 000	1 750 000	4 201 125	2 765 000	3 978 750	2 674 500	1 045 000	1 045 000	1 045 000	1 353 750
	skumulowane		520 000	1 040 000	1 527 500	2 047 500	4 370 625	6 120 625	7 870 625	9 620 625	13 821 750	16 586 750	20 565 500	23 240 000	24 285 000	25 330 000	26 375 000	27 728 750
EV [zł]	w okresie		520 000	520 000	325 000	520 000	1 548 750	1 750 000	1 750 000	1 750 000	2 800 750	2 765 000	2 652 500	1 783 000	1 045 000	1 045 000	1 045 000	902 500
	skumulowane		520 000	1 040 000	1 365 000	1 885 000	3 433 750	5 183 750	6 933 750	8 683 750	11 484 500	14 249 500	16 902 000	18 685 000	19 730 000	20 775 000	21 820 000	22 722 500



Rys. 2. Zmiana wartości wskaźników AC oraz EV wraz z realizacją projektu. Źródło: opracowanie własne
Fig. 2. Change in value of AC and EV with project realisation



Rys. 3. Zmiana wartości wskaźników SPI oraz CPI wraz z realizacją projektu. Źródło: opracowanie własne
Fig. 3. Change in value of SPI and CPI with project realisation

szczególnych zadań. Odbiory te nie były zapisane wcześniej w planie projektu w formie kamieni milowych, a stanowiły jedynie inicjatywę własną - dobrą praktykę kierownika projektu.

Skutkiem zlecania podwykonawcom dużych zadań, bez pozyskania od nich planu ich pracy oraz w konsekwencji braku wiarygodnej informacji o postępie prac oraz stanie budżetu jest brak wiarygodnych informacji pozwalających na ocenę stanu projektu w oparciu o EVM. Jeśli przyjrzymy się charakterystyce linii AC na rys. 4 oraz linii SPI na rys. 5 w okresie 8-10 to można wyciągnąć pochopne wnioski o tym, iż projekt w sferze budżetu niemal eksplodował, a przecież zaprezentowana sytuacja jest jedynie rezultatem wcześniejszego zaliczkowania części zleconych prac, co jednak nie było wcześniej (w procesie planowania projektu) brane pod uwagę.

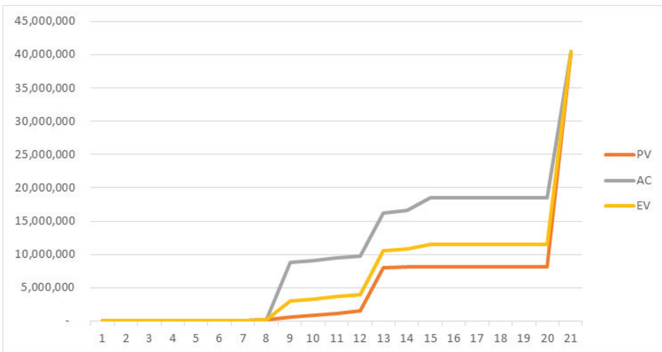
3. Podsumowanie – wnioski – rekomendacje

a. Osoby, które korzystają z informacji o stanie projektu (kierownicy projektów oraz komitety sterujące, a także PMO) muszą być bardzo dobrze przygotowane do jej praktycznego stosowania – muszą dobrze znać i umiejętnie stosować nomenklaturę oraz nazewnictwo wskaźników, co nie jest w początkowym etapie stosowania metody łatwe. Oznacza to potrzebę regularnych i intensywnych szkoleń w zakresie metody, która o ile z matematycznego punktu widzenia jest prosta, to nie jest powszechnie stosowana w branży górniczej.

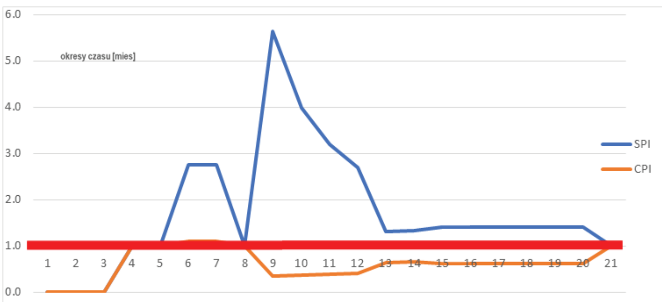
b. Warunkiem koniecznym, aczkolwiek niewystarczającym, dla efektywnego stosowania metody jest przygotowanie informacji o planowanym projekcie z maksymalnie możliwą do określenia dokładnością. Co oznacza owa dokładność? Otóż zdaniem autorów musimy podzielić pracę na

Tab. 3. Harmonogram prac projektu wdrożenia innowacyjnego wyposażenia w kopalni. Źródło: opracowanie własne
Tab. 3. Work schedule for the project to implement innovative equipment in the mine

	Zadanie		Okres 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	[illegible]	1 kpl				1																	
	Koszty [illegible]	80 000 zł				[illegible]																	
	Wykonanie					[illegible]																	
2	Projekt [illegible]	1 kpl						0,25		0,75													
	Koszty [illegible]	[illegible]								[illegible]													
	Wykonanie							[illegible]		[illegible]													
3	Zakup kompletnej obudowy wraz z niezbędnymi materiałami i urządzeniami pomocniczymi	1 kpl													1								
	Koszty [illegible]	[illegible]													[illegible]								
	Wykonanie														[illegible]								
4	Przygotowanie wyrobiska [illegible]	275 mb									50	50	50	50	50	25							
	Koszt stały (zł/mies)	[illegible]									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							
	Koszt zmienny (zł/mb)	6 000 zł																					
	Wykonanie										[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							
5	Wykonanie [illegible] komory montażowej	11 szt												3	4	4							
	Koszt stały (zł/mies)	[illegible]												[illegible]	[illegible]	[illegible]							
	Kz (zł/mb)	10 000 zł																					
	Wykonanie													[illegible]	[illegible]	[illegible]							
6	Zakup kombajnu	1 kpl									[illegible]												[illegible]
	Koszty [illegible]	25 000 000 zł																					[illegible]
	Wykonanie										[illegible]												[illegible]
7	Zakup wyposażenia przodkowego	1 kpl															[illegible]						[illegible]
	Koszty [illegible]	[illegible]																					[illegible]
	Wykonanie																[illegible]						[illegible]
PV [zł]	w okresie		-	-	-	[illegible]	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-	-	[illegible]
	skumulowane		-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AC [zł]	w okresie		-	-	-	[illegible]	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-	[illegible]
	skumulowane		-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
EV [zł]	w okresie		-	-	-	[illegible]	-	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	-	-	[illegible]
	skumulowane		-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CV			-	-	-	-	-	7 500	7 500	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
SV			-	-	-	-	-	52 500	52 500	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CPI			0,000	0,000	0,000	1,000	1,000	[illegible]	[illegible]	1,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,000
SPI			0,000	0,000	0,000	1,000	1,000	2,750	2,750	1,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



Rys. 4. Zmiana wartości wskaźników SPI oraz CPI wraz z realizacją projektu wdrożenia innowacyjnego wyposażenia w kopalni. Źródło: opracowanie własne
Fig. 4. Change in value of EV, AC and PV in project implement innovative equipment in the mine



Rys. 5. Zmiana wartości wskaźników SPI oraz CPI wraz z realizacją projektu wdrożenia innowacyjnego wyposażenia w kopalni. Źródło: opracowanie własne
Fig. 5. Change in value of SPI and CPI in project implement innovative equipment in the mine

części, które pozwolą nam na rzeczywistą obserwację realizacji, np. podział na zadania/podzadania, dla których potrafimy w wiarygodny sposób oszacować rezultat oraz postęp ich wykonania. Ponadto, oprócz zakresu planowanych prac niezbędne jest określenie wartości kosztu/budżetu dla realizacji poszczególnych zadań tak, aby możliwe było zbudowanie relacji: zrealizowany zakres – poniesione koszty.

c. Bez systematycznego aktualizowania informacji o realizowanych projektach z odpowiednim poziomem ich szczegółowości, stosowanie metody będzie nieefektywne. O ile w przypadku projektów realizowanych własnymi siłami takie informacje są zazwyczaj dostępne – można w prosty sposób policzyć metry, tony, roboczogodziny czy kilowaty - to w przypadku projektów realizowanych w trybie „klienckim", gdy za stronę operacyjną projektu odpowiada podmiot zewnętrzny, dostęp do wiarygodnych danych może być utrudniony. Wynika to najczęściej z braku odpowiednich zapisów w zakresie rzeczowym zawartej umowy.

d. Typowym problemem, często występującym w procesie analizy projektu jest brak jednoczesnej informacji o zrealizowanym zakresie prac wraz z przypisanym do tej pracy kosztem jej realizacji. O ile zakres można w prosty sposób zweryfikować, o tyle w przypadku informacji finansowej może być to bardzo trudne do wyegzekwowania, zwłaszcza, jeżeli nie zapewniono systemowego raportowania finansowej sfery projektu przez jego wykonawcę już na etapie podpisywania z nim umowy. W najlepszy wypadku dane te będą oparte o szereg domysłów lub symulacji.

e. Z uwagi na charakter metody, informacje będące wynikiem jej stosowania, powianny służyć do systemowej oceny projektów, realizowanych przez organizację oraz badania trendów ich realizacji dla ew. wykrywania możliwych trudności. Nie jest to, zatem narzędzie adresowane tylko dla kierownika projektu, ale dedykowane bardziej dla komórki zajmującej się systemowym gromadzeniem i przetwarzaniem informacji o realizowanych projektach – narzędzie dla biura zarządzania projektami.

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The Use of the Earned Value Method (EVM) to Evaluate Mining Projects – Critical Approach – Part 2 – Application Experience

Purpose of the article: the aim of the publication is to present practical examples of the application possibilities and limitations in the use of the earned value (EV) method as a tool for assessing the progress of work in projects implemented in hard coal mining enterprises in Poland.
Research method / tools: the research method will be the analysis of selected, typical project cases and the possibility of their evaluation using the earned value method.
Original results: the results of the work will be references in the effective use of the value-generated method in projects implemented in the hard coal mining industry.
Keywords: project management, earned value method, EVM, EVA, mining projects

Keywords: *project management, hard coal mining, earned value method*

Transformation of Corporate Culture in the Aspect of European Green Deal - Polish Raw Materials Industry

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Abstract

The article presents an overview of the concept of the European Green Deal and the term ESG. The paper presents how these activities can and will affect the shape and level of corporate culture of Polish enterprises, especially those operating in the mining industry. The basic activities that each EU country will have to implement under the European Green Deal, with particular emphasis on those affecting the raw materials industry, have been presented.

Keywords: *mining company, corporate culture, European Green Deal, ESG*

1. Introduction

Decarbonation, green deal, sustainable development, CSR, CO_2 emissions, ecology - these terms have significantly affected the operation of Polish raw material industry, especially hard coal mines, over the last few years. The executives of these entities have to make difficult decisions to adapt their entities to constantly updated requirements. These changes strongly shape their corporate culture, sometimes even forcing them.

Culture is defined as the totality of principles, rules and human actions, the products of human work and artistic creation and it constitutes the collective output of society. It is created on the basis of specific biological and social characteristics of humans, conditions of their existence, developing and transforming in the historical process. On the other hand, the organizational culture of an enterprise is its element, which in a specific way defines this enterprise. The authors of the article have already discussed this topic in previous publications [1, 7, 8, 10, 11, 12, 13], however, this article includes a brief explanation of this culture.

Its components have been and still are described by many scientists and scholars, but one of the most popular models is the one developed by the American psychologist Edgar H. Schein, who divided culture into 3 levels: assumptions, norms and values and artifacts. In each of these groups there are corporate-specific elements, which together form the culture of the company.

The subject of the authors' research was corporate culture of Polish entities operating in the field of mining industry in Poland, in particular one component of this culture - health and safety culture. The results of the research show that this component always provides an opportunity to shape something as increased awareness among employees makes them identify more and more strongly with the principles and values prevailing in the company. The authors have also conducted a strategic analysis in this area and its results are published in the following articles [4, 5, 12].

However, mining companies today should direct their activities not only towards the health and safety culture of the company. Current trends and indications, arising from international agreements or actions and regulations of the European Union basically force changes. As part of the work on this subject, but in reference to activities focused on creating corporate culture in terms of sustainable development and CSR, the authors also published the following articles. [8, 9].

This article closely describes the aspect of the most current guidelines for conducting business, related to the EU document adopted last year, which concerns the so-called European Green Deal. The provisions of this document make changes in the area of corporate culture of entities operating in the mining industry an imperative necessity.

2. A new business reality

The primary goal of companies has always been to create added value, especially in recent years. Times when the company value was measured solely on the basis of profit are long gone. In recent decades, the range of factors determining the value of a company has expanded to include full financial information and its impact on society and the environment - from the way resources are obtained, through production, to the distribution of goods and services.

One of the most important concepts that assesses the activities of entities is the ESG criterion. ESG refers to Environment, Social, Governance and is an important indicator of how socially responsible entities are. As corporate social responsibility has already become a fact, the need to integrate it with the corporate culture seems to be just a formality.

The new reality of business is manifested in many levels of entities activities. Industry 4.0 requirements and strive for it, ESG standards, the European Green Deal and the unexpected SARS-COV19 pandemic force changes in management processes and in the organisation of companies' operations in every industry.

Changes, in turn, are connected with the Deming cycle. According to this concept, continuous improvement takes place in several logically consecutive stages. These are: Plan – Do – Check – Act (also understood as improvement), hence this cycle is also called PDCA cycle.

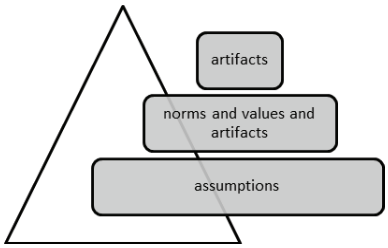

Fig. 1. Schein's corporate culture model source. Own study based on [6]
Rys. 1. Piramida kultury organizacyjnej wg Scheina źródło. Opracowanie własne na podstawie [6]

Fig. 2. Deming cycle. Source: Own elaboration
Rys. 2. Cykl Deminga. Źródło: Opracowanie własne

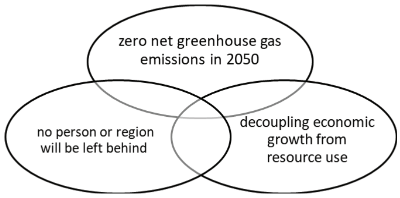

Fig. 3. Assumptions of the European Green Deal. Source: own study based on [14]
Rys. 3. Założenia Europejskiego Zielonego Ładu. Źródło: opracowanie własne na podstawie: [14]

Deming cycle is currently the basic form of shaping activities related to the introduction of changes, innovations or increasing the effectiveness of operations. Therefore, Deming cycle should be used in cases of transformation or changes in the corporate culture of business entities.

3. European Green Deal

The assumptions of the European Green Deal include the actions of each country towards common EU objectives. Faced with the findings that "Europe needs a new growth strategy to transform the Union into a modern, resource-efficient and competitive economy. Basic assumptions are presented in Figure 3.

The European Green Deal is defined as an action plan for the sustainable economy of the entire European Union. The document assumes that this effect can be achieved by ransforming climate and environmental challenges into new opportunities, but in all areas of politics. It is also emphasised that this transformation is supposed to be fair and inclusive.

As a result, the assumption of the European Green Deal include an action plan that allows for:

- efficient functioning of closed economy, which will contribute to more efficient use of resources,
- reduction of contamination levels.

Realisation of the goals set out in the document is undoubtedly connected with a number of necessary actions that will affect every member of the EU. For our country, it will require undertaking actions in all sectors of our economy, such as:

- investments in environmentally friendly technologies,
- supporting industrial innovation,
- introducing cleaner, cheaper and healthier forms of private and public transport,
- decarbonation of the energy sector,
- ensuring greater energy efficiency of buildings,
- working with international partners to improve global environmental standards.

All these activities will be reflected in the functioning of Polish entities, especially those related to the mining industry. This, in turn, forces the introduction of changes that will affect their corporate culture.

The basic assumptions of the transformation of the economies of the EU countries to the assumptions of the European Green Deal are shown in Figure 3. The entry in the top right corner, referring to stimulation of innovations and support for scientific research, seems to be of particular importance for the changes. Innovation linked to Deming cycle may lead to permanent and constructive changes, both in the management and operational sphere of entities operating on the Polish raw materials market, but it may also introduce new quality in the areas of their corporate culture.

One of the areas in which the provisions of the European Green Deal will be of particular importance is the activity related to the provision of clean, affordable and safe energy. The general assumptions in this area are defined by the following provisions [16]:

- Further decarbonation of the energy system is crucial for achieving the climate goals for 2030 and 2050.

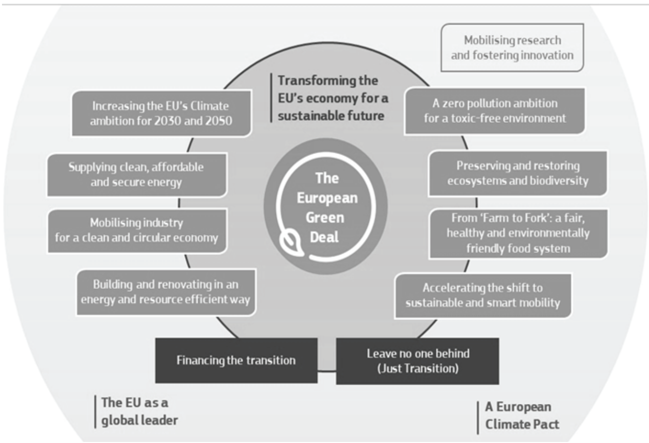

Fig. 4. The European Green Deal. Source: [14]
Rys. 4. Europejski Zielony Ład. Źródło: [14]

- By the end of 2019, Member States will present their revised energy and climate plans, whereas the Commission will assess the level of ambition of these plans and the need for additional measures if the goals set are insufficient.
- The transition to clean energy should involve and benefit consumers. Renewable energy sources will play a key role. Intelligent integration of renewable energy sources, energy efficiency and other sustainable solutions in all sectors will reduce carbon emissions at the lowest possible cost.
- Measures should be put in place to protect households that cannot afford the necessary energy services to ensure a basic standard of living.
- Achieving climate neutrality also requires an intelligent infrastructure. Strengthening cross-border and regional cooperation will help to reap the benefits of switching to clean energy at affordable prices.

The assumptions described above require a number of organisational, management or conceptual changes from Polish entities in the mining industry. This concerns in particular the entities directly related to the mining process, especially hard or brown coal mining. Any change introduced in accordance with the above mentioned assumptions will be followed by changes in the corporate culture of these entities. Thus, the proper implementation of these changes, with a deliberate change in the shape of the corporate culture will allow for a smooth transition through the transformation process.

4. ESG

ESG is an acronym of three words expressing the three aspects of operation of business entities: Environment, Social, Governance.

The environmental aspect is closely related to the environment and can be understood as a continuation of the principles of sustainable development, meaning an action that does not affect the environment. It is related to the concepts of reduction of greenhouse gas emissions, protection of biodiversity, waste water treatment and implementation of closed economy through waste recycling.

Social considerations should be understood as both internal: investments in human capital (employee training) and external: concern for customer satisfaction, relations with the local community.

The Governance aspect refers to the management methods within organisational structure, including its transparency and openness to signal possible irregularities, employee relations, members and wages of the management, and investor relations, i.e. communication with the stock ownership. It also concerns the principles of remuneration, the instances of corruption and shareholders' rights.

In Poland, ESG is still associated with listed companies. Since September 2019, The Warsaw Stock Exchange publishes the WIG-ESG index, which replaced the RESPECT Index [2, 3], calculated over 10 years. The WIG-ESG index is made up of companies from WIG20 and mWIG40, and the shares of companies listed on this index depend on the ESG ranking.

For some time now, it seems that the ESG triad has overcome the CSR institution, extending the catalog of non-financial elements related to running a business and giving a new, deeper meaning to the notion of enterprise value. Companies that do not pay enough attention to environmental, social and corporate governance (ESG) standards can be confronted with reluctant investors, especially in the conditions of volatility associated with the coronavirus [17].

ESG aspect is also related to compliance with the requirements under Regulation 2019/2088 on disclosure of information relating to sustainable development in the financial services sector. Recently published draft implementing act for this regulation, which is currently under consultations, presupposes that financial institutions will be required to report on 32 indicators, such as

- carbon footprint
- energy consumption
- relationship with the environment
- water consumption and sewage disposal
- waste production
- indicators of the gender pay gap
- protection of whistleblowers
- human rights protection efforts, including the supply chain
- anti-corruption and anti-bribery efforts

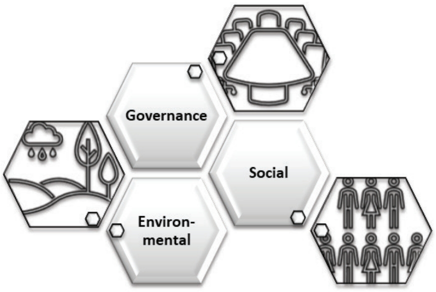

Fig. 5. ESG. Source: Own study
Rys. 5. ESG. Źródło: opracowanie własne

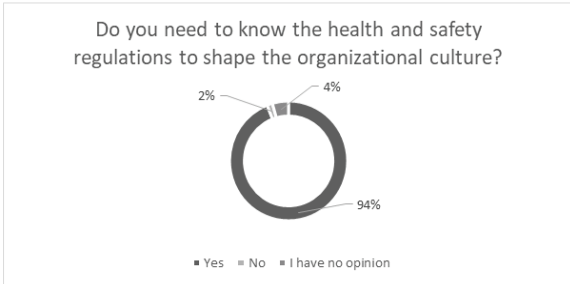

Fig. 6. The results of the survey on the necessity of knowing health and safety regulations to shape corporate culture. Source: own study
Rys. 6. Wyniki badan ankietowych w zakresie potrzeby znajomości przepisów bhp do kształtowania kultury organizacyjne. źródło: opracowanie własne

These indicators will include data from all companies under the obligation of financial market participants to include the risks for sustainable development and take into account the adverse effects on sustainable development in their activities and presentation of information about financial products. The regulation will be effective from 1 January 2022. This means that financial institutions will require companies to provide relevant data including information for 2021[18].

Thus, it is clearly visible that the trend related to the European Green Deal is strongly entering the specificity of functioning of Polish entities. A clear translation is already visible in the case of financial institutions. In the case of mining industry entities, these changes will be enforced not only by legal regulations, but also by their desire to achieve a balance in ESG areas. In order for such transformations to smoothly enter the structure of forms, their corporate culture must be properly shaped.

The need for raising awareness of employees and stakeholders about the changes can be confirmed by the results of surveys conducted among employees of the mining industry. As many as 94 percent of those surveyed said that knowledge of health and safety regulations is necessary to shape corporate culture (Figure 6).

6. Summary and conclusions

The European Green Deal provides for the implementation of a number of legal regulations containing new disclosure requirements for ESG information and data by financial institutions. Their development will require the acquisition of a number of detailed data from corporate clients by banks, insurers and investment funds, and will therefore require the aggregation and development of relevant data by companies using external financing or being capital market participants [18].

The assumptions of the European Green Deal announce a number of important, wide adjustment changes for entities operating on the Polish market, especially for entities operating in the raw materials industry. The need to adapt to these assumptions will force a number of structural, organisational and management changes, also in the area of corporate culture.

Sustainability is a concept known to everyone today. Practically every entity on the market operates on the basis of CSR assumptions. ESG becomes a step forward and a necessity. The European Green Deal is another challenge. Fitting all these elements together and integrating them into the corporate culture can contribute to the success of these entities. As studies [15] show, incorporating the ESG criteria into the company's strategy may have a positive impact on financial performance, increase competitive advantage, reduce operational risk and help to obtain financing. Today, lenders, job applicants, consumers and investors all over the world, including Poland, pay great attention to how the company cares about the environment, society and corporate governance.

The paper presents results of research conducted in AGH University of Science and Technology no. 6.16.100.215.

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Transformacja kultury organizacyjnej w aspekcie European Green Deal – polska branża surowcowa

W artykule przedstawiono ogólny zarys koncepcji Europejskiego Zielonego Ładu oraz pojęcia ESG. Przedstawiono, w jaki sposób te działania mogą i będą wpływać na kształt i poziom kultury organizacyjnej polskich przedsiębiorstw, zwłaszcza działających w branży wydobywczej. Przybliżono podstawowe działania, jakie każdy kraj unijny będzie musiała przeprowadzić aby wypełnić założenia Europejskiego Zielonego Ładu, ze szczególnym uwzględnieniem tych, które mają istotne znaczenie dla branży surowcowej.

Słowa kluczowe: *przedsiębiorstwo górnicze, kultura organizacyjna, Europejski Zielony Ład, ESG*

Production Risk – Selected Aspects of its Occurrence and Management on the Example of a Longwall

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Abstract

The production process carried out in longwall faces of hard coal mines is characterized by a high production risk due to a number of factors determining it. Therefore, it is necessary to recognize this risk and then reduce its occurrence. This article presents the mining and geological as well as technical and organizational conditions of the process carried out in the longwall face. The possibilities of risk assessment and its quantification in the production process implemented in the longwall face of hard coal mines for the selected mining technology are also presented. It was found that the constantly evolving BI class tools are intended to support the decision-making process based on the knowledge derived from the events that take place every day in the enterprise, including longwall faces. The use of appropriate computational tools and methodologies to analyze collected data may contribute to reduce the negative effects of the risk that occurs in the mining process.

Keywords: *production risk, longwall face, mining process, mine, mining industry*

1. Risk management as a process

The concept of risk is inherent in every human activity. The risk defined as an unwanted event which may or may not happen often determines the course of many of the so-called production cycles. In the case of analysis of the risk present in the production process, we can speak of the so-called production risk. It includes all possible (both positive and negative) deviations and fluctuations in the area of the assumed goals and achieved results of the company [1].

Risk management itself can be defined in a broad and narrow sense. In a broad sense, it is a system of methods and actions aimed at reducing the degree of risk impact on the functioning of an economic entity and at making optimal decisions to this end. In a narrow sense, risk management consists in taking actions aimed at limiting external influences, unpredictable factors on the organization [5].

The production process carried out in longwalls of hard coal mines is characterised by high production risk, due to a number of factors that determine it. The factors influencing the mining process can be divided into two groups: geological and mining conditions, and technical and organisational conditions. Geological and mining conditions constitute a number of obstacles in the course of the production process, which is carried out in specific conditions, i.e. underground. Technical and organisational conditions are specific in the sense that they, among other things, rely on the use of machines and equipment that work together in a certain way, depending on the technology used, as well as on the need to include the time wasted on getting to the longwall in the total working time. The occurrence of the above mentioned factors may cause the destabilisation of the production cycle in the longwall. The decisions made in this process are therefore closely related to the conditions of uncertainty and the risk that can be understood as the effects of that uncertainty. The authors have already addressed the subject of optimisation of the processes carried out in the longwall, with respect to production itself [2,3,6, 9, 11, 12, 14] or process organisation. [4, 15,16].

2. General identification of the risk in the longwall

The deposits currently exploited in Poland are in the form of seams, i.e. layers lying on a large area that are limited from the bottom and top by two more or less parallel planes [7]. In order to extract a coal deposit, it is necessary to make it accessible, i.e. to make the opening-out heading. Then, the field designated for mining is cut by means of gates (top and bottom), along which the operation is carried out.

In the Polish hard coal mining industry, the vast majority of longwalls are led with fall of roof, in which the shearer operates as a mining machine. Bidirectional mining is the most commonly used technology. The production cycle then includes a single passage of the shearer along the wall and consists of the following activities: the shearer sumps into the face, the support is moved, the drive is moved, the conveyor is moved, the shearer starts mining, the conveyor is moved (Fig1.) [8].

The course of the production process carried out in the longwall of hard coal is determined by a number of factors (regardless of the adopted technology of uni- or bidirectional mining). The decisions made within this process are therefore closely related to the conditions of uncertainty and the risk that can be understood as the effects of that uncertainty. The factors influencing the mining process can be mainly divided into two groups: mining and geological conditions (Table 1) and technical and organisational conditions (Table 2).

3. Possibilities of risk assessment and its quantification in the production process carried out in longwall of hard coal mines

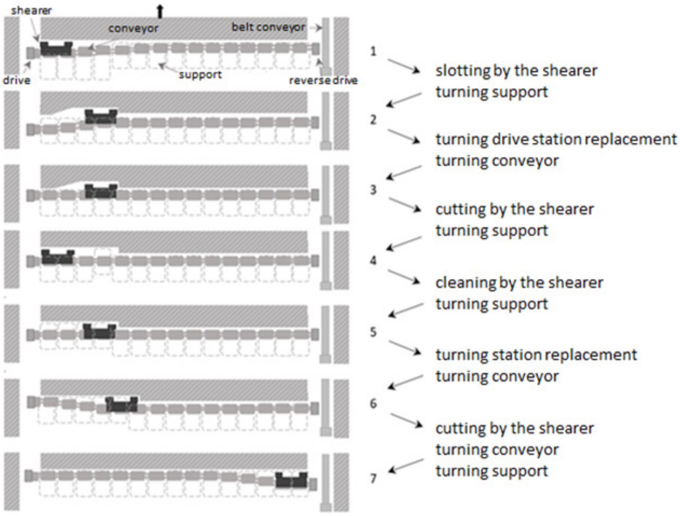

Fig. 1. General pattern of the production cycle realised in the longwall. Source: based on [8]
Rys. 1. Ogólny schemat cyklu produkcyjnego realizowanego w przodku ścianowym. Źródło: opracowano na podstawie [8]

One of the methods widely used for the risk assessment of the production process is the FMEA method. Based on the analysis of production cycles carried out in longwall of hard coal mines, it is possible to assess the risk of the production process using the FMEA method.

The FMEA (Failure Mode and Effect Analysis) method is also known under other names, i.e. FMECA (Failure Mode and Criticality Analysis) or AMDEC (Analyses des Modes de Deffaillace et Leurs Effects). It started to be used in the 60s in the USA in projects related to astronautics (elements of spacecraft, etc.). FMEA has become so popular and effective that it has been implemented in the nuclear, chemical, aerospace, electronics and automotive industries. Already in the 90's, it was included in the ISO 9000 or QS 9000 standards for the automotive industry. This is an analysis of the types of errors and their effects and consists in determining the cause and effect relationships of potential product defects taking into account the criticality factor. The main objectives of FMEA are to continuously identify potential product or process defects, eliminate them and reduce the risk of their occurrence to a minimum. This makes it possible to successively improve the studied phenomena [20].

The method consists in examining all possible faults before the design solution is approved, thus avoiding errors at a later stage. FMEA analysis is used in both unit and mass production. It may concern a single component or the whole product, several operations or the whole technological process. Conducting the FMEA of a product is advisable if the newly implemented material, part or technology poses a high risk to humans or the environment. Conducting the FMEA of the process, on the other hand, is justified when it is necessary to identify factors that may have led to manufacturing interruptions. They may be related to processing methods or parameters, measuring tools or machines [19].

The quantitative analysis aims to determine the criticality factor (LPR), i.e. the risk factor associated with the occurrence of a defect. The numerical evaluation is on a scale from 1 to 10 and is conducted on the basis of three criteria:

- frequency of defects (P),
- the significance of the defect for the customer, i.e. the extent to which the defect is important to them (Z),
- level of detection, i.e. the probability that a given defect will not be detected by the manufacturer and will be delivered to the customer, the so-called possibility of detection (W). The product of these three variables creates a priority number, determining it according to the formula:

$$LPR = Z \times P \times W$$

The LPR number that can take values from 1 to 1000 is of great importance. The higher the value, the greater the risk associated with the defect. It is therefore common to establish a specific criticality level above which all errors are analysed [19].

In order to conduct FMEA analysis of the production process carried out in longwall of hard coal mines in Poland, a list of potential failures of particular activities in the production process was drawn up. The anticipated effects of these events, the reasons for the failure and available prevention methods were determined. The methodology and results of the method are described in detail in the publication [18].

According to the FMEA method, if the LPR value is less than 100, it is assumed that the given failure does not pose a significant threat to the process, it is the so-called threshold of acceptability. Special attention should be paid to failures for which the LPR value is much higher than 100. In the case of the analysed process, these are failures causing the shearer to stop working, which, in turn, halts the mining of the wall. The reasons for these situations are as follows: lack of power supply (caused by various types of failures or natural hazards such as exceeding the permitted concentrations of gases (e.g. methane), burying the conveyor or support with output, as well as unfavorable geological conditions (overgrowth, low parameters of coal, roof falls, etc.). The greatest impact on the process disturbance has the occurrence of the above-mentioned failures during the shearer's operation, i.e. during the mining, cleaning and sumping of the shearer.

Tab. 1. Mining and geological conditions influencing the occurrence of risks and uncertainties in the process carried out in longwall of hard coal mines. Source: [18]

Tab. 1. Uwarunkowania górniczo-geologiczne wpływające na występowanie ryzyka i niepewności w procesie realizowanym w przodkach ścianowych kopalń węgla kamiennego. Źródło: [18]

Factor	*Description*
Type of roof and type of floor	It depends mainly on the class of roof and floor rocks, but also on the thickness of the mined seam and the tendency of coal to self-ignite.
Coal workability	A feature closely related to the compactness of coal. The higher the compactness indicator, the more difficult the rock is to work. The workability of a rock is understood as its susceptibility to being separated from the face by tools, mining machines or explosives. The workability is related to the hardness and compactness of the rock, but also to the pressure of the rock mass and the transverse dimensions of the longwall and its progress. There are three groups of seam, depending on the value of the workability indicator, marked with the letter "*f*".
Seam thickness	This is the shortest distance between the roof and the floor. Depending on the thickness of the deposit, a division of hard coal seams into thin and thick seams is assumed.
Inclination of seam	Overlie of the seam can be horizontal or at a certain angle of inclination to the horizontal plane. The angle formed by the plane of the floor or roof of the seam with the horizontal plane is called the angle of seam inclination. Seams are divided into four groups depending on the angle of seam inclination.
Natural hazards	Natural hazards, including those related to rock and gas ejection, are one of the most dangerous hazards in underground mining. The risk of methane and rock ejection increases with increasing depth. As a result of mining at deeper and deeper depths, an increase in the seams' methane content is observed, which at the same time reduces the gaseous permeability of coal, contributing to the increase of this threat. Factors determining the occurrence of the threat are, among others: gas-bearing capacity of the deposit (methane content), compactness of rocks, pressure and intensity of gas desorption and conducting works in the vicinity of geological disturbances.

Tab. 2. Technical and organisational conditions influencing the occurrence of risks and uncertainties in the process carried out in longwall of hard coal mines. Source: [18]

Tab. 2. Uwarunkowania techniczno-organizacyjne wpływające na występowanie ryzyka i niepewności w procesie realizowanym w przodkach ścianowych kopalń węgla kamiennego. Źródło: [18]

Factor	Description
Mechanical system	Rational selection of the shearer-conveyor-support system usually results in shorter cycle times.
Technical parameters of machines	Despite the fact that today's shearers show an increasing work speed and, consequently, can theoretically show higher productivity, their actual performance is determined by mining and geological factors, in particular the degree of coal workability and roof conditions.
Equipment failure frequency	It can be assumed that the longer machines and equipment are used, the more often they can fail. Therefore, it seems important to carry out timely maintenance and quick repairs.
Organisation of the production cycle	Operation method, the form of work organisation and the system of work, and the training and experience of employees are the factors that seem to be the most predictable. It is possible to manage the properly trained staff in the longwall in an optimal way.

The process is slightly less affected by the occurrence of these failures when moving the conveyor or support. The methods of prevention for failures that carry the greatest risk include shearer's supervision, employee supervision, maintenance of correct geological documentation and support condition control. After conducting analysis, the recommended prevention should be implemented and a deadline should be set for recalculating the LPR in order to compare the results and take steps to eliminate or minimise the impact of failures on the production process. Nevertheless, taking into account the specific nature of mining production, it will be difficult to eliminate the risk associated with these failures, due to the high unpredictability of these events [18].

On the basis of the analyses of production cycles carried out in longwall of hard coal mines, a process map was developed for various mining technologies. Figure 2 shows unidirectional mining technology.

Distortions destabilising the process may and do occur in each of the elements of the process presented on the map. Therefore, it is important to identify the risk of their occurrence and to determine and take preventive measures as accurately as possible.

Within the framework of the production process diagram presented in Figure 2, 4 modules can be distinguished:

- Module 1: preparatory work (m1)
- Module 2: cutting (m2)
- Module 3: final works (m3)
- Module 4: cleaning (m4)

In each of these four modules, it is possible to distinguish the risk that may arise from technical and organisational, as well as geological and mining conditions, and which stops the realisation of the process, which in consequence leads to no extraction. Qualitative (descriptive) risk assessment - e.g. carried out on the basis of FMEA methodology, can be quantified using e.g. the method described in detail in the following publication [13]. It concerns the risk assessment for the implementation of the production plan.

As previously indicated, factors destabilising the process carried out in longwall of hard coal mines are divided into two groups: geological and mining, and technical and organisational. Their unpredictability and impact on the production cycle is so significant that it may result in, for example, variable (unstable) shearer's movement. Then, the assessment of the effectiveness of such a production process (e.g. through the assessment of the stream of rock mined in that process) should take into account its unstable (undetermined) character.

The risk associated with the possibility of failing to implement production plans is therefore significant and should be determined. To do that, the authors of the paper [7] have proposed to use an indicator of the intensity of the stream of mi-

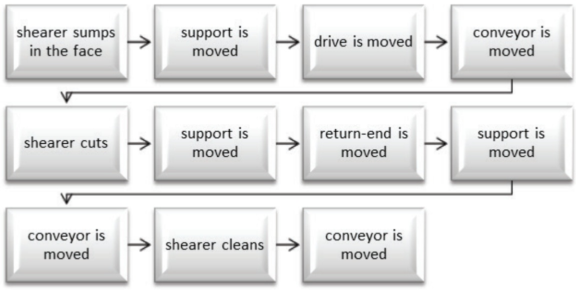

Fig. 2. Process map for unidirectional shearer mining. Source: Own study
Rys. 2. Mapa procesu dla technologii jednokierunkowego urabiania kombajnem. Źródło: Opracowanie własne

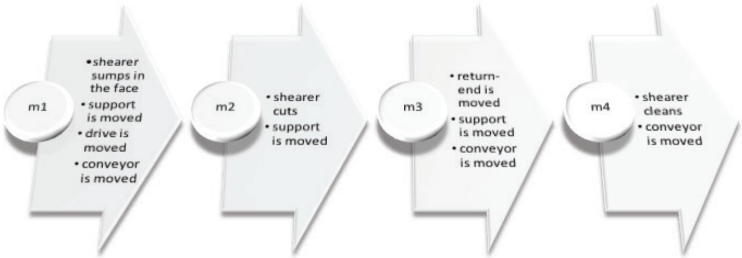

Fig. 3. Division of the production cycle in the longwall into modules. Source: [13]
Rys. 3. Podział cyklu produkcyjnego realizowanego w przodkach ścianowych na moduły. Źródło: [13]

ned rock in the function of probability. Assuming that some of the quantities describing this process are determined and some of them are described as random variables, it is possible to assess the probability of implementation of the assumed production plans.

Determined data, adopted in the proposed method, take the following values:

- longwall length
- longwall height
- web depth
- bulk density of coal
- web use index
- distance from the shearer stop position to the junction between the longwall and the gate road
- shearer length
- distance of the advancing conveyor from the supports
- minimum distance of the advancing conveyor from the shearer
- distance of the advancing roof supports from the shearer

On the other hand, the following values were treated as random variables:

- shearer maneuvering speed (shearer speed when clearing the shearer route)
- shearer working speed
- shearer working speed when cutting
- boot end movement time
- drive movement time

In the paper[10] the scheme of calculations to be made in order to obtain the characteristics of the stream of mined rock indicator has been described. For this purpose, it is necessary to perform a calculation procedure, divided into four stages.

The proposed method can be useful to evaluate the effectiveness of the production cycle in the longwall. In production risk assessment, it comes down to answering the following questions:

- What is the probability that the intensity of the stream of mined rock will not exceed a certain amount of extraction?
- What is the probability that the intensity of the stream of mined rock will be within the given limits?

4. Summary

Polish companies operating in the mining industry more and more often reach for modern solutions from the borderline of IT and communication. This is due to the continuous development of new philosophies of effective management, increasingly supported by Business Intelligence tools.

It is assumed that the idea of BI is to rely on huge amounts of information, which in itself may not be of any value or carry no information. However, using such fields or technologies as: statistics, econometrics, operational research, artificial intelligence, databases, business reporting, analytics, data mining or benchmarking can be a great help in management processes.

Polish mining companies systematically try to use the collected data for decision support processes.

In terms of reducing production risk, BI solutions can be very useful. The tools described above show how the available data can be used for analysis, the results of which can reduce or eliminate risk. The development of BI tools and the steadily growing computing power open wide doors for such analyses, even in a continuous system. It is assumed that in the field of knowledge management issues - knowledge bases (i.e. the

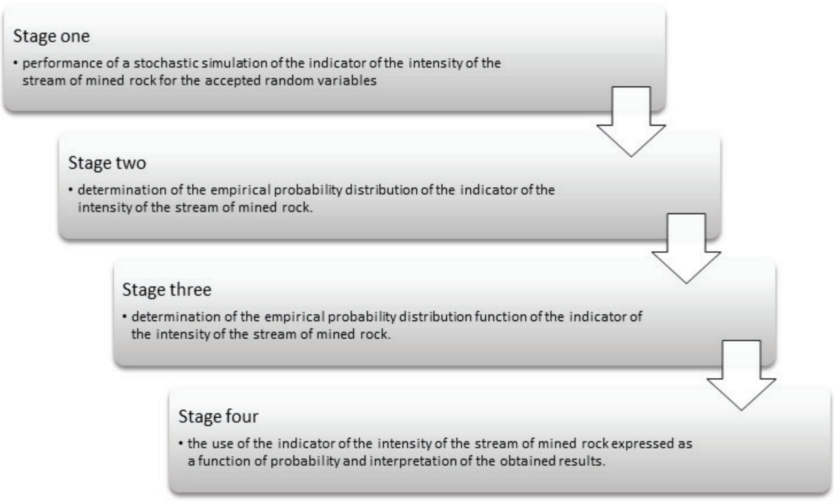

Fig. 4. Stages of obtaining a characteristic of the intensity of the stream of mined rock. Source: Own study
Rys. 4. Etapy uzyskania charakterystyki natężenia strugi urobku. Źródło: Opracowanie własne

basis of BI solutions) are a tool supporting knowledge identification, gathering, organising and sharing.

The knowledge bases collect data on the longwalls themselves. The data collected in them constitute a set of information about mining and geological as well as technical and organisational conditions that occurred during mining. So, those that influence the risk of the production process the most. In addition, it includes information related to technological interruptions, the reason for their occurrence and the way to eliminate the obstacle. There is also information on the duration of individual activities within the production cycle, data on the composition of the air, and all others that could and/or contributed to the way and quality of operation. Such a knowledge base is an important element when deciding to start mining a new wall. On the basis of the collected knowledge, the most similar longwall, which has already been mined, is searched for, and then decisions are made with respect to the way of operation. This is particularly important in terms of the overall functioning of a mine, because decisions made at this stage are crucial and binding during the functioning of a given longwall. Therefore, all financial expenses, the way people are hired, the management of the machine park and related costs and investments, the way the excavation is made available and, as a consequence, its aeration throughout the entire duration of exploitation and a number of other aspects typical of the production process, such as the selection of coal in an underground mine for activities and decisions, will systematically affect the entire mine. Therefore, it is extremely important and helpful to create and then use such a database [17].

Risk management is a current problem, not only for the mining industry. The best decision is a decision based on facts, which should be supported by appropriate and valid conclusions. It seems that the constantly expanding BI class tools are intended to support the decision-making process, and this is based on the knowledge coming from events that take place every day in the company. Appropriate equipping of collected data with computational tools and methodologies can contribute to reducing the negative effects of risks that occur in the mining process.

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Ryzyko produkcyjne – wybrane aspekty występowania oraz zarządzania na przykładzie przodka ścianowego

Proces produkcyjny realizowany w przodkach ścianowych kopalń węgla kamiennego charakteryzuje się występowaniem wysokiego ryzyka produkcyjnego, ze względu na szereg determinujących go czynników. Konieczne zatem jest rozpoznanie tego ryzyka a następnie ograniczanie jego występowania. W niniejszym artykule przedstawiono uwarunkowania geologiczno- górnicze oraz techniczno-organizacyjne procesu realizowanego w przodku ścianowym. Zaprezentowano także możliwości oceny ryzyka i jego kwantyfikacji w procesie produkcyjnym realizowanym w przodku ścianowym kopalń węgla kamiennego dla wybranej technologii urabiania. Stwierdzono, że stale rozbudowujące się narzędzia klasy BI z założenia mają wspierać proces decyzyjny i to właśnie w oparciu o wiedzę pochodzącą ze zdarzeń, które codziennie mają miejsce w przedsiębiorstwie, w tym także w przodkach ścianowych. Odpowiednie wyposażenie gromadzonych danych w narzędzia i metodyki obliczeniowe może przyczyniać się do ograniczania negatywnych skutków ryzyka, jakie występuje w procesie wydobywczym.

Słowa kluczowe: *ryzyko produkcyjne, przodek ścianowy, proces wydobywczy, kopalnia, przemysł wydobywczy*

New Drilling Design by Doubled Holes in Surface Mines

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Abstract

Drilling of holes in mines is a very important factor that generally has a great influence on the operability, productivity and especially the cost of a ton of ore extracted. Therefore, in this paper, we will see a technique that helps us to optimize the drilling-blasting ring by making doubled holes in each position in the block to be fragmented at the company of CGMSG (quarry of aggregates).

Keywords: *quarrying and mining, design of drilling, blasting*

Introduction

Drilling and blasting are seen as sub-systems of the size reducing operations in mining. To have better design parameters for economical excavation of mineral production and good fragmentation, the drilling and blasting operations needs to be optimized to improve fragmentation, which in turn will have a positive impact on the diggability of the material, reducing the time and energy to load. Better fragmentation sizes, meaning producing more fines, will reduce the energy required to crush and grind the material hence increasing crusher and mill throughput. Other benefits include improving the conditions of the bench floor, reducing flyrock, reducing ground vibrations and reduce secondary blasting.(Joel Edem Kwaku Gadikor. 2018). Most previous works have focused on drilling and blasting just in terms of costs reduction by different means. Afeni and Afum et al. tried to investigate the cost effects of different drilling equipment and blasting patterns respectively in two open pit mines through experimental and onsite observations (T.B. Afeni. 2009), (B.O. Afum, V.A. Temeng. 2015). Some other researchers made attempts to optimize drilling and blasting operations from the technical point of view; Sontamino and Drebenstedt addressed a dynamic model for a bench blasting design (Sontamino P, Drebenstedt C. A. 2012). Bowa introduced a practical method in an open pit mine to optimize blasting design parameters such as bench height, drill hole diameter, spacing, etc. (V.M. Bowa. 2015). Tosun and Konak determined a particular charge for blasting operation to reduce operating costs through an experimental method (A. Tosun, G. Konak. 2015). In addition, some other researchers tried to study the environmental aspect of drilling and blasting operations; Lashgari et al. and Attalla et al. investigated the emission of NOx from blasting elements in a surface coal mine through data gathering and mathematical equations (M.I. Attalla, and al. 2008), (E. Pruyt. 2013).

In recent years, Algeria has known a rapid dynamic in the construction projects such as; buildings, roads, and infrastructure, which increase the demand of the aggregates production in quarries.(Remli. S et al, 2019). To do this, it is necessary to find solutions to optimize the mining process to meet the requirements of the mining industry. The objective of this work is to optimize the drilling in mines and quarries by using a technique consist by doubling of holes in each location in the block to be fell that directly due to the relative change of blast plan such as the distance between holes and that between rows.

Materials and methods

Geographical location of Sarl CGMSG

The study area is part of wilaya of Bouira which is located in central part of northern Algeria. The Sfail El Faidja quarry is located at 8 km as the crow flies from el hachimia and 18 km as the crow flies to south of capital of Bouira wilaya.

Geology of the deposit

The deposit consists of Cenomanian formations, represented by alternating limestone, marl and predominantly marly clay. The limestones are gray to platinum and dark gray to the break, they are very compact and massive with centimeter calcite vein or slits. The latter represent two structural directions oriented N 020 and N 140 which cut the limestone banks in paving stones or lozenges, and after alteration gives an appearance of beads(CGMSG, 2013).

The strength of this formation is much reduced east of the deposit, where it does not exceed 20 m and greater westward or reaches 40 m. The east-west transition from deposit is marked by a loophole of NW-SE direction. The limestone and marly formations extend in a dip of 15 to 20 ° towards the SSW and direction N100 to N110.

Role of drilling

Drilling is the process of making a hole into a hard surface where the length of hole is very large compared to the diameter (Pathak, 2014). Drilling and Blasting is the most common method for breaking and loosening solid rock in surface mines. The general objective is to produce the broken material that can be excavated and loaded.

Surface mining requires drilling for different purposes that include (Pathak, 2014):

- Production drilling i.e. for making holes for placement of explosives for blasting.

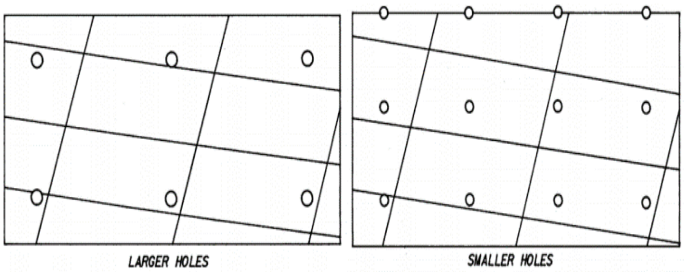

Fig. 1. Two different meshs of drilling confronted with the same grid of discontinuities. Illustration according of U.S. Bureau of Reclamation, 2001
Rys. 1. Dwie różne siatki wiercenia skonfrontowane z tą samą siatką nieciągłości. Ilustracja według US Bureau of Reclamation, 2001

Tab. 1. Characteristics of limestone quarry
Tab. 1. Charakterystyka kamieniołomu wapienia

uniaxial compression resistance	113 Mpa
Los Angeles test	23
Micro Devaltest	27
Limestonerate (calcite and / or organic)	77.42 %

Tab. 2. Blasting plan parameter for doubled and simples holes
Tab. 1. Charakterystyka kamieniołomu wapienia

Parameters	**Simple hole**	doubled holes
Holes number	100	100
Holes length	16 m	16 m
Bench Height	15 m	15 m
Burden	4 m	5.65 m
Spacing	4 m	5.65 m
Holes diameter	102 mm	102 mm
Holes Inclination (β)	85°	85°
Number of rows	03	02
Sub-drill	1 m	1 m
Stemming	2.4 m	2.4
Charge of explosive in a hole	111.5 kg	111.5 kg
Total amount of explosives (Temex + Anfo)	11150 kg	11150 kg
number of electric detonators	100 pieces	50 pieces
Specific Consumption of explosives	464 g/m^3	464 g/m^3

	Simples holes	**Doubled holes**	**Optimization rate**
drilling machine displacement time to drill holes	1 h and 20 min	1 h and 2 min	22%
Blasting operation time	2 h and 30 min	2 h	20 %

- Exploration drilling i.e. for sample collections to estimate the quality and quantity of a mineral reserve.
- Technical drilling i.e. during development of a mine for drainage, slope stability and foundation testing purposes.

In conditions where the spatial frequency of one or more sets of discontinuities is large, it is notoriously preferable to blast the benches with a reduced hole diameter; this allows for a tighter drilling pattern with equivalent specific consumption. A loose mesh of drilling in this type of situation can lead to whole portions of the bench that are little or not fragmented (see Figure 01). This remark also applies to blasting in conglomerate rocks.

Experimentation

The experience of the doubled holes was made at CGMSG quarry for aggregates (Fig. 02), so some data on limestone are mentioned in Table 01 where the rock is characterized by an average hardness with a value of uniaxial compression resistance of 113 MPa. In addition, the rock mass is slightl cracked.

Drilling procedure involves to drill two adjacent holes instead of a single hole in each location, the distance between them is 0.5m to 0.7m depending on the hardness and stability of rock mass. This distance is intended to avoid the convergence between holes at certain depth. During the process of loading explosives into holes, priming is done by connecting a single pair of holes by a single electric detonator (Figures 02 and 03).

Parameter of blast plan

In this experiment, both tests are done using the doubled and single holes (Figure 04). The blasting plan parameters in both cases are shown in Table 02.

The determination of the mesh of doubled holes is by the following relation:

$A' = B' = \sqrt{(A*B)}$ or

– A and B represent the distance between the holes and that between the rows successively.

– A' and B' represent the distance between the doubled holes and that between the rows successively.

Results and discussion

After having the same blasting results in both cases (well-defined grain size, good inclination of the bench face,

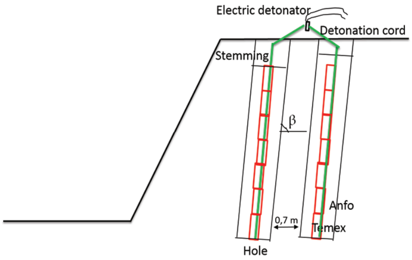

Fig. 2. Schema of doubled holes in the bench
Rys. 2. Schemat podwójnych otworów

Fig. 3. Photographies of doubled holes test
Rys. 3. Fotografie testu podwójnych otworów

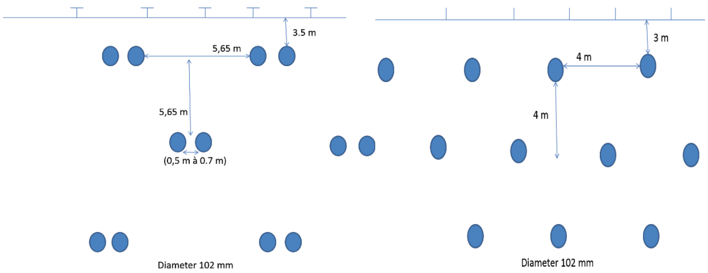

Fig. 4. Drilling plan for simple and doubled holes
Rys. 4. Plan wiercenia otworów prostych i podwójnych

Fig. 5. Blasting results for doubled and simples holes
Rys. 5. Wyniki strzelania otworami pojedynczymi i podwójnymi

good shape of broken rock pile and good shape of the bench) figure 05. So we can conclude that the use of the technique of doubled holes (table 03) has actually allowed us to benefit the blast operation time with a rate of 20% and especially in the necessary quantity distribution time of the explosive material in each hole (manual loading), so the benefit of the connection time of two cords coming from the doubled holes by a single electric detonator. So the latter also allowed us to minimize the cost of felling that will positively affect the cost price of a ton of rock felled. Also thanks to this technique, distance of moving of drilling machine to drill all holes is decreased, so an optimized displacement rate of 22% which due practically to the increase of drilling yield.

All these optimizations quoted above in the time of the operation of blasting due automatically to the reduction of cost price of the drill-blast ring.

On the other hand, the use of doubled holes technique causes an excess of the shock wave due to increase of seismic and acoustic waves generated from the instantaneous charge elevation; and this, for quarries that are using the sequential exploder. So it is not recommended to use this technique in quarries near to habitats.

Knowing that the choice of drilling machine depends essentially on the geometry of deposit, the physicomechanical properties of the rocks and the planned production. So there are companies already bought drills for such a reason but after that, it knows an increase of the production according to demand of the market, therefore to satisfy business needs,, it is necessary to carry out this technique to avoid the purchase of other drilling machine that affect the cost price and even the national economy (reduction of the number of drilling machine import).

Conclusion

Doubled holes drilling design has allowed us to virtually reduce drilling and blasting times as well as increase felling production, so all of these optimizations actually due to the cost reduction of a ton of rock extracted. On the other hand, the use of this technique of preference is avoidable when the mine is located in the neighborhood of habitats because the doubled holes drilling due to increase of instantaneous charge which causes the damage of houses and infrastructures caused by the intensity of seismic wave. In addition, this technique is not effective in the case of very cracked rock mass, because the majority of explosive energy escapes through the cracks so we will get a bad blast result (high rate of Out-sized).

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Nowy projekt wiercenia przez podwójne otwory w kopalniach odkrywkowych

Wiercenie otworów w kopalniach jest bardzo ważnym czynnikiem, który generalnie ma duży wpływ na funkcjonalność, produktywność, a zwłaszcza na koszt tony wydobytej rudy. Dlatego w tym artykule przedstawiono technikę, która pomaga zoptymalizować prace wiertniczo-strzałowe poprzez wykonanie podwójnych otworów w każdym miejscu w bloku do rozdrobnienia. Badania przeprowadzono w firmie CGMSG (kamieniołom kruszyw).

Słowa kluczowe: *wydobycie, górnictwo, projektowanie odwiertów, prace strzałowe*

Brine Evaporation Speed Enhancement by Solar Energy for Optimization of Salt Production of Lake Merouane El Oued Southeastern of Algeria

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Abstract

In this present paper we will study an assembly of two systems for collecting solar energy at the unit of SME (Salins Merouane El Meghaier) located in southeastern Algeria, by the development of a black grid floating in the brine and a reflection mirror of the solar radiation directed towards the evaporating surface in the test pan P4 and also a witness pan P0 which helps us to illustrate the influence of these two systems, results will be obtained suggest an increase in the evaporation-crystallization rate of P4 compared to that of P0 which is due to the improvement of the annual production of SME unit.

Keywords: *Algeria, lake, solar energy, mirror, black body, optimization, evaporation-crystallization, salts*

Introduction

The brine represents an important source of mineral salts suitable for domestic and industrial uses. The salts are composed of mainly halite mixed with other impurities such as carbonates, bicarbonates, and sulfates of sodium and potassium respectively. Thermodynamic calculations based on Pitzer's ion interaction model indicate that the lake brine is under-saturated with respect to the major dissolved mineral salts (Kasedde and al., 2014).

Algeria has considerable salt potential thanks to the very favorable climate conditions for the production of solar salt in chotts or lakes of the North, chotts or lakes of the highlands and high plains and chotts or vast depressions of the Saharan platform. These latter environments (chott, lake and depression) in Algeria have been the subject of rare detailed studies (Haddane Abdennour and al 2015). Among the lagoon areas of North Africa, chott Melghir and Merouane constitute with all the Tunisian chotts the largest closed depression (Gueddari.M; 1980). The regions of chott Merouane and Melghir are characterized on the surface by consolidated dunes of very fine sand (about 10 m thick), cemented at depth by gypsums, and the thickness of the sand is very important where the vegetation favors the stabilization of desert winds. Underlying we find these fine sands about 70m of clays which in turn rest on about 35m of sand and sandstone, forming part of the most important aquifer (Cornet, A, 1964).

This region has a Saharan climate with very high temperatures in summer (50°C in July and less than 5°C in January), a real evaporation exceeding 480mm/year where winds are very frequent in the region (Maximum speed of about 4.20 m/s). Precipitation is very rare and does not exceed 30 mm/year (Messaoud HACINI and al, 2004).

Solar energy is an important energy resource for salt precipitation from lake (KASEDD H. and al, 2015), it is one source of free energy that is inexhaustible in supply and use. Many processes in the mining and mineral processing industry, such as fractional crystallization and leaching lend themselves to solar applications. These operations constitute a major portion of the chemical processing employed in the purification and concentration of salts from brine. Enhancing brine evaporation in the solar ponds can be used not only as a means to offset energy costs to improve efficiency, but also to provide a suitable processing environment (Lesino and al., 1991; Folchitto 1991; Guijt and al, 1999). A number of experimental and modeling investigations directed towards the utilization of solar energy to enhance brine evaporation have been reported in literature. Abdel-Aal and Al-Naafa, 1993 investigated the enhanced evaporation of saline water in multi-purpose solar desalination units using flat-plat solar collectors. Their results showed that the concentrated solar energy input was estimated to be 3.5 times than that of direct solar flux allowing separation of soluble mineral salts such as NaCl, MgCl2 and others. Zhang and al, 1993 presented a simulation model of evaporating brine by solar radiation for salt production where the different parameters involved in the behavior of the salt pan were studied. Huang and al., 1999 investigated the effect of a black insulation sheet on the evaporation rate from a shallow salt pan. Results showed that the evaporation rate of the salt pan increased by 10%. In another attempt, Tamimi and Rawajfeh, 2007 modeled the thermal performance of solar evaporative ponds charged from Dead Sea water. The model results showed that the efficiency of any solar evaporator is limited by the optical absorptivity of the saline water as an upper limit. Zeng and al, 2011 demonstrated a strategy for solar evaporation enhancement using floating light-absorbing magnetic particles. In their investigation, evaporation was enhanced by a factor of 2.3 in the solar evaporation of 3.5% water. Horri and al., 2014 modeled the solar evaporation process assisted by floating light porous materials. The model results showed that the evaporation rate can be enhanced by approximate factors of 2.3, 2, and 1.8 when using 0.045, 0.023, and 0.015 g of light absorbing material respectively.

Fig. 1. Photography of the Merouane Chott, salt pans and the salt production unit
Rys. 1. Fotografia Merouane Chott, solarów i wytwórni soli

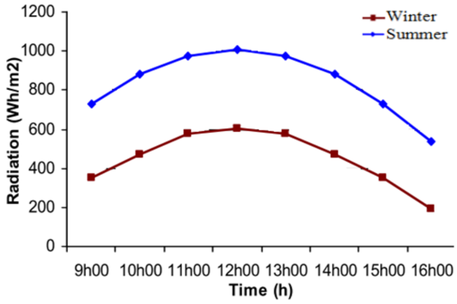

Fig. 2. Solar radiation Evolution of El Oued region
Rys. 2. Promieniowanie słoneczne. Zmiany w regionie El Oued

This work aims to assemble the concentration of two systems of solar radiation in the brine by the development of a black grid and a reflection mirror, and this for object to optimize the process of NaCl crystallization at SME unit figure.01 in order to master the quantitative and qualitative plan according to the needs of the market. So a test is done during the months of December and January on pans near the lake Merouane gave us more encouraging results.

Materials and methods

Solar Radiation and Sun Position of Lake Merouane

Figure.02 shows the solar radiation evolution in Wh/m² during the day time (in hours), one in winter and the other in summer. The radiation increases gradually in both cases until reaching a maximum value between noon and 2:00 pm with the only difference that the solar radiation in winter has not exceeded the value of 600 Wh/m² but in summer it has reached the value of 1000 Wh/m² (A. Khechekhouche2017).

Sun Height and Azimuth

Using Sun Earth Tools software online, the azimuth and elevation (see annex table N°01) of the day 27/12/2016 was determined to know the sun position as it traveled around the test point figure.03.

Figure 04 illustrates that the sun position in the south side is between the interval of sunrise time at 6:40 (where the elevation at - 0.833° and the azimuth at 117.18°) and almost at noon 11:35, after this last, the sun position is in the south west where the sunset at 16:34 of the evening where the elevation to - 0.833° and the azimuth to 242.14°. The curve of sun trajectory figure.05 illustrates also a more and more increase of elevation and azimuth angles from - 0.833° up to 32.5° and from 117.88° up to 180° successively, and that between the interval Cited above, then the azimuth angle stay to increase up to 242.14° while the elevation decreases to - 0.833° which is the sunset.

The estimation of evaporation from weather data

Two requirements must be met to permit continued evaporation H. L. Penman (1948). There must be a supply of energy to provide the latent heat of vaporization, and there must be some mechanism for removing the vapour, i.e. there must be a sink for vapour. Analytical attacks on the problem start from one of these two points and it is convenient to consider the latter first as it has been the more popular.

Empirical equations

Until recent years the approach was empirical, a hundred years' work since Dalton having produced little improvement in the form of equation he gave. In essentials it is

$$E=(e_s-e_d)\, f(_u) \quad (1)$$

where E is the evaporation in unit time, e, is the vapour pressure at the evaporating surface, e_d is the vapour pressure in the atmosphere above, and $f(_u)$ is a function of the horizontal wind velocity. For water, e_s is known if the surface temperature is known. Of the many empirical formulae cast into this form, one due to Rohwer (193I) summarizes results of very intensive work at Fort Collins, Colorado, at 5000 ft. above sea-level. Other things being equal, Rohwer found a small variation of evaporation rates with atmo-

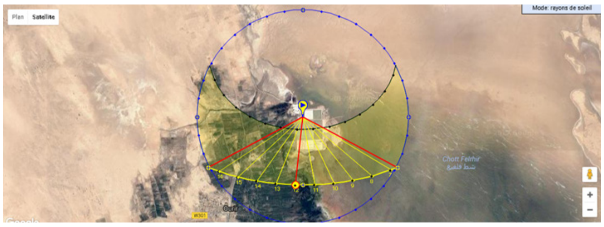

Fig. 3. The hourly position of the sun in relation to the test point
Rys. 3. Godzinowe położenie słońca w stosunku do punktu testowego

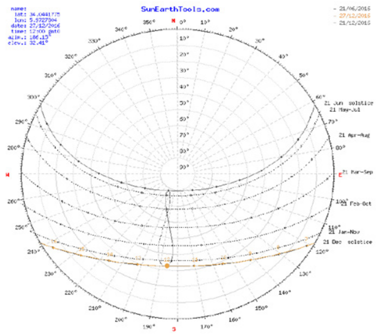

Fig. 4. Position of the sun each hour for sunshine to sunrise
Rys. 4. Położenie słońca w każdej godzinie do wschodu słońca

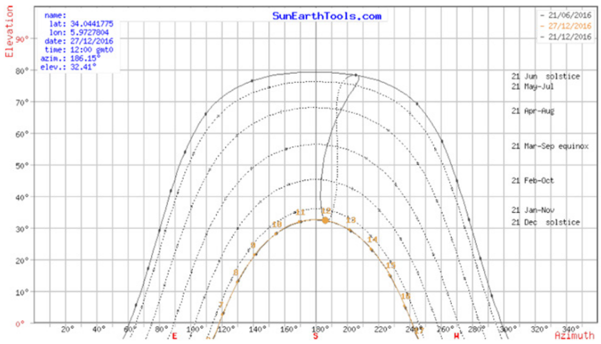

Fig. 5. Trajectory of the sun each hour for sunshine to sunrise
Rys. 5. Trajektoria słońca w każdej godzinie od wschodu do zachodu słońca

spheric pressure, and reduced to conditions at sea-level, his equation for the daily rate from an open water surface 3 ft. square is

$$E=0.40(e_s-e_d)(1+0.27u_0), \text{ mm/day} \quad (2)$$

Where vapour pressures are in mm. mercury, and wind speed at ground level is in m.p.h. Examining the effect of size of surface on evaporation rates, over a period of 485 days, he compared the observed values of evaporation from a large surface 86 ft. diameter with the estimates based on (2), and found the mean value of observed/ estimated to be 0.77. There is some bias here, however, for the average wind speed over the whole period was only 1.50 m.p.h, and examination of the individual daily records shows that on the rare occasions of a wind speed in excess of 3 m.p.h. the correction factor is nearly unity. The ground wind velocity u0, is an extrapolated value estimated from a number of readings at various heights, and if from Rohwer's u, z curve we interpolate at 2 m., the relation becomes

$$E=0.4(e_s-e_d)(1+0.17u_2) \text{ mm/day} \quad (3)$$

And except at very low wind speeds might be expected to apply to large open water surfaces.

Experimentation

In this study, we did a test next to the salt pans of the unit SME during the months of December and January, therefore the pans dimensioned in the table No 01,02 are made of plastic, and implanted on the ground to avoid the heating of its outer walls by solar radiation figure.06, They are filled by brine of lake Merouane with a density of 23.6 B°, the volume of this last is 22.44 dm³ in each pan, a black grid floating BB2 on the surface of brine in P4 figure.07 thanks to a fixed balloon on which. The orifices of the grid gives way to passage of air towards the brine surface for its agitation (formation of the salt crystals) and releases the evaporated particles of water to the air, the pan P4 is also equipped with a standard mirror (simple) for the reflection of solar radiation towards the evaporating surface of the brine. Thus, the results obtained are in

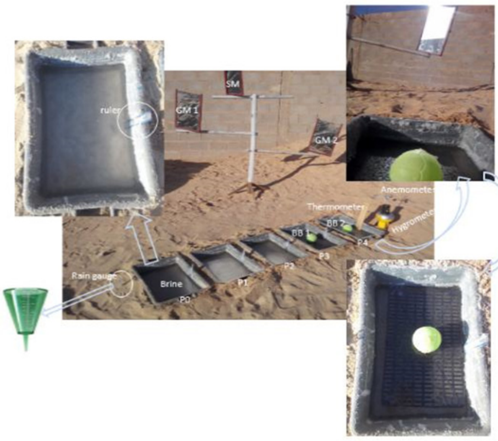

Fig. 6. Photograph of the pans during the test
Rys. 6. Zdjęcie panelu podczas testu

comparison with the witness pan P0 in order to know the difference in the crystallization rates between them. A follow-up of the evaporation measures every morning at 9.00 am thanks to the rules fixed in each pan.

In this paper, we just did a study for the pans P0 and P4. The other results of P1, P2 and P3 will be studied later.

Pans equipments

Sizing of the equipments used

Equipments of measure:

Densimeter: The accuracy of measure is ± 0.001 g/ml.

Weather station (anemometer, hygrometer, rain gauge and thermometer)

The accuracy of the integrated sensor suite of the weather station for measuring each climatic variable was ± 6% for wind speed, ± 4% for relative humidity, ± 4% for rainfall, and 0.5oC for ambient temperature.

Results and discussion

Statistical analysis of the evaporation results

The Statistica software is used to compare the evaporation of brine in the two pans P0 and P4 (see annex Table N°02) table, hence the results obtained in annex Table N°03.

The test used is that of the normal law N (0, 1) useful for the comparison of the two u, so we propose the hypotheses H0 and H1.

To compare the effect of the reflection mirror and the black grid on the volume of evaporated water for the two pans P0 and P4.

We have:

$$\begin{cases} H_0: u1 = u2 : \text{the reflection mirror and the black grid have no effect on the volume of evaporated water.} \\ H_1: u1 \neq u2 : \text{the reflection mirror and the black grid have an effect on the volume of evaporated water} \end{cases}$$

$$\text{So; to be } U_{calculated} = \frac{\bar{x}1 - \bar{x}2}{\sqrt{\frac{s1^2}{n1} + \frac{s2^2}{n2}}} = \frac{0{,}561 - 0{,}748}{\sqrt{\frac{(0{,}16)^2}{52} + \frac{(0{,}22)^2}{37}}} = -4{,}4104$$

The value of u_2 for α = 5% read on the table of the normal law N (0, 1) is $u_{theoretical\ (0,05)} = 1{,}96$

We have $U_{calculated} = -4{,}4104 \notin]-1{,}96;1{,}96[$ therefore, we reject H0 and we accept H1, which says: there is a significant difference between the two pans P0 and P4 so the reflection mirror and the black grid have an effect on volume of the evaporated water.

The climate during this test appeared favorable for the natural evaporation of the brine (average wind speed 1.13 m/s and average humidity 36%). So from figure.08, the daily average of the evaporated water volume of the pan P4 is 0.425 ± 0.207 dm^3 against this one of the P0 is 0.300 ± 0.154 dm^3 which due to a spacing between the curves of a value average of 0.125 dm^3, this difference explains the significant influence of the solar radiation concentration thanks to the reflection mirror (S. Remli., and al., 2018) and the floating black grid in the brine of P4, which due to the evaporation reinforcement of the water amount in it which took 37 days (12/12/2016, 17/01/2017) for total evaporation in comparison with the brine of pan P0 which also took 52 days (12/12/2016, 01/02/2017) as a result we have a profit of 15 days, so an optimization of the salt crystallization process up to 41%. As the study of the average evaporation flux from the traditional system (KASEDD H. and al., 2015) is about 0.02 kg/m^2-hr while that of the enhanced system is about 1.68 kg/m^2-hr, corresponding to a brine temperature increment from 30°C to 50°C. The results show that the evaporation of the brine is increased with the implementation of parabolic solar concentrator as compared to the natural process. The increment in the evaporation flux implies a decrease in the number of days for the crystallization process thus improved productivity. Also, the simulation analysis of Diaz R.B.F and al 2012, they used a Concentrated Solar Thermal Energy to Enhance Sea Salt Production in Southern Spain, so the evaporation rate is drastically increased with the enhanced system compared to the evaporation rate through the natural process. It is estimated that the enhanced system evaporates water six to ten times faster than the natural process.

We have also in figure.09 the curves of the brine and crystallized salt volume in the pans P0 and P4 initiate by the same amount (22.44 dm^3), then they known a spacing more and more between them until the end of salt crystallization where its volume is 7.48 dm^3. There is also a remarkable growth of volume curves due to the precipitation of 2.5 mm in the day (11/01/2017).

To know the difference in temperatures between the pans P0 and P4 generated by the use of the reflection mirror and the black grid, we made hourly measurements of them compared to that ambient during the day 27/12/2016. So the re-

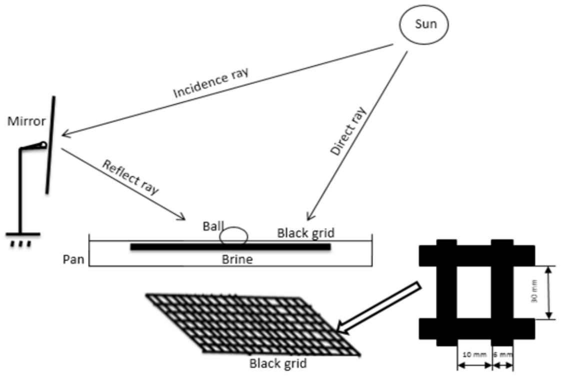

Fig. 7. Assembly of solar radiation concentration systems of the pan P4
Rys. 7. Montaż układów koncentracji promieniowania słonecznego P4

Tab. 1. The equipment of each pan
Tab. 1. Wyposażenie każdego panelu

Brine Pan	with Grand Mirror GM1	With Small Mirror SM	With Black Body BB1	With black body + Grand mirror BB2 + GM2
P0 (Witness)				
P1	■			
P2		■		
P3			■	
P4				■

Tab. 2. The dimensions of the test equipment
Tab. 2. Wymiary sprzętu badawczego

Designation	Dimension, m	area, m^2
P0, P1, P2, P3, P4	0.55 * 0.34	0.187
SM	0.31 * 0.19	0.0589
GM1, GM2	0.48 * 0.30	0.144
BB1, BB2	0.46 * 0.26	0.119

sults obtained are recorded in table N°04 and represented by curves in figure.10. From these last, the temperatures averages of the pans P0 and P4 from 09:00 to 16:00 are 16 ± 2.82°C and 20 ± 3.93°C successively, they initiate by 11°C and 13°C at 09: 00 and then they are accompanied by a growth of the values with a spacing more and more between them up to 5°C during 13:00, this hour represents the temperature threshold during this day, it keeps its value until 14:00 then they knew a slight decrease in its values of 17.5°C for the pan P0 and 22°C for that P4. The ambient air temperature is almost symmetrical with respect to the curves of the pans and its average value is 34.18 ± 2.82°C.

Lake Merouane characterized by an arid region. The exploitation of salt at the unit SME is done by the traditional method with an annual production of 150 000 T/year. The harvesting companion begins with the pumping and ends with the rehabilitation of infrastructure and harvesting means from December to July, which is the life of the lake during the year. The process involves pumping the brine from the lake to 22 Be°, this operation will commence on month of December. The pumped volume decreases appreciably with the evaporation, it is necessary to make additions to maintain the height of the brine in the salt pans, also it is customary to pump 30 to 50 cm of brine layer, once the pumping from the last table is finished the feeding of the first one is repeated until the end of the filling of the lake. After the crystallization of salt, harvesters (harvesting machinery) harvest this crystallized layer from the end of June but they encounter enormous difficulties due at their stops because the rapid hardening of this layer (very high temperature in the summer period), the harvesting continues thanks to the loaders but unfortunately they provoke the layer salt against which generates alterations in the salt pans and a bad quality of the salt. The product is transported by trucks to the washing station for washing and storage in camels and sometimes screening before washing (ENASEL 2011).

In addition, the lake knows variations in the percentage of chemical elements in the brine according to time (temperature, wind… etc) which have a negative influence on the quality of the salt especially the concentration of NaCl.

These last years, the SME unit is known a strong demand for salt products in the market, such as long-term contracts for orders from countries, France, Spain, Niger… etc which leads to an increase in production by realization other salt pans, which poses a problem for the unit: reservations of agricultural area in this region (date palms) currently occupied.

To solve all these problems mentioned above, we propose to install the systems of solar radiation concentration in the salt pans (after an economic study shows the profitability of this investment) which serve to mastery the quality of the salt by the concentration of these systems when the lake becomes rich in percentage of NaCl and low in that of Mg (undesirable salts) and by deconcentration in the opposite case. Also this installation has given us an early crystallization of the salt layer where the climate is favorable for the harvest (a soft salt layer for harvesters), on the other hand there is a possibility

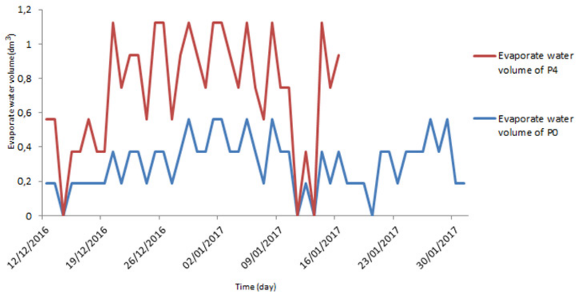

Fig. 8. Curve of evaporated water volume of the pans P0 and P4
Rys. 8. Krzywa objętości odparowanej wody w panwiach P0 i P4

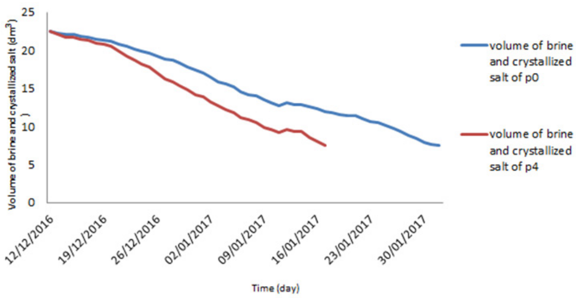

Fig. 9. Curve of the brines and crystallized salt volumes of the pans P0 and P4
Rys. 9. Krzywa solanek i objętości skrystalizowanych soli w panwiach P0 i P4

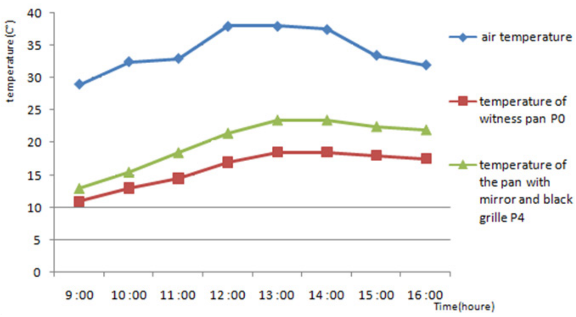

Fig. 10. Curves of air temperature, P0 and P4
Rys. 10. Krzywe temperatury powietrza, P0 i P4

of multiplying the production by another operation (pumping until harvest) and this all depends on the capacity we want to install it.

The rational choice of such a technology requires a technical and economic comparison, which depends essentially on the cost price of a ton of salt extracted, the latter is determined by the knowledge of a bank of information such as: the prices of investments, the wage bill of labor, the energy consumed... etc.

Conclusion

the test done in the company of Salins Merouane El Meghaier (SME) suggests that the systems of solar radiation concentration in the pan P4 filled by the brine have a significant influence on the rate of evaporation-crystallization compared to the witness pan P0, this influence due to an acceleration of the process of the solar salt crystallization thanks to a free energy respectful to the environment, thus an optimization of the stay time until 41% if the surfaces of the black grid and the mirror of reflection represent 63 % and 77% respectively, and those compared to the evaporation surface of the brine.

This work in comparison with other works like Diaz R.B.F and al 2012, KASEDD H. et al. 2015…etc depends mainly on the production yield and the investment costs of these systems, and to choose the adequate system it is necessary to make a detailed technical and economic study which decides the rational choice.

The optimization by solar energy and the presence of a biodiversity favorable environment represent assets of sustainable development of the solar salt industry as well as the development of a region rich in fauna and flora and geotouristic.

Annex: Tab. 1. The angles of elevation and azimuth every hour of the day 27/12/2016
Załącznik: Tab. 1. Kąty wzniesienia i azymut o każdej godzinie dnia 27.12.2016

Date	27/12/2016/GMT0	
Coordinates	34,0441775 - 5,9727804	
Location	El Meghaier Algeria	
Houre	Elevation	Azimut
06:40:24	-0,833°	117,88°
07:00:00	2,71°	120,66°
08:00:00	12,84°	130,07°
09:00:00	21,54°	141,25°
10:00:00	28,16°	154,57°
11:00:00	31,98°	169,87°
12:00:00	32,41°	186,15°
13:00:00	29,4°	201,82°
14:00:00	23,4°	215,67°
15:00:00	15,15°	227,37°
16:00:00	5,32°	237,17°
16:34:27	-0,833°	242,14°

Annex: Tab. 2. Results of evaporation and precipitation of the witness pan P0 and that equipped by the mirror and black grid P4
Załącznik: Tab. 2. Wyniki parowania i wytrącania z szalki obserwacyjnej P0 i tej wyposażonej w lustro i czarną kratkę P4

Number of Day	Day	volume of brine and crystallized salt dm³		volume of evaporated water dm³		precipitation (mm)	Meteorological observation
		Witness pan P0	pan with mirror + black grill P4	Witness pan P0	pan with mirror + black grill P4		
1	**12/12/2016**	**22,44**	**22,44**	-	-	0	
2	**13/12/2016**	**22,253**	**22,066**	0,187	0,374	0	Clear sky
3	**14/12/2016**	**22,066**	**21,692**	0,187	0,374	0	Clear sky
4	**15/12/2016**	**22,066**	**21,692**	0	0	0	**cloudy**
5	**16/12/2016**	**21,879**	**21,505**	0,187	0,187	0	**cloudy**
6	**17/12/2016**	**21,692**	**21,318**	0,187	0,187	0	Clear sky
7	**18/12/2016**	**21,505**	**20,944**	0,187	0,374	0	**cloudy**
8	**19/12/2016**	**21,318**	**20,757**	0,187	0,187	0	**cloudy**
9	**20/12/2016**	**21,131**	**20,57**	0,187	0,187	0	Clear sky
10	**21/12/2016**	**20,757**	**19,822**	0,374	0,748	0	Clear sky
11	**22/12/2016**	**20,57**	**19,261**	0,187	0,561	0	Clear sky
12	**23/12/2016**	**20,196**	**18,7**	0,374	0,561	0	Clear sky
13	**24/12/2016**	**19,822**	**18,139**	0,374	0,561	0	Clear sky
14	**25/12/2016**	**19,635**	**17,765**	0,187	0,374	0	Clear sky
15	**26/12/2016**	**19,261**	**17,017**	0,374	0,748	0	Clear sky
16	**27/12/2016**	**18,887**	**16,269**	0,374	0,748	0	Clear sky
17	**28/12/2016**	**18,7**	**15,895**	0,187	0,374	0	Clear sky
18	**29/12/2016**	**18,326**	**15,334**	0,374	0,561	0	Clear sky
19	**30/12/2016**	**17,765**	**14,773**	0,561	0,561	0	Clear sky
20	**31/12/2016**	**17,391**	**14,212**	0,374	0,561	0	Clear sky
21	**01/01/2017**	**17,017**	**13,838**	0,374	0,374	0	Clear sky
22	**02/01/2017**	**16,456**	**13,277**	0,561	0,561	0	Clear sky
23	**03/01/2017**	**15,895**	**12,716**	0,561	0,561	0	Clear sky
24	**04/01/2017**	**15,521**	**12,155**	0,374	0,561	0	Clear sky
25	**05/01/2017**	**15,147**	**11,781**	0,374	0,374	0	Clear sky
26	**06/01/2017**	**14,586**	**11,22**	0,561	0,561	0	Clear sky
27	**07/01/2017**	**14,212**	**10,846**	0,374	0,374	0	Clear sky
28	**08/01/2017**	**14,025**	**10,472**	0,187	0,374	0	Clear sky
29	**09/01/2017**	**13,464**	**9,911**	0,561	0,561	0	Clear sky
30	**10/01/2017**	**13,09**	**9,537**	0,374	0,374	0	Clear sky
31	**11/01/2017**	**12,716**	**9,163**	0,374	0,374	**2,5**	**rainy**
32	**12/01/2017**	**13,09**	**9,537**	0	0	0	Clear sky
33	**13/01/2017**	**12,903**	**9,35**	0,187	0,187	0	**cloudy**
34	**14/01/2017**	**12,903**	**9,35**	0	0	0	Clear sky
35	**15/01/2017**	**12,529**	**8,602**	0,374	0,748	0	Clear sky

36	**16/01/2017**	**12,342**	**8,041**	0,187	0,561	0	Clear sky
37	**17/01/2017**	**11,968**	**7,48**	0,374	0,561	0	Clear sky
38	**18/01/2017**	**11,781**		0,187		0	Clear sky
39	**19/01/2017**	**11,594**		0,187		0	Clear sky
40	**20/01/2017**	**11,407**		0,187		0	Clear sky
41	**21/01/2017**	**11,407**		0		0	Clear sky
42	**22/01/2017**	**11,033**		0,374		0	Clear sky
43	**23/01/2017**	**10,659**		0,374		0	Clear sky
44	**24/01/2017**	**10,472**		0,187		0	Clear sky
45	**25/01/2017**	**10,098**		0,374		0	**cloudy**
46	**26/01/2017**	**9,724**		0,374		0	Clear sky
47	**27/01/2017**	**9,35**		0,374		0	Clear sky
48	**28/01/2017**	**8,789**		0,561		0	Clear sky
49	**29/01/2017**	**8,415**		0,374			
50	**30/01/2017**	**7,854**		0,561			
51	**31/01/2017**	**7,667**		0,187			
52	**01/02/2017**	**7,48**		0,187			

Annex: Tab. 3. Obtained results by Statistica software
Załącznik: Tab. 3. Wyniki uzyskane przez program Statistica

after	N° of actives	Average	Median	Minimum	Maximum	1st Quartile	3rd Quartile	Extended Quartile	standard deviation
P0	**52**	**0,294885**	**0,374000**	**0,00**	**0,561000**	**0,187000**	**0,374000**	**0,187000**	**0,158615**
P4	**37**	**0,414432**	**0,374000**	**0,00**	**0.748000**	**0,374000**	**0,561000**	**0,187000**	**0,216536**

Annex: Tab. 4. The hourly monitoring of air and brines temperatures P0 and P4
Załącznik: Tab. 4. Cogodzinne monitorowanie temperatur powietrza i solanek P0 i P4

time (hour)	Air temperature C °	Temperature of the witness pan P0 C °	Temperature of the pan with mirror and black grill P4 C °	Meteorological observation
9 :00	**29**	**11**	**13**	Clear sky
10 :00	**32,5**	**13**	**15,5**	Clear sky
11 :00	**33**	**14,5**	**18,5**	Clear sky
12 :00	**38**	**17**	**21,5**	Clear sky
13 :00	**38**	**18.5**	**23,5**	Clear sky
14 :00	**37,5**	**18,5**	**23,5**	Clear sky
15 :00	**33,5**	**18**	**22,5**	Clear sky
16 :00	**32**	**18**	**22**	Clear sky

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Zwiększenie szybkości parowania solanki dzięki energii słonecznej w celu optymalizacji produkcji soli w jeziorze Merouane El Oued w południowo-wschodniej Algierii

W niniejszym artykule przeanalizowano zastosowanie dwóch systemów do wykorzystania energii słonecznej w jednostce SME (Salins Merouane El Meghaier) zlokalizowanej w południowo-wschodniej Algierii, poprzez wdrożenie czarnej siatki unoszącej się w solance i lustrzanego odbicia światła słonecznego. Promieniowanie skierowano na powierzchnię lustrzaną P4, i na powierzchnię doskonale czarną P0, co pozwoliło porównać oba rozwiązania. Uzyskane wyniki sugerują wzrost szybkości parowania i krystalizacji P4 w porównaniu z P0, który ocenioną analizując wyniki rocznej produkcji jednostek MŚP.

Słowa kluczowe: *Algieria, jezioro, energia słoneczna, lustro, ciało doskonale czarne, optymalizacja, krystalizacja przez odparowanie, sole*

International Steam Coal Market and the Price Situation in Poland – Part I

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Abstract

The purpose of the paper was to analyse steam coal prices of Polish producers with reference to the main spot price indices of steam coal from international markets. The research covered the years 2010–2019. Due to the complexity of the discussed issues, the article is divided into two parts. The first part discusses the European steam coal market, with a particular focus on Poland. The investigation has shown that for many years both the production and consumption of steam coal in OECD Europe countries was in a declining trend. In the case of production, the CAGR for the years 2010–2018 was -6.6%, and the average annual rate of decrease in consumption of this raw material was 3.0%. Not only has decarbonisation policy contributed to this decline, but also the growing share of renewable energy, and coal and other energy sources price ratio (reduction of the share of coal in a country's fuel mix). The main exporters of steam coal to the OECD Europe market in those years were primarily: Russian Federation (43–77 Mt/y with 26–46% share), Colombia (35–63 Mt/y; 21–31%), USA (11.0–36.0 Mt/y; 7–16%) and South Africa (6.5–26.5 Mt/y; 4–12%). In the years analysed, the production of steam coal in Poland amounted to 50.0–67.5 million tonnes per year (Mt/y). In 2012–2015, Polish production exceeded domestic demand for this raw material by several percent, and in the remaining years accounted for 83–90% of domestic consumption. Along with declining Polish production, imports of steam coal, which varied between 6–16 Mt/y, grew in importance.

Keywords: *steam coal, prices, international coal market, Poland*

1. Introduction

Analysis of the statistics presented in the publications of the International Energy Agency (Coal Information, 2011–2019; during the drafting of the paper, data was available until 2018) shows that within Europe Poland is one of the most important producers and users of steam coal. According to official national data (ARE, 2010–2020), the production of steam coal in Poland in 2010–2019 totalled 50.0–67.5 Mt/y. In 2012–2015, domestic production exceeded Polish demand for steam coal by a few percent, and in the remaining years of the second decade of the 21st century accounted for 83-90% of domestic consumption of this raw material.

As of 31 December 2019 (PGI, 2020), Poland's steam coal reserves amounted to 45.2 billion tonnes (Bt), accounting for 70% of hard coal reserves and 52% of total hard coal and lignite reserves. On a European scale, at the end of 2019 (BP, 2020) the share of Polish total proved reserves of anthracite and bituminous coal was 37.0% (i.e. 21.1 Bt), and on a global scale 2,8%.

The question is often asked: since domestic steam coal production largely covers the demand of domestic consumers, does the price situation on the international market influence the prices of coal offered to Polish consumers? The purpose of the paper is to analyse the prices of steam coal of Polish producers in relation to the main spot price indices of steam coal from international markets in 2010–2019.

Due to the complexity of the discussed issues, the article is divided into two parts. The first part discusses the European steam coal market, with a particular focus on Poland.

2. European steam coal market

The introduction mentions that Poland is among the leading European producers and consumers of steam coal. So what exactly was the production and consumption of steam coal in Europe and Poland in the second decade of the 21st century?

The analysis of the data published in Coal Information (2011-2019) shows that steam coal production in Europe has been in a downward trend for years. Although during the first three years of the second decade of the 21st century, the total production of steam coal in OECD Europe countries annually exceeded 100 Mt, it decreased in the following three years to over 80 Mt/y, and in 2018 to 62 Mt (Figure 1). The average annual rate of decrease in the production of this raw material between 2018 and 2010 was -6.6%. Among the leading producers of steam coal in the OECD Europe countries in 2010-2018 Poland should be mentioned first with its 60–83% share in total coal production, and then follow smaller producers: Czech Republic (4–7%), Spain (3-8%), Turkey (2–3%) and Germany (2–6%); the latter stopped using hard coal in 2018.

The consumption of steam coal has been decreasing at a lower rate. For all OECD Europe countries the 2010–2018 CAGR was -3.0%; the maximum consumption happened in 2012 amounting to 286 Mt, and the minimum in 2018 – amounting to 207 Mt (Figure 1). Several factors influenced the volume of coal consumption in those countries. In addition to decarbonisation policy and growing share of renewable energy, the coal-gas price ratio also had a significant impact contributing to a reduction in the share of coal in a country's fuel mix. As recently as 2010, the total production

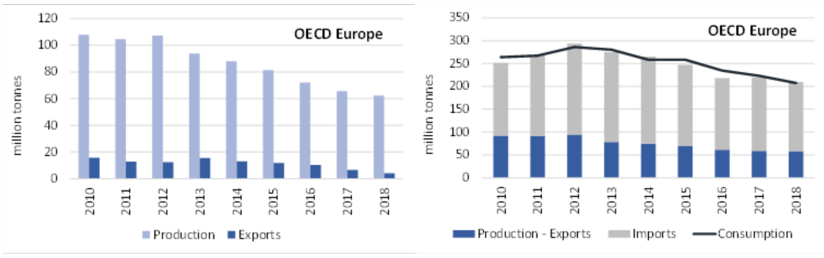

Fig. 1. Comparison of production and exports (a), and consumption and imports (b) of steam coal to OECD Europe, 2010–2018. Source: Own study based on (Coal Information 2011–2019)

Rys. 1. Porównanie produkcji i eksportu (a) oraz zużycia i importu (b) węgla energetycznego do krajów OECD Europe, lata 2010–2018

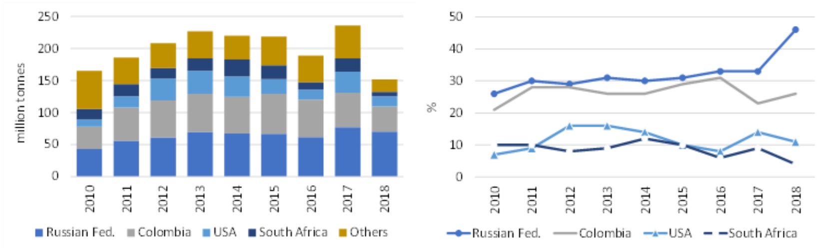

Fig. 2. Main steam coal exporters to OECD Europe, 2010-2018; a) volume in million tonnes, b) share in %. Source: Own study based on Coal Information (2011–2019)

Rys. 2. Główni eksporterzy węgla energetycznego do OECD Europe, lata 2010-2018; a) wolumen w mln ton, b) udział w %

of OECD countries covered 41% of their needs for steam coal, and in 2018 dropped by 11 percentage points. Coal from international markets grew in importance. For comparison, at the beginning of the second decade of the 21st century, the share of imported coal in production was 60%, and in 2018 increased by 13 percentage points. Despite this fact, since 2013 total steam coal consumption in OECD Europe countries has been in a downward trend, and the average annual rate of decrease in consumption of this raw material for 2010–2019 was -3.0%.

3. Major suppliers of steam coal

The graph in Figure 2 shows in volume terms the main exporters of steam coal to OECD Europe countries in 2010–2018 (Figure 2a) as well as their share (Figure 2b) across all countries in this group. The analysis of steam coal suppliers to the aforementioned European countries exhibits two groups of exporters: the first with a share in total imports exceeding 20% (Figure 2b) and the second with a share of several dozen percent (Figure 2b). The first group includes the Russian Federation and Colombia while the second group includes the US and South Africa.

For the Russian Federation, the European market has for years been an important destination for coal exports. According to Coal Information statistics (2011–2019), in 2010–2018 the Russian Federation exported 43.2–76.9 Mt of steam coal annually to recipients from OECD Europe countries, which accounted for 26–46% of total coal exports to these countries. In the case of Colombia, annual coal supplies to OECD Europe countries in 2010–2018 amounted to 34.8–62.6 Mt (21–31%).

The other two countries: the US and South Africa are referred to as 'shuttle exporters', and their share in supplying a given geographical region - in addition to the external demand for steam coal – also depends on its price level on the international market. This issue will be discussed in more detail later on in the paper. In 2010–2018 the exports of steam coal from the US to OECD Europe countries totalled 11.0–36.0 Mt/y (7–16%) and the exports from South Africa amounted to 6.5–26.5 Mt/y (4–12%).

4. Poland in comparison with other European countries

Analysis of individual steam coal producers in OECD Europe countries from Coal Information statistics (2011–2019) shows that in 2010–2018 Poland was its most important producer, and the country's share in total output steadily increased (Figure 3). For the first four years of the analysed decade Polish steam coal production accounted for over 60% of total output in OECD Europe countries and although Poland reduced the number of active coal mines, similarly to other OECD Europe countries (e.g. Germany, Spain, the Czech Republic), its share in comparison with the whole group of countries exceeded 80% starting from 2016.

In addition to the fact that Poland is the main producer of steam coal in OECD Europe countries, its share in total exports of this raw material is also at relatively high levels (see Figure 3). In 2010–2015, exports fluctuated between 42–55%, and in the subsequent two years accounted for as much as two thirds of OECD Europe exports. With consumption remaining at similar levels (see Figure 4) and decreasing demand from the main countries importing Polish steam coal, the decline in domestic production observed for several years has not been conducive to an increase in exports.

Poland also ranks first in terms of steam coal consumption, its share however being not as dominant as in the case of other OECD countries. And although in volume terms coal consumption was in a downward trend (Figure 4) (in 2018 it fell by 9.9 Mt compared to 2010 and totalled 62.6 Mt), Poland's share in total consumption of OECD Europe countries fluctuated between 23–30%, and from 2015 onwards its

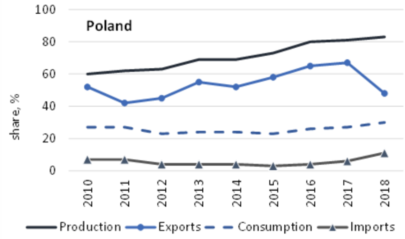

Fig. 3. Poland's share in steam coal production and consumption, exports and imports against OECD Europe countries, 2010–2018. Source: Own study based on Coal Information (2011–2019)
Rys. 3. Udział Polski w produkcji i zużyciu oraz eksporcie i imporcie węgla energetycznego w krajach OECD Europe, lata 2010–2018

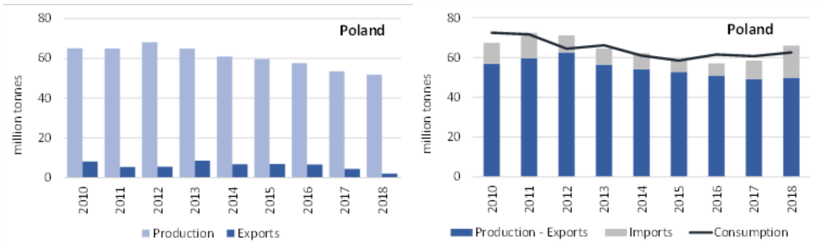

Fig. 4. Comparison of steam coal production and exports (a), consumption and imports (b) to Poland, 2010–2018. Source: Own study based on Coal Information (2011–2019)
Rys. 4. Porównanie produkcji i eksportu (a) oraz zużycia i importu (b) węgla energetycznego do Polski, lata 2010–2018

steady growth is observed. The growing share of Poland in the consumption of steam coal at European level was due not only to the improvement of the efficiency of transformations in the energy sector, but also to the reduced demand resulting from replacing coal with other energy sources (e.g. RES, gas) (Grudziński, 2013; Szczerbowki and Ceran, 2015; Gawlik, 2018; Grudziński, 2018; Olkuski, 2018; Stala-Szlugaj and Grudziński, 2019; Kaszyński and Kamiński, 2020; Nyga-Łukaszewska et al., 2020, Sobczyk et al., 2020).

5. Imports of steam coal to Poland

The slow decline in domestic steam coal production and the demand remaining at similar levels in the last years were among the factors that influenced the volume of steam coal imports to Poland. However, before discussing import volumes, the authors first want to focus on steam coal buyers in Poland.

The graph in Figure 5 illustrates the sales structure of steam coal imported to Poland. Due to the fact that Poland started detailed monitoring of imported steam coal (as well as the directions of the sales) in 2012, the data presented in the graph begin with that year.

The analysis of imported steam coal sales (Figure 5) shows that the main buyer is a so-called group of other domestic customers (56–76%). The group consists of a large number of customers represented by (Stala-Szlugaj, 2017) individual buyers (households), agricultural and horticultural households, small industry, public administration, health care and a number of other unspecified recipients.

Due to the fact that the group of other domestic recipients uses steam coal mainly for heating purposes, among the factors influencing its consumption are the temperatures prevailing in a given winter season. Other key factors influencing the volume of steam coal consumed by this group include (Stala-Szlugaj, 2017; Stala-Szlugaj, 2018) its price ratio versus other energy carriers as well as the level of energy poverty.

The years 2010–2011 were characterised by relatively cold winters, so there was a relatively high demand for coal. The analysis of steam coal grades sold to domestic customers (ARP, 2011–2020) and the consumption of steam coal by households (CSO, 2011–2019) revealed that the share of domestic sales of coarse and medium-size grades (i.e. the grades most frequently used by households) in the consumption of steam coal in Polish households in those two years totalled 75–88%. Domestic sales of these grades (ARP, 2011–2020) were at 7–8 Mt/y. Although in volume terms, in the next two years domestic sales remained at similar levels, their share dropped to 72–74%. In the following years, the share of sales of the said domestic grades fell to 61–69%, and in volume terms to 6–7 Mt/y.

Also noteworthy is the second group of purchasers of imported steam coal (see Figure 5), i.e. the power industry (electric utilities and industrial plants combined). In 2012–2019, its share in the directions of sales of imported steam coal changed between 15–26%. In order to ensure the generation of electricity to domestic consumers, this group relies primarily on the supply of domestic raw material which it purchases on long-term contracts whereas deliveries from the international spot market are treated as complementary supplies. Annual coal consumption by this group in 2010–2018 (CSO, 2011–2019) was 37.6–44.1Mt. In terms of grades, electric utilities use coal fines and the annual volume of these grades sold by domestic producers amounted to 31.2–38.8 Mt in 2010–2019 (ARP, 2011–2020). Domestic supplies accounted for 79–90% of the coal consumed by this group of recipients.

In 2012–2019, these two groups of consumers purchased in total 83–94% of steam coal imported to Poland.

So how did imports of steam coal to Poland develop? In volume terms, in 2010–2019 they varied from 5.6 to 15.7 Mt/y

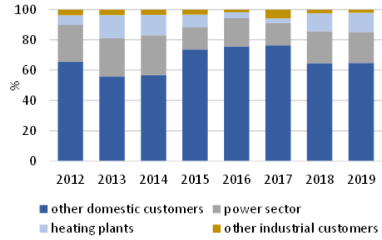

Fig. 5. Buyers of steam coal imported to Poland, 2012–2019. Source: Own study based on ARP (2012–2020)
Rys. 5. Struktura nabywców importowanego węgla energetycznego do Polski, lata 2012–2019

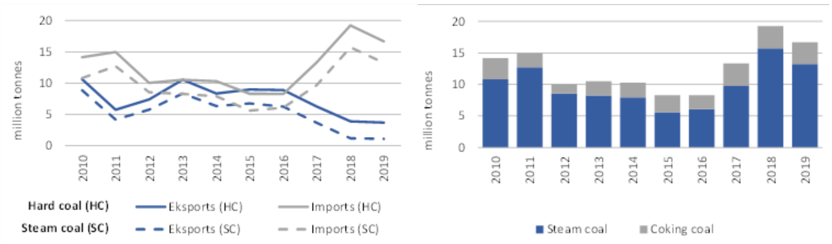

Fig. 6. Imports of steam coal to Poland in 2010–2019; a) imports compared to exports, b) imports broken down into steam coal and coking coal. Source: Own study based on (ARP, 2012–2020)
Rys. 6. Import węgla energetycznego do Polski w latach 2010–2019; a) import w porównaniu z eksportem, b) import w podziale na węgiel energetyczny i węgiel koksowy

(see Figure 6a) excluding the years 2013 and 2015–2016 where Poland was a net importer of this raw material. In 2010–2019, the share of steam coal in total hard coal imports to Poland was 68–85% (see Figure 6b). Within all OECD Europe countries, after Germany (20–29%) and Turkey (10–19%), Poland is the third importer of this raw material with a share of 4–11% (see Figure 3).

6. Summary

The first part of this article was devoted to discussing the European steam coal market. Poland was given particular attention.

Steam coal production in Europe has been in a downward trend for years. The average annual rate of decrease in the production of this raw material between 2018 and 2010 was -6.6%. The consumption of steam coal has been decreasing at a lower rate, and for all OECD Europe countries the 2010–2018 CAGR was -3.0%. As recently as 2010, the total production of OECD countries covered 41% of their needs for steam coal, and in 2018 dropped by 11 percentage points. Coal from international markets grew in importance. The main exporters of steam coal to the OECD Europe market in those years were primarily: Russian Federation (43–77 Mt/y with 26–46% share), Colombia (35–63 Mt/y; 21–31%), USA (11.0–36.0 Mt/y; 7–16%) and South Africa (6.5–26.5 Mt/y; 4–12%).

Within Europe, Poland is one of the most important producers and users of steam coal. Between 2010 and 2018, Polish production of 52–68 Mt/y accounted for 60–83% of the extraction of this raw material in all OECD Europe countries. The annual consumption of 58–72 Mt represented 23–30% of the consumption of OECD Europe countries. For many years, Poland's domestic production was the primary supplier of coal to its domestic market. However, with the decreasing number of mines, which resulted in lower extraction, imports of steam coal have grown in importance. According to Polish statistics, between 2010 and 2019 the import of steam coal to Poland varied from 6 Mt (in 2015) to 16 Mt (in 2018).

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Międzynarodowy rynek węgla energetycznego a sytuacja cenowa w Polsce – część I

Celem artykułu była analiza cen węgla energetycznego polskich producentów w odniesieniu do głównych indeksów cen spot węgla energetycznego z rynków międzynarodowych. Badaniami objęto lata 2010–2019. Ze względu na złożoność poruszanej problematyki, artykuł został podzielony dwie części. W części pierwszej omówiono europejski rynek węgla energetycznego, szczególnie skupiając się na Polsce. W artykule omówiono także europejski rynek węgla energetycznego. Badania pokazały, że od wielu lat zarówno produkcja, jak i zużycie węgla energetycznego w krajach OECD Europe znajduje się w trendzie malejącym. W przypadku produkcji CAGR dla lat 2010–2018 wyniósł -6,6%, a średnioroczne tempo spadku zużycia tego surowca wyniosło 3,0%. Do tego spadku przyczyniła się nie tylko polityka dekarbonizacyjna, ale również rosnący udział energetyki odnawialnej oraz relacje cen między węglem a innymi nośnikami energii (zmniejszenie udziału węgla w miksie paliwowym danego kraju). Głównymi eksporterami węgla energetycznego na rynek OECD Europe w tych latach były przede wszystkim: Fed. Rosyjska (43–77 mln ton/rok, z 26–46% udziałem), Kolumbia (35–63 mln ton/rok; 21–31%) oraz USA (11,0–36,0 mln ton/rok; 7–16%) i RPA (6,5–26,5 mln ton/rok; 4–12%). W analizowanych latach produkcja węgla energetycznego w Polsce rocznie wynosiła 50,0–67,5 mln ton. W latach 2012–2015 polska produkcja o kilka procent przekraczała krajowe zapotrzebowanie na ten surowiec, a w pozostałych latach stanowiła 83–90% jego krajowego zużycia. Wraz z malejącą polską produkcją rósł na znaczeniu import węgla energetycznego, który zmieniał się w zakresie 6–16 mln ton/rok.

Słowa kluczowe: *węgiel energetyczny, ceny, międzynarodowy rynek węgla, Polska*

International Steam Coal Market and the Price Situation in Poland – Part II

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Abstract

The purpose of the paper was to analyse steam coal prices of Polish producers with reference to the main spot price indices of steam coal from international markets. The research covered the years 2010–2019. Due to the complexity of the discussed issues, the article is divided into two parts. The second part focuses on the analysis of steam coal prices on the European and Polish markets. Analysis of the price indices of the main exporters of steam coal to the European market showed that the prices on international spot markets are closely linked. An investigation into the dependence of prices of the main exporters of steam coal to the European market (Russia, Colombia, the US, and South Africa) on the CIF ARA Mix index confirmed this phenomenon. The calculated coefficient of determination varied between 0.922–0.998. The comparison of the volatility of the average monthly prices of the two Polish steam coal market indices (PSCMI) with the spot indices of CIF ARA Mix and FOB Russia Mix showed that the trends on the international spot market are different from those on the Polish market. This coincidence only occurred when comparing annual average prices, and only when the prices of PSCMI were shifted backwards by one year. This shift backwards is due to the way in which Polish producers have contracts with their customers. Poland is dominated by long-term contracts with prices set once a year. Having shifted the annual averages of both PSCMIs backwards by one year, the differences between the indices decreased to about 1PLN/GJ (previously they had reached 3PLN/GJ). The calculated coefficient of determination for both PSCMIs and CIF ARA Mix for 2010–2018 equalled: R2=0,88 (PSCMI_1/Q) and R2=0,89 (PSCMI_2/Q).

Keywords: *steam coal, prices, international coal market, Poland*

1. Introduction

Within Europe Poland is one of the most important producers and users of steam coal. The production of steam coal in Poland in 2010–2019 totalled 50.0–67.5 Mt/y (ARE, 2010–2020). In the remaining years of the second decade of the 21st century accounted for 83–90% of domestic consumption of this raw material.

The purpose of the paper is to analyse the prices of steam coal of Polish producers in relation to the main spot price indices of steam coal from international markets in 2010–2019. Due to the complexity of the discussed issues, the article is divided into two parts. The first part discusses the European steam coal market, with a particular focus on Poland. The second part focuses on the analysis of steam coal prices on the European and Polish markets.

2. Coal prices on the European market

Price indices are commonly used in the international trade of steam coal. They express prices related to coal of standardised quality. For the purposes of this paper, price indices have been taken into account for the following NAR (Net As Received) parameters: a calorific value of 6,000 kcal/kg (25 MJ/kg), a sulphur content of maximum 1% and an ash content of maximum 15%. Prices are quoted in US dollars and refer to fine grades and grain classes of 0–50 mm.

In the markets of importers, the indices values are CIF (i.e.: cost-insurance-freight) or CFR (i.e.: cost&freight) based prices in the port of the importer. In contrast, exporters compete with each other on the basis of prices quoted on a FOB (free-on-board) basis in the port of the exporter.

The analysis was carried out for the following averages calculated by the authors: monthly and annual prices of steam coal from daily spot market quotations (spot market – these are so-called spot transactions with a 15–90 day forward delivery window depending on the coal index). The data used for the calculation came from the following sources: Argus (2010–2019), Platts (2010–2019a,b) and the globalCoal internet platform (globalCoal, 2010–2019). As the presented indices from international markets are the average of the minimum of two indices, and in some periods of time the average of three indices, the name of the indices compared in this article uses the symbol 'Mix'.

Since the aim of the paper is to analyse how Polish steam coal prices depend on the international market, the most important price indices for the North–Eastern European market were taken into account (Figure 1). In the case of the importers' market, this was the index for the terminals of Amsterdam–Rotterdam–Antwerp (the so-called ARA terminals) i.e. CIF ARA Mix. For exporters, coal prices taken into account were from Russia (FOB Russia Mix) in the Baltic terminals, from Colombia (FOB Columbia Mix) in the terminals of the Caribbean Sea, from South Africa (FOB SA Mix) in the terminal of Richards Bay and, in the case of the United States, in the port of Chesapeake Bay on the Atlantic Ocean (FOB USA Mix).

The beginning of 2011 marked the beginning of a gradual decline in prices on international steam coal markets (see

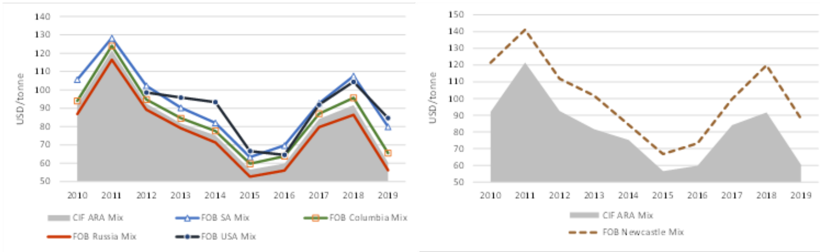

Fig. 1. Average annual steam coal indices: major exporters to the European market (a); main global coal benchmarks (b). Source: Own study based on (Argus, 2010–2019; Platts, 2010–2019a,b; globalCoal, 2010–2019)

Rys. 1. Średnie roczne indeksy węgla energetycznego: głównych eksporterów na rynek europejski (a); głównych światowych benchmarków węglowych (b)

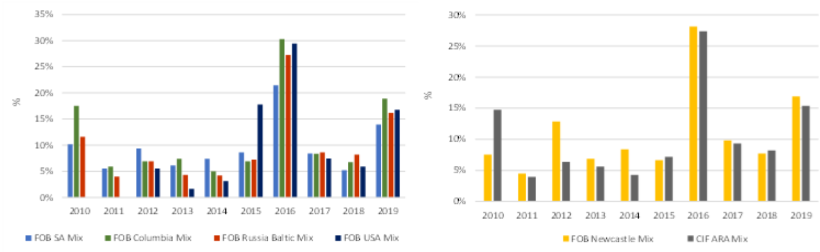

Fig. 2. Variability of average monthly steam coal indices: major exporters to the European market (a); major global coal benchmarks (b). Source: Own study

Rys. 2. Zmienność średnich miesięcznych indeksów węgla energetycznego: głównych eksporterów na rynek europejski (a); głównych światowych benchmarków węglowych (b)

Figure 1a,b) which lasted until 2015. The prices of the main steam coal suppliers to the European market decreased by 36–40%, dropping to USD 53–67 per tonne. Although prices were in a downward trend, the volatility of average monthly prices during the year was relatively small, at several per cent (see Figure 2a). In the case of the main benchmark for steam coal imported to Europe, i.e. the CIF ARA Mix index, the decrease was 39%, falling to USD 57 per tonne, and the volatility of average monthly prices ranged between 4% and 7% (see Figure 2b). Comparing it with the values of the index for the Asian market (FOB Newcastle Mix being the main benchmark for coal exported from Australia), it can be seen that they change in similar trends (see Figure 1b, 2b).

The main reason behind those falls was the oversupply of coal on international markets. The growing production of the main global exporters of steam coal (Australia, Indonesia, Russia, Colombia) was accompanied by weaker demand from both industrialised and developing countries. In the US, due to the so-called 'shale revolution', the production of oil and gas from unconventional sources increased significantly, as a result of which part of domestic coal was replaced by gas in the power industry, and the excess of steam coal was directed to export.

In 2016, this trend changed mainly by the situation in the Chinese market. China had introduced a number of measures aimed at reducing overcapacity in its coal sector and improving the efficiency and profitability of other mines. As a result of those measures, domestic coal production fell significantly and prices rose sharply. As a result, demand for imported coal increased, and China once again became the world's largest importer of steam coal. Events on the Chinese market had repercussions on global coal markets, contributing to price increases which further reduced global demand for coal, especially in the power sector. Other energy carriers, such as natural gas and renewable energy, became the main beneficiaries.

Compared to 2015, the prices of the main exporters of steam coal to the European market increased by 7–10% (see Figure 1a), and considering the whole 2016, the volatility of average monthly prices was 21–30% (see Figure 2a). The CIF ARA Mix index increased by 6% (y/y) to USD 60 and reached 27% volatility of average monthly prices.

Over the next three years, as a result of a fall in demand, mainly from China, and large stocks accumulated not only at users but also at port terminals, prices followed a downward trend. For example, at the terminals of the European ports of Amsterdam–Rotterdam–Antwerp, coal stocks remained at 5–7 Mt. In 2019, the fall in prices of the main exporters to the European market was 19–31% (see Figure 1a) and CIF ARA Mix prices decreased by 34% (see Figure 1b).

The formation of market prices for steam coal is influenced by several factors which include basic factors, ad hoc factors and exchange rates (Lorenz, 2006; Lorenz and Grudziński, 2009; Lorenz, 2014).

Among the basic factors, the key role is played by the level of demand for steam coal and trends in its developments, as well as the costs of coal extraction. The quantity of coal reserves, their geographical distribution and the costs of transporting this raw material also play an important role. In 2012, for instance, as a result of competition from cheaper 'shale' gas, American coal producers lost a significant part of their domestic market and started looking for opportunities to place their raw material on the international market. This was made possible namely by cooperation with railway operators who aligned their freight rates with the API2 index (the API2 index corresponds to the price under CIF ARA conditions). As a result, US coal prices followed trends in maritime trade. Another important fundamental factor is cost and price com-

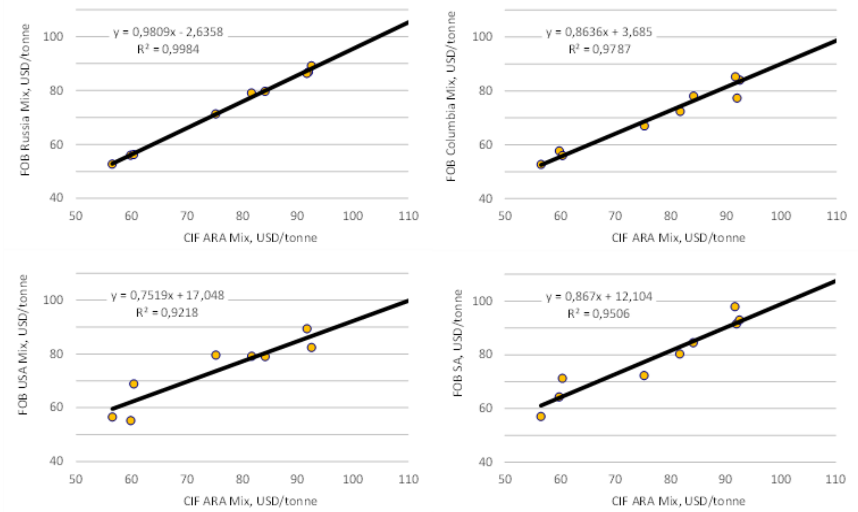

Fig. 3. Correlations of average annual CIF ARA Mix prices with the prices of the main steam coal exporters to the European market: FOB Russia Mix, FOB Columbia Mix, FOB USA Mix and FOB SA Mix. Source: Own calculations

Rys. 3. Korelacje średnich rocznych cen węgla energetycznego CIF ARA Mix z cenami głównych eksporterów węgla energetycznego na rynek europejski: FOB Russia Mix, FOB Columbia Mix, FOB USA Mix oraz FOB SA Mix

Tab. 1. Specification of PSCMIs. Source: TGE, 2020

Tab. 1. Specyfikacja polskich indeksów węglowych

Index	Fine coal grades	Calorific value [MJ/kg]	Sulphur content [%]
PSCMI 1	20-23/1	$20 \le Q_i^r < 24$	$S_t^r < 1$
PSCMI 2	23-26/08	$23 \le Q_i^r < 27$	$S_t^r < 0,8$

petitiveness of other energy carriers and the environmental conditions regarding coal extraction and its use.

As far as ad hoc factors are concerned, weather, among other things, is crucial, affecting the energy demand of end users, the conditions of opencast mining operations, and transport. In 2010–2011 and 2017–2018, for instance, heavy rainfall flooding mines and production and transport infrastructure particularly affected Colombia, contributing to the decline in coal extraction and exports from that country. In Russia, coal wagons often freeze during the winter months, which results in temporary difficulties in accessing them. Among other ad hoc factors, random events and transport constraints also play an important role. Random events are also referred to as force majeure and include natural disasters, catastrophes, pandemics or long-term strikes. As far as transport constraints are concerned, they include both land and inland waterway transport, as well as maritime transport, etc.

The last factor is the value of national currencies of coal exporters and importers referred to the US dollar.

The next step of the analysis was to correlate the indices of the main four exporters of steam coal to the European market (Russia, Colombia, the US and South Africa) with the CIF ARA Mix index (Figure 3).

The analyses carried out show how much energy coal prices on the international coal market are interconnected. Sometimes price relatives in different parts of the world and at different times are disrupted by local factors (such as strikes, weather anomalies, logistical problems), but in the long term these relatives are quite stable. The study of the relationship between the main four exporters of steam coal to the European market (Russia, Colombia, USA and South Africa) with the CIF ARA Mix index gives a very high result. The R^2 coefficient ranging from 0.922 to 0.998 confirms these statements. The determination factor for coal from Russia (R^2 = 0.998) is particularly notable. Russian coal sellers shape their prices in such a way that they are competitive when compared to prices in ARA terminals (on average their prices are lower by about 5%). This allows Russian coal suppliers to maintain their competitive advantage over non-European suppliers (Colombia, South Africa, USA).

3. Prices of steam coal on the Polish market

The next step of the analysis was to answer the question regarding the impact of the situation on the international market on steam coal prices in Poland in the context of large coal imports.

In Poland, two official coal indexes are published for steam coal: PSCMI 1 and PSCMI 2 (PSCMI – Polish Steam Coal Market Index). They are published by the Polish Power Exchange (TGE, 2020) and calculated by ARP Katowice. The Mineral and Energy Economy Research Institute of the Polish Academy of Sciences also took part in the development of the methodology of this index. Both indices are based on the selling prices of fine steam coals with specific quality parameters and calculated ex-post. The oldest published values of these indices refer to January 2011. The PSCMI 1 reflects the pricing of fine steam coals sold to electric utilities and industrial plants whereas the PSCMI 2 reflects the pricing of fine steam coals sold to industrial and district heating plants. The specification of Polish coal indices is presented in Table 1.

Figure 4 compares prices of Polish steam coal market indices (index for power plants and CHP plants: PSCMI_1/Q and for industrial and district heating plants: PSCMI_2/Q) with prices of steam coal: CIF ARA Mix and FOB Russia Mix. The

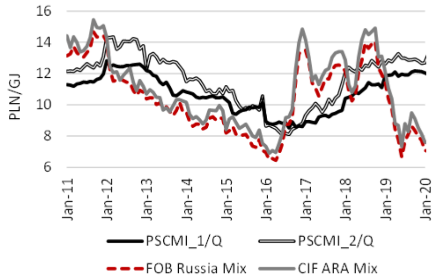

Fig. 4. Comparison of average monthly CIF ARA Mix, FOB Russia Mix prices with PSCMIs. Source: Own study based on data from TGE 2020, NBP 2020, Argus (2010–2019), Platts (2010–2019a,b), globalCoal (2010–2019)

Rys. 4. Porównanie średnich miesięcznych cen CIF ARA Mix, FOB Russia Mix z polskimi indeksami węglowymi PSCMI

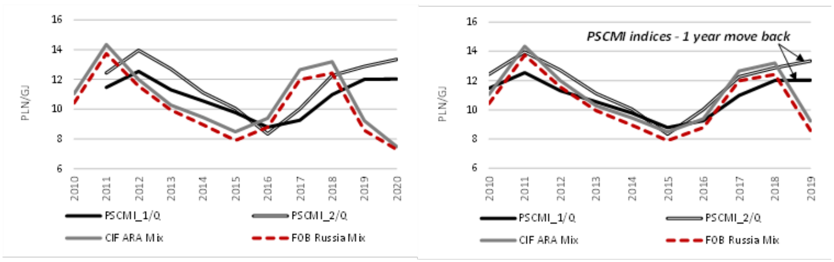

Fig. 5. Comparison of annual averages of PSCMIs with average annual coal prices of CIF ARA Mix, FOB Russia Mix, a) actual quotations, b) PSCMI quotations with year N-1. Source: Own study based on (TGE, 2020; NBP, 2020; Argus, 2010–2019; Platts, 2010–2019a,b; globalCoal, 2010–2019)

Rys. 5. Porównanie średnich rocznych polskich indeksów węglowych PSCMI z średnimi rocznymi cenami węgla CIF ARA Mix, FOB Russia Mix, a) notowania rzeczywiste, b) notowania PSCMI przesunięte o rok wstecz N-1

prices presented in the chart are monthly averages expressed in PLN/GJ. As the prices of the CIF ARA Mix and FOB Russia Mix indices are expressed in US dollars, they are converted into PLN using the exchange rate from (NBP, 2020).

The comparison of the volatility of PSCMI_1/Q and PSCMI_2/Q monthly prices with the spot indices CIF ARA Mix and FOB Russia Mix shows that the trends from the international spot market are different from the Polish market, mainly in the recent period. A very strong price competition can be observed between these markets. Domestic coal buyers, seeing the discrepancies between the national and international markets, may in the long term switch to spot purchases at the cost of breaking national contracts. Imports to Poland are priced at prices correlated to the market linked to the CIF ARA index, and this means that the Polish market will eventually be forced to react with lower prices or a drop in production.

The situation appears different when comparing prices of PSCMIs and spot prices of CIF ARA Mix and FOB Russia Mix calculated as annual averages (Figure 5). PSCMIs varied annually from 9 to 13 PLN/GJ for PSCMI_1/Q and from 8 to 14 PLN/GJ for PSCMI_2/Q, while CIF ARA Mix and FOB Russia Mix varied from 8 to 14 PLN/GJ.

The graph presented in Figure 5a shows a relatively high convergence of Polish coal prices with international market prices. It can be concluded that prices (annual average) on the Polish domestic market follow the global market represented by CIF ARA Mix and FOB Russia Mix prices with a one-year delay. The visible annual delay is due to the way in which contracts are concluded between coal producers and its recipients. In addition, the Polish market is definitely dominated by contracts in which the price is set on an annual basis. After shifting the quotations of the PSCMI_1/Q and PSCMI_2/Q backwards by one year compared to CIF ARA Mix and FOB Russia Mix (Figure 5b), a very high convergence of prices is visible.

This is confirmed by the results in Table 2 showing price differences between PSCMIs and CIF ARA Mix indices with year N and year N-1. The convergence concerns not only trends in evolution but also the price levels. Greater differences are observed in 2019, but it should be mentioned that only six months of 2020 were used for this calculation. This may lead to the conclusion that after six months of 2020, the prices on the Polish domestic market have not yet reacted to the price situation on the international market in 2020.

In the next step of the research, a correlation was made between PSCMIs prices and CIF ARA Mix prices. Due to the fact that the Polish market is definitely dominated by contracts (the price is determined on an annual basis), the average annual prices of PSCMI_1/Q and PSCMI_2/Q delayed by one year were taken into account for correlation, and the results are presented in Figure 6. Due to the very high correlation of the FOB Russia Mix index with the CIF ARA Mix index (see Figure 3), the results of the correlation of PSCMIs with the FOB Russia Mix index were not included because of the similar results obtained.

The correlation between the prices of PSCMIs and CIF ARA prices for 2010–2018 is very high: for PSCMI_1/Q the R^2=0,882 (Figure 6a), and for PSCMI_2/Q the R^2=0,893 (Figure 6b). After 2018, trends on the domestic market have been diverse from those on the international market (see Figure 5a,b). As data for the first half of 2020 show, this trend may continue in 2020 as well. However, in the event that high coal imports to Poland continue, a reaction of the domestic market to the price level of imported coal should be expected.

As mentioned earlier, PSCMIs reflect the actual prices of domestic coal sold to Polish buyers. The analysis performed

Tab. 2. Comparison of price differences between PSCMIs and CIF ARA Mix indices with year N and year N-1 of Polish indices, in PLN/GJ. Source: Own calculations

Tab. 2. Porównanie różnic cen między indeksami PSCMI i CIF ARA Mix bez przesunięcia i z rocznym przesunięciem wstecz indeksów polskich, w zł/GJ

Year	PSCMI 1- CIF ARA Mix		PSCMI 2- CIF ARA Mix	
	Year N	Year N-1	Year N	Year N-1
2010		0,42		1,38
2011	-2,88	-1,81	-1,92	-0,40
2012	0,54	-0,69	1,95	0,71
2013	1,03	0,27	2,43	0,83
2014	1,10	0,33	1,66	0,60
2015	1,30	0,31	1,57	-0,14
2016	-0,60	-0,13	-1,05	0,64
2017	-3,39	-1,67	-2,62	-0,39
2018	-2,21	-1,18	-0,93	-0,32
2019	2,78	2,80	3,64	4,11

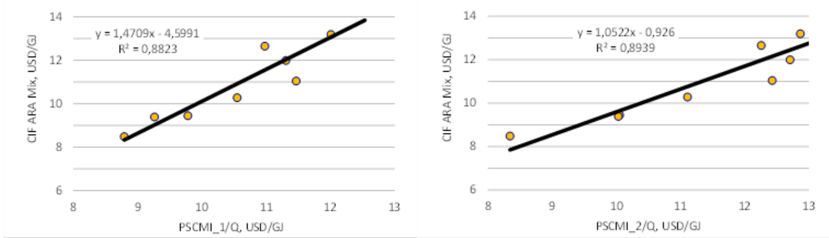

Fig. 6. Correlation of CIF ARA Mix prices with PSCMI_1/Q (a) and PSCMI_2/Q (b). Source: Own calculations

Rys. 6. Korelacja cen indeksów CIF ARA Mix z polskimi indeksami węglowymi PSCMI_1/Q (a) oraz PSCMI_2/Q (b)

showed a large correlation between PSCMIs and CIF ARA Mix and FOB Russia Mix. A study by Grudziński (2009) showed that CIF ARA coal prices are correlated with oil prices (WTI and Brent), so it can be concluded that the prices of PSCMIs are also correlated with oil prices and other energy carriers. The analyses by Nyga-Łukaszewska et al. (2020) confirmed this conclusion giving evidence of the correlation between PSCMIs and the natural gas market.

4. Summary

As the analyses from the first part of this article showed, within Europe, Poland is one of the most important producers and users of steam coal. For many years, Poland's domestic production was the primary supplier of coal to its domestic market. However, with the decreasing number of mines, which resulted in lower extraction, imports of steam coal have grown in importance.

The main consumer of steam coal in Poland is the sector of electric utilities. With the growing share of imported coal in Poland, the question has arisen as to whether the price situation on the international market affects the prices of coal offered to Polish consumers.

The analysis carried out focused in particular on the quotations of the CIF ARA Mix index being the benchmark for steam coal imported into Europe. The price level of this index is influenced by many macroeconomic factors and the level of prices of competitive fuels. Investigating the relationship between the main four exporters of steam coal to the European market (Russia, Colombia, USA and South Africa) and the CIF ARA Mix index gave a very high result: the R^2 coefficient ranged from 0.922 to 0.998.

The comparison of the volatility of PSCMI_1/Q and PSCMI_2/Q monthly prices with the spot indices CIF ARA Mix and FOB Russia Mix has shown that the trends on the international spot market are different from the Polish market. However, the transition to average annual prices has shown the convergence of price trends in Poland and on the international market. It has been found that in the case of PSCMIs there is a one-year delay in relation to world prices (result of contracts with price set on an annual basis). After moving the annual averages of PSCMIs backwards by one year, the differences between them and the CIF ARA Mix index for 2010–2018 decreased to about 1 PLN/GJ (previously they reached 3 PLN/GJ). The calculated coefficient of determination for both PSCMIs with CIF ARA Mix index is high: for the years 2010–2018 the coefficient was R^2=0,882 and R^2=0,893 respectively.

Due to incomplete data for 2020 (only data for the first half of the year were available), the year 2019 saw trends on the domestic market diverge from the international market. If high coal imports to Poland continue, it can be expected that the domestic market will react to the price level of imported coal.

It is to be expected that when seeing the discrepancy between the national and international market, the domestic buyers will respond, for instance, by increasing the proportion of steam coal purchased from the international spot market at the expense of national contracts. As the prices of coal imported to Poland are assessed at prices correlated with the market linked to the CIF ARA index, it can be expected that the Polish market will eventually be forced to react, for example, by lowering price levels or decreasing domestic production.

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Międzynarodowy rynek węgla energetycznego a sytuacja cenowa w Polsce – część II

Celem artykułu była analiza cen węgla energetycznego polskich producentów w odniesieniu do głównych indeksów cen spot węgla energetycznego z rynków międzynarodowych. Badaniami objęto lata 2010–2019. Ze względu na złożoność poruszanej problematyki, artykuł został podzielony dwie części. W części drugiej skupiono się na analizie cen węgla energetycznego na rynku europejskim i polskim. Analizując indeksy cenowe głównych eksporterów węgla energetycznego na rynek europejski zauważono, że ceny na międzynarodowych rynkach spot są ze sobą bardzo ściśle powiązane. Potwierdziło to badanie zależności pomiędzy cenami głównych eksporterów węgla energetycznego na rynek europejski (Rosją, Kolumbią, USA i RPA) a indeksem CIF ARA Mix. Obliczony współczynnik determinacji zmieniał się w granicach 0,922–0,998. Porównanie przebiegu zmienności średnich cen miesięcznych dwóch polskich indeksów węglowych (PSCMI) z indeksami spot CIF ARA Mix oraz FOB Russia Mix pokazało, że tendencje z międzynarodowego rynku spot są odmienne od panujących na rynku polskim. Zbieżność ta wystąpiła dopiero przy porównaniu cen średnich rocznych i to dopiero w sytuacji, gdy ceny polskich indeksów węglowych przesunięto o rok do tyłu. Przesunięcie to wynika ze sposobu zawierania kontraktów polskich producentów z odbiorcami. W Polsce dominują kontrakty długoterminowe, w których ceny ustalane są raz w roku. Po cofnięciu średnich rocznych obu indeksów PSCMI o rok wstecz różnice między indeksami zmalały do około 1 PLN/GJ (wcześniej sięgały 3 PLN/GJ). Wyliczony współczynnik determinacji dla obu PSCMI i indeksu CIF ARA Mix dla lat 2010–2018 wyniósł: R2=0,88 (PSCMI_1/Q) oraz R2=0,89 (PSCMI_2/Q).

Słowa kluczowe: *węgiel energetyczny, ceny, międzynarodowy rynek węgla, Polska*

Propozycja metodyki prowadzenia procesu logistyki węgla kamiennego w segmencie odbiorców indywidualnych w Polsce. Część pierwsza: Kontekst teoretyczny i rynkowy dla proponowanej metodyki

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Abstrakt

Niniejsza publikacja przedstawia propozycję metodyki organizacji i prowadzenia procesu logistyki węgla kamiennego w segmencie odbiorców indywidualnych w Polsce. Została ona przedstawiona w układzie trzech części. W pierwszej zaprezentowano przede wszystkim podstawowe determinanty pojęciowe proponowanej metodyki, waskazując także na zasadniczą rolę dystrybucji i logistyki dla charakterystyki oraz prowadzenia strategii marketingowej przedsiębiorstwa. Obok powyższego przedstawiono także obecny obraz tego procesu w zakresie strategii dystrybucji i logistyki prowadzonej przez przedsiębiorstwa górnicze w Polsce w aspekcie segmentu odbiorców indywidualnych. W drugiej części artykułu autor zaprezentował autorską propozycję systemu dystrybucji opartego na pomiarze pojemności rynku. W trzeciej zaś przedstawił przykład zastosowania proponowanego systemu dystrybucji, wskazując na jego wysoką efektywność ekonomiczną.

Słowa kluczowe: *węgiel kamienny, odbiorca indywidualny, dystrybucja bezpośredni i pośrednia, logistyka, pojemność rynku, pojemność rynku*

1. Wprowadzenie

Od kilku dekad obserwowany jest szereg dużych zmian w wielu aspektach prowadzenia życia człowieka. Odpowiadają za nie zwiększające się tempo postępu technicznego, globalizacja i wręcz rewolucja komunikacyjna. W wielu przypadkach zmiany te przynoszą szanse rozwojowe, ale w innych stwarzają duże wyzwania, a wręcz fundamentalne problemy. Szanse dotyczą osób i organizacji opierających swoje działanie na nowoczesnych technikach i technologiach; kreatywnych i nie bojących się zmian. Dla ludzi i jednostek organizacyjnych nie posiadających natomiast takiego potencjału rozwojowego, powyższe zmiany są najczęściej dużymi wyzwaniami. Choć nie jest to łatwe, podstawowym zadaniem w takich sytuacjach jest próba przekucia tych wyzwań właśnie na szanse. Brak jej podjęcia, a także błędy w prowadzeniu tego procesu, prowadzą niestety do powstawania ogromnych problemów, kończących się często spektakularnymi, strategicznymi porażkami. Przed powyższymi wyzwaniami stoi zdaniem autora również polskie górnictwo.

O ile w aspekcie ogólnoświatowym nie zmieniła się maksyma wypowiedziana wiek temu przez Maxa Plancka, że „Górnictwo nie jest wszystkim, ale bez górnictwa wszystko jest niczym", gdyż to właśnie produkty tej branży najczęściej rozpoczynają i w przyszłości będą rozpoczynały łańcuchy tworzenia wartości, to opisywany w poprzednim akapicie proces zmian powoduje, że nie zawsze jest ona już w pełni aktualna z perspektywy łańcuchów tworzenia wartości występujących do tej pory na poziomie pojedynczego państwa. Otwierające się coraz szerzej granice (w tym dla produktów górniczych), coraz bardziej efektywne procesy logistyczne (we wszystkich sposobach prowadzenia transportu), coraz większa substytucja produktowa w zakresie zaspokajania potrzeb grzewczych (odnawialne źródła energii, proekologiczność), rozwój prawodawstwa i świadomości proekologicznej (obniżanie emisji spalin, zakazy palenia węglem) powodują, że próba obrony powyższej maksymy Plancka z perspektywy obywatela Polski lub szerzej Unii Europejskiej stanowi trudność.

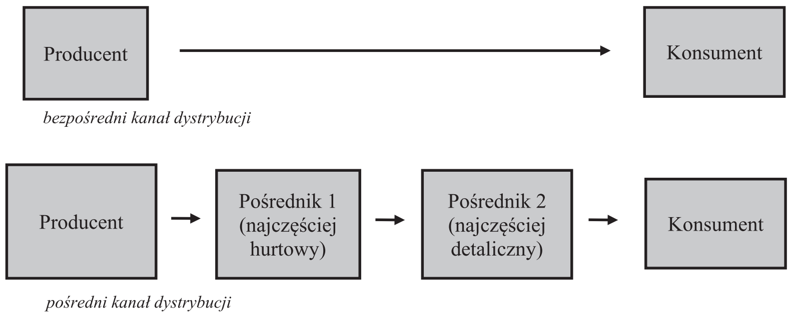
W świetle powyższych wskazań zasadniczym staje się pytanie o sposoby prowadzenia działań rynkowych przez przedsiębiorstwa górnicze. Niniejsze praca stanowi jeden z etapów prac autora, których celem stało się określenie obecnej wartości rynku polskiego w jego części dotyczącej odbiorców indywidualnych oraz określenie propozycji systemu zarządzania nim, czyniąc to w oparciu o ideę marketingu relacyjnego.

2. Dystrybucja jednym z elementów fundamentowych strategii marketingowej przedsiębiorstwa

Idea marketingu relacyjnego została stworzona przez Gronroos'a. Zaprezentował on ją jako: „Zyskowna budowa, utrzymywanie i rozwijanie relacji z konsumentami i innymi partnerami przy realizacji wzajemnych celów obu stron, poprzez wymianę wartości i spełnienie zobowiązań" (Gronroos, 1977).

Pierwsze aplikacyjne zastosowania tej koncepcji pojawiły się w firmach usługowych, ale już w roku 1983 została ona zaadaptowana do marketingu wyrobów przemysłowych (wdrożenia IBM) (za Anton, 1996). Rozwój myśli marketingu relacyjnego doprowadził do rozszerzenia jego definicji do pojęcia: „Rozumienie i przewidywanie potrzeb konsumentów, integracja zasobów, środków i działań organizacji w celu zyskownego, skutecznego dostarczania i komunikowania odpowiednich dóbr i usług w sposób bardziej efektywny od organizacji konkurencyjnych" (Morden, 1991) oraz ostatecznej formuły 5I (ang. Identification, Individualization, Interaction, Integration, Integrity) (Lenskold, 2003).

W ramach marketingu relacyjnego wyróżnia się trzy główne podprocesy (etapy): segmentacja rynku, strategia od-



Rys. 1. Bezpośrednie i pośrednie kanały dystrybucji. Źródło: Kotler, Keller (2012)
Fig. 1. Direct and indirect distribution channels

działywania na rynek oraz kontrola działań rynkowych. Dzięki badaniu i dzieleniu rynku na zyskowne sektory (obiekty), budowaniu zróżnicowanej strategii oddziaływania na nie oraz kontroli efektywności prowadzonych na nich działań, marketing relacyjny pozwala na tworzenie długotrwałych i zyskownych związków z klientami w każdym z segmentów, które wspólnie tworzą pole aktywności rynkowej przedsiębiorstwa (Kotler, 2005). Korzystając z tej koncepcji pyta się więc o potrzeby klienta i równolegle sprawdza jego atrakcyjność rynkową dla firmy. Na bazie wyników badań buduje się następnie zróżnicowany system oddziaływania na rynek (sektory, grupy klientów), a po jego wprowadzeniu, poprzez użycie narzędzi kontrolnych, analizuje efektywność prowadzonych działań.

Proces ten ma doprowadzić do integracji celów i pracy dostawcy oraz klienta, a w konsekwencji powodować powstawanie tzw. zysków przez zadowolenie. Podstawową zasadą marketingu relacyjnego jest trwałość zysków, co dzieje się dzięki zadowoleniu. Wiąże się ona z wysoką lojalnością generującego je zadowolonego klienta.

Jednym z fundamentalnych elementów drugiego z etapów budowy marketingu relacyjnego, realizowanym poprzez budowę strategii marketingowej, jest tzw. miejsce.

„Miejsce, jako jeden z czynników „4P" odnosi się do dystrybucji i dostępności produktu. Jest elementem marketingu-mix związanym z efektywnym zarządzaniem dystrybucją produktów na rynku tak, aby produkt znalazł się w odpowiednim miejscu i czasie zgodnie z potrzebami klientów i przy odpowiednim poziomie kosztów" (Kotler, Armstrong, 2014).

Dystrybucja jest więc zbiorem działań i decyzji związanych z udostępnieniem wytworzonych produktów finalnym odbiorcom. Czynności te obejmują nie tylko przemieszczanie towarów do miejsc, w których konsumenci chcą je nabywać, ale również dostarczanie towarów we właściwym czasie, kompletowanie asortymentu towarów tak, aby konsumenci mogli łącznie nabywać towary zaspakajające tę samą potrzebę oraz stworzenie optymalnych warunków zakupu (Kotler, Keller, 2012).

W zespole instrumentów i działań związanych z dystrybucją, głównym elementem jest kanał dystrybucji. Skowronek i Sarjusz-Wolski (Skowronek, Sarjusz-Wolski, 2012) rozumieją go jako środek, który umożliwia fizyczne przemieszczanie produktów przez system i poprzez który dokonuje się sprzedaż.

Nie sposób nie dostrzec w tej definicji strategicznego znaczenia kanałów dystrybucji. Z tego powodu istotnym składnikiem strategicznego myślenia w organizacji musi być jasno określony pogląd na politykę kanałów dostawczych i ekspedycyjnych, który powinien prowadzić do osiągnięcia celów danej organizacji. Za Kotlerem i Kellerem (Kotler, Keller, 2012) kanały dystrybucji obejmują doprowadzenie wytwarzanych produktów do punktów sprzedaży detalicznej oraz oferowanie tych artykułów bezpośrednim konsumentom. Powinny one uwzględnić wiele czynników, takich jak: lokalizacja sieci detalicznej, jej wielkość i rodzaj, różnorodność asortymentu, formy sprzedaży i ekspozycji towarów, formy obsługi oraz zakres usług dodatkowych.

Podstawowym kryterium podziału kanałów dystrybucji, ważnym również dla niniejszej pracy, jest ilość podmiotów (ogniw) uczestniczących w procesie przechodzenia produktu od producenta do konsumenta. Wyróżnia się w tej kwestii dwa podstawowe typy kanałów dystrybucyjnych (Skowronek, Sarjusz-Wolski, 2012):

- kanały bezpośrednie,
- kanały pośrednie.

Sposób ich konstrukcji przedstawiono na rysunku 1.

Kanał bezpośredni występuje, gdy producent nie korzysta z pośrednika i sprzedaje wytworzone przez siebie produkty bezpośredniemu konsumentowi. Jest to najkrótszy możliwy kanał dystrybucji, nazywany przez Kotlera i Kellera kanałem zero szczeblowym (Kotler, Keller, 2012).

Kanał taki posiada następujące zalety:

- całkowita kontrola producenta nad rynkiem zbytu, cenami produktów i poziomem usług,
- lepsza informacja zwrotna na temat popytu i podaży na rynku,
- szybszy czas przepływu produktów od producenta do nabywcy,
- szybszy czas płatności za zakupione produkty,
- maksymalizacja zysku z tytułu sprzedaży,
- lepsze dostosowanie oferty rynkowej do wymagań klienta,
- możliwość nawiązania trwałych relacji z klientem.

Wadami tego kanału są natomiast:

- zmniejszenie wolumenu sprzedaży poprzez mniejszy zakres penetracji rynku, wynikający z ograniczonej przepustowości tego kanału dystrybucji,
- przeniesienie na producenta całkowitych kosztów dystrybucji,
- długi czas oczekiwania na spodziewane efekty w stosunku do poniesionych nakładów,
- możliwość pojawienia się konfliktu w kanale dystrybucji,

Rys. 1. Bezpośrednie i pośrednie kanały dystrybucji. Źródło: Kotler, Keller (2012)

Fig. 1. Direct and indirect distribution channels

Kryteria klasyfikacji	Typy kanałów
Liczba pośredników	1. bezpośrednie 2. pośrednie
Liczba szczebli pośrednich	1. krótkie 2. długie
Liczba pośredników	1. wąska 2. szeroka
Rodzaje przepływających strumieni	1. transakcyjne 2. rzeczowe
Znaczenie kanału dla producenta	1. podstawowe 2. pomocnicze
Charakter powiązań między uczestnikami kanału	1. konwencjonalne 2. zintegrowane 2.1. kontraktowe 2.2. korporacyjne 2.3. administracyjne

- konieczność rozbudowy struktury organizacyjnej firmy,
- przeniesienie na producenta całkowitego ryzyka sprzedaży.

Pośredni kanał dystrybucji ma miejsce, gdy w procesie przemieszczania produktu od producenta do konsumenta uczestniczą pośrednicy – punkty skupu, hurt, sprzedawcy detaliczni, bądź inni (Kotler, Keller, 2012).

Zaletami takiego rozwiązania są:

- zwiększenie wolumenu sprzedaży poprzez większy zakres penetracji rynku,
- łatwiejszy dostęp do nowych rynków zbytu,
- zmniejszenie kosztów i ryzyka, związanych z samodzielną dystrybucją towarów,
- zmniejszenie liczby kontaktów z końcowymi nabywcami, pozwalające na znaczną redukcję kosztów,
- brak konieczności realizacji pewnych działań przejętych przez pośredników (np. pakowanie),
- koncentracja i specjalizacja w zakresie produkcji.

Do wad takiego rozwiązania zaliczyć natomiast można:

- brak realizacji pełnego zysku z tytułu sprzedaży,
- dłuższy okres oczekiwania na płatności,
- utratę całkowitej kontroli nad rynkiem zbytu, ceną i innymi elementami marketingu-mix,
- trudności ze znalezieniem pośredników o odpowiednich kwalifikacjach,
- możliwość integracji wstecznej ze strony detalistów.

Łącząc ze sobą przedstawiane powyżej podstawowe cechy dystrybucji bezpośredniej i pośredniej, już Luis Bucklin (Bucklin, 1966) zauważył, że należy dążyć w swojej strategii dystrybucji do minimalizacji kosztów kanału przy uwzględnieniu maksymalizacji realizacji oczekiwanej przez klienta użyteczności. To powoduje, że dość często wykorzystywaną strategią dystrybucji jest tzw. dystrybucja mieszana (Frankowska, Jedliński, 2011). Dążąc do jak najlepszego wypełnienia maksymy wskazanej przez Bucklina wykorzystuje ona wspólnie kanały bezpośrednie i pośrednie.

Ważnym elementem wyboru w zakresie rodzaju stosowanej dystrybucji jest stopień jej intensywności, rozumiany z jednej strony jako zakres geograficzny i a z drugiej jako natężenie działań dystrybucyjnych na jednostkę powierzchni (Mruk, 2003). W związku z tym wyróżnia się dystrybucję (Frankowska, Jedliński, 2011):

- intensywną,
- selektywną,
- ekskluzywną.

Długie i szerokie kanały oraz możliwie duża ilość miejsc sprzedaży charakteryzują dystrybucję intensywną, wykorzystywaną w przypadku artykułów codziennego użytku. Produkty oferowane przez ograniczoną liczbę pośredników, przy zastosowaniu węższych kanałów, sprzedawane są przy pomocy dystrybucji selektywnej (sprzęt RTV, AGD, ubrania). Produkty luksusowe, o unikalnych cechach użytkowych i wysokiej cenie jednostkowej, rozprowadzane są zazwyczaj za pomocą dystrybucji ekskluzywnej, w której producent oferuje swoje produkty przy pomocy tylko kilku, bądź jednego pośrednika, posiadającego wyłączne prawo sprzedaży.

Kolejnym ważnym podziałem kanałów dystrybucji jest ich rozdzielenie na kanały krótkie i długie (Skowronek, Sarjusz-Wolski, 2012). Przez kanał krótki rozumie się kanał złożony z najwyżej jednego pośrednika występującego pomiędzy producentem a kupującym (Kotler, Keller, 2012). W przypadku kanałów długich jest ich więcej.

Biorąc pod uwagę analizy prowadzone w dalszych częściach pracy ważnym podziałem kanałów dystrybucji staje się również rozróżnienie na dystrybucję wąską, realizowaną przez niewielką liczbę podmiotów w zakresie jednego ogniwa w kanale (Kotler, Keller, 2012) oraz szeroką, w przypadku której szerokie kanały dystrybucji pojawiają się wtedy, gdy na poszczególnych etapach dystrybucji określonego produktu występuje duża liczba tworzących je podmiotów (Kotler, Keller, 2012).

Obok wskazywanych powyżej (uważanymi przez autora za jego doświadczeniem zawodowym za najważniejsze i najczęściej stosowane, w praktyce przemysłowej kategorie podziału dystrybucji) literatura określa występowanie również innych podziałów. Ich układ, zawierający również powyżej przedstawiane, zaprezentowano w tabeli 1.

Obok kanałów dystrybucji w ramy systemu dystrybucyjnego zalicza się również fizyczną dystrybucję. W ostatnich 30-u latach rozwinęła się ona w formę koncepcji zarządzania łańcuchem dostaw (ang. supply chain management; SCM). Wiąże się ona z zakupem właściwych czynników produkcji (surowce, komponenty, sprzęt i wyposażenie), wydajną ich zmianą w gotowe produkty oraz wysyłką do punktów przeznaczenia (Kisperska-Moroń, Krzyżaniak, 2009).

Według koncepcji zarządzania łańcuchem dostaw przedsiębiorstwo traktowane jest jako centrum sieci wartości, obejmującej dostawców firmy i dostawców jej dostawców oraz bezpośrednich odbiorców i ich końcowych klientów. Wycho-

Rys. 2. Przykłady wizualizacji opakowań z węglem typu Ekogroszek nie oznaczane marką przedsiębiorstw górniczych. Źródło: Opracowanie własne na podstawie http://allegro.pl/listing/listing.php?order=m&string=Ekogroszek&bmatch=s0-hou-1-4-1026 z dnia 15.09.2020
Fig. 2. Examples of visualization of packaging with coal of the Ekogroszek type not marked with the brand of mining companies

dząc z tego punktu widzenia firma powinna zgrać wszystkie strony tego łańcucha, by dostarczać na docelowym rynku klientom jak najlepszą wartość. W pierwszej fazie musi ona przeanalizować swój rynek docelowy (a więc, jak zauważa autor, wyjść z założeń charakterystycznych dla marketingu relacyjnego), a następnie, cofając się w stronę początku łańcucha, budować go. Metoda ta nazywana jest planowaniem łańcucha popytu, a w połączeniu z wyjściową i tradycyjnie rozumianą fizyczną dystrybucją przyjmuje nazwę logistyki rynkowej (Kotler, Armstrong, 2014). Obejmuje ona planowanie infrastruktury pozwalającej zaspokoić popyt, a następnie umożliwiającej realizację i kontrolę fizycznego przepływu materiałów oraz towarów gotowych z miejsc wytworzenia do miejsc ich konsumpcji w celu zyskownego dla przedsiębiorstwa spełnienia wymagań klienta (Kisperska-Moroń, Krzyżaniak, 2009). Efektywna logistyka rynkowa powinna być prowadzona realizując cztery podstawowe zadania (Copacino, 1997):

1. Podjęcie decyzji dotyczącej wartości, jakie firma chce zaoferować klientom (Jaki zakres czasowy realizacji zamówień? Jaki poziom dokładności zamówień i fakturowania?).
2. Podjęcie decyzji dotyczącej najlepszego pod kątem dotarcia do klienta układu kanału i strategii sieciowej (Czy firma powinna obsługiwać klientów bezpośrednio, czy z udziałem pośredników? Które produkty brać z których zakładów wytwórczych? Ile magazynów utrzymywać i gdzie powinny się one znajdować?).
3. Wypracowanie doskonałości operacyjnej w prognozowaniu sprzedaży, zarządzaniu gospodarką magazynową, zarządzaniu transportem i zarządzaniu gospodarką materiałową.
4. Wprowadzenie rozwiązania za pomocą najlepszych systemów informatycznych, sprzętu, polityki i procedur.

Zadanie numer dwa stało się jednym z głównych celów metodycznych i aplikacyjnych niniejszej pracy, realizowanych poprzez zapewnienie efektywnego, drożnego systemu dystrybucji węgla kamiennego do segmentu odbiorców indywidualnych.

3. Obecne strategie dystrybucji i logistyki stosowane przez przedsiębiorstwa górnicze w Polsce

Obserwacje prowadzone przez Bogacza (Bogacz, 2011), Magdę, Bogacza, Franika, Migzę, Celeja (Magda, Bogacz, Franik, Celej, Migza, 2014), Bogacza (Bogacz, 2018), potwierdzane również przez Grabowską (Grabowska, 2013), pokazały, że wszystkie przedsiębiorstwa górnicze z sektora górnictwa węgla kamiennego w Polsce zdecydowały się na strategiczne wykorzystanie w aspekcie dystrybucji swoich produktów do odbiorców indywidualnych przede wszystkim pośrednich kanałów dystrybucji. Co prawda dopuszczają one możliwość zakupu bezpośrednio w kopalniach, ale warunki handlowe tegoż (ceny, minima zakupowe, zasady kontraktacji) jasno wskazują na nastawienie się w tej kwestii na sprzedaż business to business. Powyższe strategie są w pełni akceptowane przez organ właścicielski, a więc Skarb Państwa, który jak pokazują lata 2015-2019, nie realizuje zapowiadanych na konferencji prasowej w dniu 06.05.2014 planów budowy państwowej sieci składów węgla.

W ramach dystrybucji pośredniej węgiel sprzedawany jest konsumentom poprzez sieć autoryzowanych sprzedawców. Są to firmy zewnętrzne, niepowiązane z producentem, którym w mniejszym stopniu (LW Bogdanka S.A.- podział odbiorców na finalnych nabywców węgla (FNW) (gospodarstwa domowe) oraz pośredniczące podmioty węglowe (PPW) (http://www.lw.com.pl/pl,1,s427,formularz_przystapienia_do_asw.html z dnia 11.09.2020) lub w stopniu większym (PGG S.A., Tauron Wydobycie S.A.) narzucono pewne warunki współpracy. Realizują one jednakże swoją politykę handlową oraz marketingową, w tym produktową i promocyjną. Drugą, jeszcze mniej związaną z przedsiębiorstwami górniczymi grupę firm stanowią tzw. partnerzy handlowi (PGG S.A.) lub sprzedawcy dealerzy (Tauron Wydobycie S.A.), którzy nie otrzymali ze strony producenta żadnych wskazań co do sposobu prowadzenia marketingu danego produktu. Wybór tego, pośredniego sposobu prowadzenia dystrybucji został podyktowany względami kosztowymi. Jest on po prostu najtańszy. Wiąże się bowiem z minimalnym zaangażowaniem finansowym, dając jednakże rynkowi dostęp do produktu. Z drugiej strony niski koszt obsługi nie przenosi się w odpowiednim stopniu na poziom budowania swojego rynku, wizerunku a wynikowo marki. Nie przynosi więc odpowiednich efektów w skali długoterminowej. Zdecydowana większość producentów węgla nie narzuca bowiem swoim dystrybutorom żadnych wymagań handlowych, bądź marketingowych. Można wręcz zaryzykować stwierdzenie, że jedynymi przedsiębiorstwami próbującymi prowadzić kompleksowy system zarządzania swoimi klientami jest Polska Grupa Górnicza S.A. (PGG S.A.). Nie dotyczy to więc Jastrzębskiej Spółki Węglowej S.A., Lubelskiego Węgla Bogdanka S.A., Tauronu Wydobycie S.A., Zakładu Górniczego Silesia Sp. z o.o. oraz Węglokoksu Kraj Sp. z o.o.. O ile w przypadku JSW S.A. powyższy fakt może nie dziwić, gdyż spółka ta koncentruje się na produkcji węgla koksującego, o tyle w przypadku pozostałych przedsiębiorstw, brak choć tylko pewnej, systematyki w tej kwestii jest zaskakujący.

O ile trudny konkurencyjnie, samoregulujący się rynek nie pozwala narzucać zbyt wygórowanych wymagań handlowych, o tyle może dziwić brak zapewnienia odpowiedniego ujęcia w przypadku wymagań marketingowych. Tylko bowiem wspominana już powyżej PGG S.A. nakłada w sposób obligatoryjny na swoich dystrybutorów obowiązek odpowiedniej wizualizacji marketingowej miejsca sprzedaży i samego produktu, a także stworzyła kompleksowy system współpracy marketingowej ze swymi klientami, wypełniający pewne elementy marketingu relacyjnego. W przypadku Polskiej Grupy Górniczej S.A. system ten jest zewnętrznie łudząco podobny do systemu merchandisingowego (zobowiązania handlowe, sprawozdawczość wynikowa), choć posiada on zdaniem autora zaskakująco surowy jak na warunki wolnego rynku układ wymagań i sprawozdawczości narzuconej sprzedawcom węgla.

Przedstawiona powyżej charakterystyka sposobów prowadzenia dystrybucji produktu przez przedsiębiorstwa górnicze do segmentu odbiorców indywidualnych, opierająca się o system pośredni, poparta powyżej dowodami wielu jego „słabości" pod kątem efektywności funkcjonowania, przenosi się zdaniem autora niestety na pogarszającą się z roku na rok pozycję marketingową węgla kamiennego w Polsce w ogóle, a w tych ramach węgla dla gospodarstw domowych. Autor postanowił podzielić dowody potwierdzające tą tezę na następujące kategorie:

1) Dowody wizerunkowe, związane z:
- brakiem spójnej komunikacji graficznej produktu,
- brakiem spójnej komunikacji w miejscu sprzedaży produktu,
- brakiem spójnej komunikacji w zakresie marketingu bezpośredniego i PR.,

2) Dowody sprzedażowe, związane z:
- rosnącą ceną sprzedaży węgla kamiennego na składach węglowych,
- bardzo dużą (zbyt wysoką) różnicą w poziomach cen sprzedaży węgla kamiennego pomiędzy kopalnią a składem węglowym.

Dystrybucja pośrednia, choć jak wskazywano w poprzednim rozdziale będąca najtańszym sposobem prowadzenia dystrybucji, bardzo utrudnia prowadzenie spójnej strategii komunikacji producenta z rynkiem. W przypadku węgla kamiennego, w jego ofercie dla segmentu odbiorców indywidualnych przejawia się to po pierwsze w utrudnionej możliwości prowadzenia kompleksowego zarządzania marketingowego produktem. Wynika on głównie z faktu, że producenci węgla kamiennego w Polsce dają dystrybutorom możliwość tworzenia na bazie swoich produktów nowych mieszanek węglowych, a więc nowych produktów, nie narzucając im w wielu przypadkach nawet podstawowych zasad zachowania swoich praw, dotyczących jakości marketingowej i technicznej produktu, a także jego wizerunku (w tym graficznego). W ten sposób pojawiło się na rynku wiele konkurujących ze sobą, a wręcz kanibalizujących się rynkowo, marek węgli zbudowanych przez dystrybutorów. Nie posiadają one żadnych powiązań marketingowych z produktem wsadowym/surowcowym, pochodzącym z przedsiębiorstwa górniczego i nie budują one, nawet w układzie łączonym, marki produktowej przedsiębiorstwa górniczego. Przykłady takiego różnego, niespójnego markowania produktu w układzie brandingu dystrybutora przedstawiono na rysunku 2.

Powyższy obraz jest jeszcze ciekawszy w związku z tym, że same przedsiębiorstwa górnicze również stworzyły własne marki węgli dla odbiorców indywidualnych, takie jak Pieklorz, Ekoret, Retopal, tworząc dla nich systemy marketingowe. Przedstawiony powyżej miks tworzy niespójności marketingowe i nie daje możliwości budowania pojedynczej, mocnej wizerunkowo marki lub grupy takich marek, mogących efektywnie budować swój rynek zbytu. W świetle przedstawianej powyżej sytuacji zarządzania produktem, w tym jego wizerunkiem graficznym, nie wydaje się być zaskakującym jeszcze słabszy, niespójny obraz marketingowy produktu w miejscach sprzedaży, głównie na składach węglowych.

Przejawia się on w szczególności w braku zarządzania wizerunkowego miejscem takiej sprzedaży przez przedsiębiorstwa górnicze, będąc popartym często wręcz brakiem ich wpływu na system identyfikacji wizualnej tych miejsc.

Powyższe przykłady, koncentrujące się wokół węgla i miejsca jego sprzedaży, wskazywały na brak spójności marketingowej w zakresie komunikacji graficznej produktu węglowego na rynku. Niestety obok nich należy zauważyć także brak odpowiedniej aktywności przedsiębiorstw górniczych na poziomie marketingu bezpośredniego oraz PR, a więc tych dwóch grup narzędzi promocji-mix, które odpowiedzialne są za publiczny wizerunek firmy, bądź marki (Jonek-Kowalska, 2017).

Autorska propozycja metodyczna oraz przykład jej zastosowania zostaną opublikowane jako część 2 i 3 artykułu pt. „Propozycja metodyki prowadzenia procesu logistyki węgla kamiennego w segmencie odbiorców indywidualnych w Polsce", ukazując się w dwóch kolejnych zeszytach niniejszego periodyku wydawniczego.

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Methodology of Conducting the Hard Coal Logistics Process in the Segment of Individual Customers in Poland. Part One: Theoretical and Market Context for the Proposed Methodology

This publication presents a proposal of methodology for organizing and conducting the hard coal logistics process in the segment of individual customers in Poland. It was presented in a three-part system. The first one presents the basic conceptual determinants of the proposed methodology, pointing to the fundamental role of distribution and logistics for the characterization and management of the company's marketing strategy. In addition to the above, the present image of this process in terms of distribution and logistics strategies carried out by mining companies in Poland in terms of the segment of individual recipients is also presented. In the second part of the article, author presented his proprietary distribution system based on measuring the market capacity. In the third, he presented an example of the application of the proposed distribution system, pointing to its high economic efficiency.

Keywords: *hard coal, individual customer, direct and indirect distribution, logistics, market capacity*

New Way of Producing Useful Energy from Biomass in Countries Decommissioning Coal-Fired Power Plants

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Abstrakt

This paper describes a new way of processing biomass using micro-CHPU devices (Micro Combined Heat and Power Unit). The micro-CHPU device is a new idea that allows to convert chemical energy in biomass into electricity for charging batteries in small electric vehicles and into useful heat for households. To make the device readily available and inexpensive, commercial Peltier modules were used, in which their operation was inversed to create the Seebeck effect. The presented research results show that the commercial Peltier module works very well as a thermoelectric generator. The proposed devices may turn out to be very useful in the times of the revolution that has begun on the energy market in most developing countries. Nowadays, many of these countries are intensively beginning to phase out energetics based on fossil fuels. A very popular and effective method of using biomass is mixing it with coal (in the proportion of 10% to 90%) and burning it in a coal-fired power plant or CHP plant. After closing these power plants, biomass will no longer be burned there. Then, the unused biomass could be burned in micro-CHPU devices. This will prevent biomass waste in agriculture.

Keywords: *biomass, thermoelectric generator, micro combined heat and power unit, primary energy consumption, emission reduction and renewable energy source*

1. Introduction

In developing countries electricity is still produced mainly in coal-fired power plants. However, with every year coal-fired power plants are successively replaced by renewable energy sources and nuclear power plants. For example, Poland is a rapidly developing country but still coal-fired power plants generate about 80% of total electricity [1-13]. The remaining part of electricity is produced in gas power plants and from renewable energy sources. Polish agriculture produces a lot of biomass, which unfortunately is mostly wasted as there is overproduction of this biomass. Mulching is rare and burning of grass in arable fields occurs quite often although it is illegal in Poland and causes fire hazard. As a result of global warming, winters have become very mild. The winter 2019/2020 was for the first time snowless in the history of Poland and many other European countries (except in the mountains). Since around 2008, biomass has been increasingly used to generate electricity. Biomass is added to fine coal (blending) and burned (co-firing, co-milling) in coal-fired power plants and coal-fired CHP (Combined Heat and Power) plants. The share of biomass in the blend with coal is usually less than 10%. Generally, there are three most popular ways to proceed with biomass in East-Central European countries: leaving biomass in the farmland or forest; mixing 10% of biomass with 90% of coal and burning it in a coal or CHP plant; burning it in households or local biomass incineration plants. It is very important to bear in mind that, regardless of the fact which method is chosen, carbon dioxide be emitted into the atmosphere in approximately the same amount. This may seem surprising, but leaving biomass in the farmland to rot will cause the formation of carbon dioxide in quantities similar to the process of burning. Transformation of organic matter into CO_2 gas is well known [14] and is discussed, among others, in works [15-17]. Small household or local biomass incinerators for heating purposes are usually not very efficient and do not generate electricity. To sum up, the most efficient and ecological way to generate electricity from biomass energy is based on mixing biomass with coal in a coal or CHP plant. Poland and other developing countries will face a radical energy transformation in the next several years. There will be a gradual resignation from coal energy. Currently, this process is intensifying, as the coronavirus pandemic has resulted in reduction in the industrial production and, consequently, a lower demand for electricity. In the second half of 2020, the closure of several coal mines has begun and the construction of new coal-fired power plants was abandoned. As a consequence, biomass combustion in coal-fired plants will be suspended. Retrofitting of currently operating coal-fired power plants for biomass fuel is complicated technologically and too expensive – it is necessary to build a new biomass-only power plant block from scratch. A typical European coal-fired power plant produces electrical power of 1000 to 5000 MW. By comparison, the world's biggest biomass power plant is Ironbridge, in the United Kingdom, with power of 740 MW [18]. That power plant was previously a coal-fired power station with installed power of 1000 MW. Two units of the plant were converted to biomass-based power generation in 2013 [18]. The world's biggest biomass power plants are presented in table 1. Biomass power plants have significantly lower electric power in comparison to coal-fired power plants.

There is actually a new power plant block built on the site of a functioning coal-fired power plant namely in Połaniec

Tab. 1. The world's biggest biomass power plants [18]

Tab. 1. Największe na świecie elektrownie biomasowe [18]

Biomass power plant	Installed power (MW)
Ironbridge, United Kingdom	740
Alholmens Kraft, Finland	265
Toppila,Finland	210 of electrical energy and 340 of thermal power
Połaniec, Poland	205
Kymijärvi II, Finland	160
Vaasa Bio-gasification plant, Finland	140

(Poland). That 205 MW block is a rare example in Poland of a block fully operating on biomass . Other power stations use coal mixed with biomass in the proportion of 90% – 10%. Recently, small-scale biomass power plants with the capacity of several megawatts have become commercially available – for example Matsuyama Biomass Power Plant (12.5 MW) constructed by Toyota Tsusho [19]. Unfortunately, it is not easy to replace a few large coal-fired power plants with hundreds of small-scale biomass plants. This would require a complete reconstruction of the electricity grid structure and additionally cause huge financial costs. In effect, there is a belief that as a result of the closure of coal-fired power plants, the biomass market has no future in Poland and many other countries. A new strategy for the development of the biomass market is urgently needed – a strategy which can be implemented after the coal power plants are shut down in countries decommissioning coal-fired power plants.

2. Primary energy consumption

Primary energy consumption grew at a rate of 2.9% in 2018. This increase is almost double the 10-year average of 1.5% per year, and is the fastest since 2010 [20]. All fuels grew faster than their 10-year averages, apart from renewables, although renewables are still accounted for the second largest increment to energy growth. China, the US and India together accounted for more than two thirds of the global increase in energy demand, with US consumption expanding at its fastest rate in 30 years [20]. Coal consumption increased by 1.4% in 2018, this is the double of the 10-year average increase [20]. The increase in consumption was led by India (36 mtoe) and China (16 mtoe). OECD demand has fallen to its lowest level since 1975. The share of coal in primary energy has fallen to 27.2%, the lowest level in fifteen years. World coal production increased by 162 mtoe, or 4.3%. The largest increases were achieved by China (82 mtoe) and Indonesia (51 mtoe) [8]. Coal power accounts for a major share within electricity production and significantly contributes to the overall greenhouse gas emissions [21]. Electricity generation increased by over 3.7%, which was caused by China (which accounted for more than half the growth), India and USA. Renewable energy sources accounted for one third of the increase in net power production, then coal (31%), and natural gas (25%). The share of renewable energy sources in energy production has increased from 8.4% to 9.3%. However, coal still accounted for the largest share in energy generating 38% [20]. Figure 1 shows how much electricity is produced from coal.

Poland produces over 80% of energy from coal, the next country is Hong Kong, with the share lower by as much as 15%. Austria and the Czech Republic are at a similar level. In other countries this level is much lower than 40%.

3. Emission reduction and renewable energy sources

Emission reduction aims to combat the climate change and reduce the impact of harmful emissions on the environment [23, 24]. World emissions are rising, as shown in figure 2.

In 2018, the level of global emissions of 32 840 * 106 Mg CO_2 was recorded. In relation to the previous year, it was an increase of 1.9%. Almost all countries in the world contributed to the increase in emissions, except for Europe and Latin America. In China, compared to the previous year, there was an increase of 3,1%, in India 4,2%, in Russia 3,9%, and in the United States 3,1%. All increases were caused by higher energy consumption, as well as, partly, by weather conditions. CO_2 emissions decreased in the European Union by -2,1% due to a diminishing energy demand, a greater share of renewable energy sources in electricity production and weather conditions, which were affected by mild winter and autumn. In Japan, CO_2 emissions have been falling for the fifth consecutive year, thanks to the growing share of solar energy since 2016 and the increase in nuclear energy production in 2018.

The decrease in emissions in the European Union is the result of the set goals of gradual reduction of greenhouse gas emissions by 2050. The key climate and energy goals are determined in the 2020 climate and energy package and in the 2030 climate and energy framework.

The 2020 package is a set of binding rules to ensure that member states reach their climate and energy goals for 2020. The package sets out three key objectives:

- 20% reduction in greenhouse gas emissions (from 1990 levels)
- 20% of energy in the EU from renewable sources
- 20% improvement in energy efficiency

The goals were determined by EU leaders in 2007 and adopted in 2009. They are also the main goals of the Europe 2020 strategy for smart and sustainable development [24]. The EU is taking action in several areas to achieve these goals. The next climate framework was adopted in October 2014, where the following objectives were agreed upon:

Reducing greenhouse gas emissions by at least 40% (since 1990 levels) [25]

- At least 32% share in renewable energy
- Improving energy efficiency by at least 32.5%
- This framework is expected to be achieved by 2030.

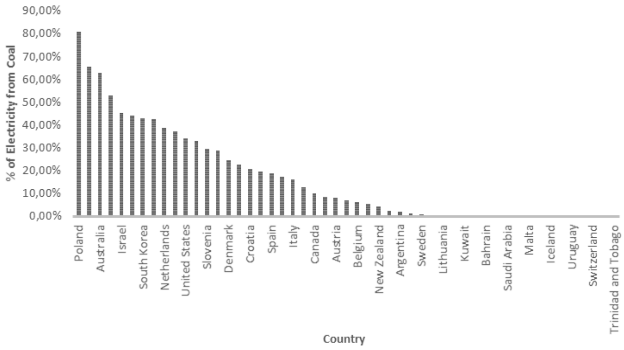

Fig. 1. Electricity from coal, 2018 (own study based on data [22])
Rys. 1. Energia elektryczna z węgla, 2018 (opracowanie własne na podstawie danych [22])

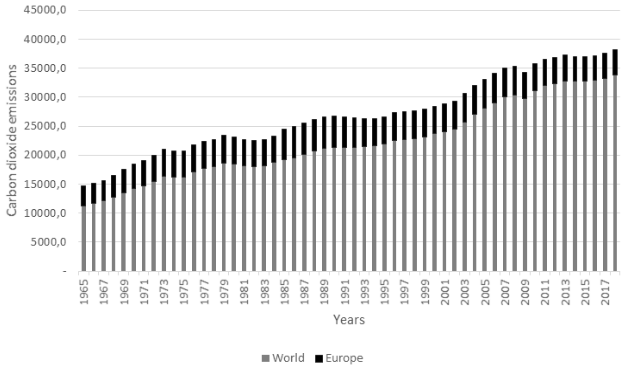

Fig. 2. World CO_2 emissions, Europe separately (own study based on data [20])
Rys. 2. Światowe emisje CO_2 (opracowanie własne na podstawie danych [20])

The term "renewable energy source" was defined in Polish law by the Act of 20 February 2015 on renewable energy sources, called the "RES Act", where RES are renewable, non-fossil energy sources including wind energy, solar energy, aerothermal energy, geothermal energy, hydrothermal energy, hydropower, wave, current and tidal energy, energy obtained from biomass, biogas, agricultural biogas and bioliquids (Article 2 of the RES Act). Renewable energy sources (RES) are generally energy carriers the use of which does not cause irreversible losses or deficits of this source in the environment. Their resources are constantly complementary and not exhaustive, and the process of supplementation can occur spontaneously and naturally, so for "renewal of the resource" no human intervention is necessary (e.g. wind). The sources of renewable energy are , among others, solar radiation, wind, heat from the Earth's interior, water, biomass, biogas, biofuels. From the indicated sources it is possible to obtain respectively: electricity, heat, cold and biocomponents. The use of energy from renewable sources has a lower negative impact on the environment than the use of fossil fuels to obtain energy. First of all, the use of renewable energy limits the emission of greenhouse gases as well as other harmful substances [26]. The current structure of renewable energy sources is shown in Figure 3.

According to the Accession Treaty signed with the European Union in 2004, Poland declared to increase the share of energy generated from renewable resources to 7,5% in 2010 and to 14% in 2020. Biomass production can therefore be a major factor contributing to the achievement of those objectives. Currently 4% of energy in the European Union is derived from biomass namely 190 million tons of biomass a year. By 2020 the use of biomass should increase up to 8% (360 million tonnes biomass a year) [28]. It is believed that Poland's potential of biomass is among the highest in Europe and is at 895 PJ [29]. The projected demand by professional energy suppliers in Poland is 8,3 million tonnes of dry biomass in 2020 and 10,6 million tonnes of dry biomass in 2030. At the same time, in accordance with the Regulation of the Minister of Economy (dated 14.08.2008), in the years 2015–2017 it was expected not to be possible to use forest biomass for co-burning (Journal of Laws No. 156, item 969). Therefore, an important part of the production of biomass for energy purposes in Poland will be the cultivation of fast-growing annual and perennial energy crops on plantations [30]. However, the implementation of these plans strongly depends on the future of coal-fired power plants.

Biomass accounts for over 60% of renewable energy in Poland [30-33]. The industry uses industrial and domestic waste as well as biomass to produce process heat. This represents around 10% of the energy generation sector. Biogas production has started relatively recently and currently there are about 200 biogas plants, which are unevenly distributed throughout the country [34]. Many rural households use biomass to heat houses and water, as well as for cooking. Table 2 summarizes the list of the largest biomass-fired power plants and their total biomass consumption in 2019.

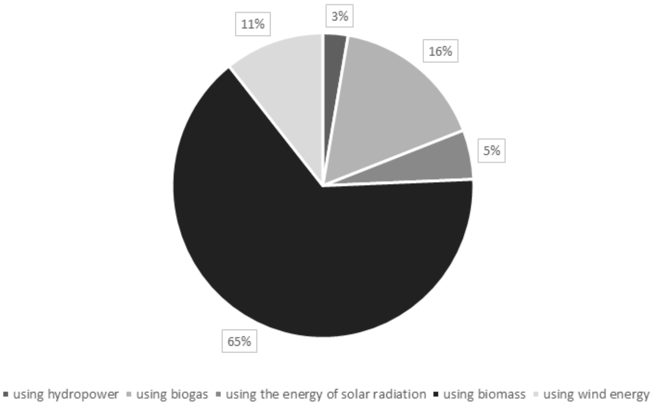

Fig. 3. Structure of renewable energy sources in Poland in 2019 (own study based on data [27])
Rys. 3. Odnawialne źródła energii w Polsce, 2019 r. (opracowanie własne na podstawie danych [27])

Tab. 2 Exemplary coal-fired and biomass power plants in Poland (own study based on data [35])
Tab. 2 Elektrownie węglowe i biomasowe w Polsce (opracowanie własne na podstawie danych [35])

Name	Total installed electric power [MWe]	Fuel
Opole Power Plant	3342,00	Hard coal, biomass
Połaniec Power Plant	1882,00	Hard coal, biomass
Turów Power Plant	1488,00	Lignite, biomass
Konin Power Plant	198,00	Lignite, biomass
Cogeneration biomass block at the Kalisz-Piwonice CHP plant	11,3 MWe i 21,3 MWt	Biomass (wood chips)
Lublin Power Plant	49,9 MW	Biomass

Some of these power plants are fully biomass-based, while others use a mixture of biomass and other fuels. These power plants will generate a significant part of Poland's demand for biomass for energy production by 2030 [35-37].

4. Materials and Methods

In the new biomass market development strategy, new biomass-only power plants should be built in places where is economically justified and it is not technically problematic. These new power plants should reach a high capacity of hundreds of megawatts, similar to those in Table 1. Currently, many new bioenergy projects, such as the Tychy CHP plant, are being implemented. There are also several other small units that use biomass gasification and syngas combustion. Several power plants use exclusively biomass, but their sizes are small and they are mainly scattered in minor Polish cities. Forest and agricultural residues as well as other organic waste are used as raw materials. Biomass is expected to serve a variety of applications, from energy and heating to enduse sectors such as construction, industry and transport ones. It is important that biomass is used locally and that high transport costs can be avoided. In addition, cogeneration systems using solid biomass and biogas are expanding in Poland. This is beneficial for the energy and heat supply sectors. According to the research of the Institute of Sustainable Development from 2018, approximately 25 TWh of electricity from solid biomass and 24 TWh from biogas can be produced by 2030. The Renewable Energy Council (2013) predicts electricity generation capacity of 4 GW by 2020 and 6 GW by 2030. Cogeneration has additional potential and is estimated to be at least 4 GW by 2030. Unfortunately, the decommissioning of coal-fired power plants may thwart these plans. Anaerobic digestion for biogas production will mainly be based on various residual organic materials. However, if the need arises, a mixture of dedicated short rotation energy crops can be used as another preferred biogas production option in Poland. The share of biomass in heating will remain high because the expansion of solar water heaters and heat pump solutions will be limited. In addition, biomass can be used in individual heating systems in buildings and industrial plants. Biomass is related to forestry and existing arable land or land that can be converted for arable or forestry use. It is available in most parts of Poland, but it varies locally. That is why, both solid waste power plants as well as biomass and biogas cogeneration plants can be found in areas where the local biomass potential is the highest.. In 2019, the average size of a biomass power plant was about 28 MW. The average size of industrial cogeneration may be 10-15 MW, depending on the industry. In district heating, larger cogeneration units with a capacity of about 50 MW are expected to arise depending on local demand. Dedicated multi-fuel combustion (co-combustion) and biomass boilers will coexist in current and newly built cogeneration power plants. The national energy policy, which is convergent with the energy and climate policy of the European Union, supports the development of renewable energy sources. The action plan aims to ensure the achievement of the goals of the Europe 2020 strategy, i.e. a 20% share of energy from renewable sources in the final energy consumption in the EU by 2020 and 27% by 2030. It should be noted that a large amount of biomass (probably most of it) in countries like Poland will still be burned in household furnaces. That biomass can be processed in household micro-CHPUs on agricultural land. The micro-CHPU (Micro Combined Heat and Power Unit) is a new idea and is presented in this paper in a general manner.

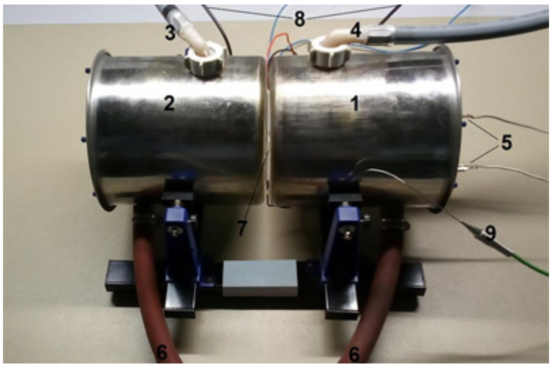

Fig. 4. Measurement setup for testing thermoelectric generators for micro–CHPU. 1 – hot water tank, 2 – cold water tank, 3 – cold water inlet, 4 – hot water outlet, 5 – electric heater (outside connectors), 6 – hydraulic hose connecting the tanks, 7 – tested thermoelectric generators, 8 – outside cables from temperature sensors (two 18B20 sensors in water–proof packed), 9 – additional temperature sensor (a thermocouple) for hot tank temperature control. In this figure Peltier modules TEC1–12715 are tested

Rys. 4. Układ pomiarowy do testowania generatorów termoelektrycznych, które zostaną zastosowane w urządzeniu micro–CHPU. 1 – zasobnik ciepłej wody, 2 – zasobnik zimnej wody, 3 – wlot zimnej wody, 4 – wylot ciepłej wody, 5 – grzałka elektryczna (zaciski zewnętrzne grzałki), 6 – wąż hydrauliczny łączący zbiorniki, 7 – badany moduł termoelektryczny, 8 – przewody wyjściowe czujników temperatury (dwa czujniki 18B20 w wodoszczelnej obudowie), 9 – dodatkowy czujnik temperatury (termopara) do kontroli temperatury na zasobniku z ciepłą wodą. W przedstawionym układzie badane były moduły Peltiera TEC1–12715

A new approach to the transformation of the biomass market is the use of dispersed micro-CHPUs not integrated with the electricity grid. Micro-CHPU is not to be confused with a biomass-powered genset. In recent years, biomass-powered gensets have become popular in areas where there is no electricity grid available. A very efficient solution is proposed, among others by All Power Labs, Berkeley, California - their aggregates achieve a continuous electric power of 25 kW and consume about 1 kg of dry biomass per 1 kWh of produced energy (heat + electrical energy) [38]. However, biomass-powered gensets are somewhat complex units. They have a biomass gasification module and spark engine. Like all internal combustion engines, biomass gensets have a limited lifetime. They do not find a wide application in Europe either - almost each village in Europe has access to the electricity grid. Unlike a biomass-powered genset, micro-CHPU is not dedicated to households without the electricity grid. This device is an ecological source of additional energy that can be used, among others, to recharge batteries in electric vehicles. Important advantages of the micro-CHPU are a no spark engine and no moving parts. The operating principle of the micro-CHPU is based on the thermoelectric Seebeck effect. This effect was discovered in 1821 but has been used more widely since the 20th century in thermocouples for temperature measurement. It should be noted that the thermocouple is a voltage signal source with a very low current-carrying capacity (it has high internal resistance). It is not a source of useful energy – it is a measurement instrument. The thermoelectric Seebeck effect is used to produce electricity in a thermoelectric generator (TEG). TEGs have gained more popularity thanks to their use in military and space technologies. TEG is usually shaped like a thin cuboid, the thickness of which is on the order of a few millimeters, and the remaining sides are several centimeters in size. This could be pictured as a plate a few millimeters thick. If there is a temperature difference between the opposite walls of the TEG module, an electric voltage is created in it. Physics of thermoelectric generators is discussed extensively in the book [39]. Nowadays, TEGs are more and more often used in various types of structures. The Authors in paper [40] show a low cost stove-top thermoelectric generator for regions with unreliable electricity supply. Research on that type of household device gained momentum at the beginning of the 21st century. In recent years, there has been development of stove-powered thermoelectric materials and generators [41]. This resulted in a significant drop in their retail price. In effect, this opens up a new application area for thermoelectric generators.

5. Results and discussions

The micro-CHPUs are dedicated to all agricultural regions, also the highly developed ones. They will be able to generate electric energy for batteries in small electric vehicles and heat energy for households. Today, this is a very attractive application area. The electric agricultural vehicle market is developing very fast and biomass could become indirectly (through electricity) a fuel for these vehicles. In recent years, many new fully electric propulsion farm vehicles have been constructed, e.g. Switchevglobal vehicles [42]. Currently, the micro-CHPU system is under construction. It contains a combustion chamber, an exhaust filter, heat collectors, boilers, thermoelectric modules and an electronics module (voltage converter and driver). In order to reduce construction costs, a consumer Peltier module was used as a thermoelectric module. This is a very important detail. Peltier modules are widely used in automotive refrigerators, medical and scientific apparatus and many other devices . The Peltier phenomenon is the opposite of the Seebeck phenomenon. The Peltier module, during its normal operation, pumps heat from one side of the module to its other side. This effect is fully reversible and the Peltier module can work as TEG. Our previous experiment has shown that it can be used for construction of a low cost solar thermoelectric water floating device to supply a measurement platform. Now the research has been extended for a larger temperature difference and has shown the great application potential of these modules. To test the properties of various Peltier modules working as thermogenerators in the temperature difference range up to 50˚C, the circuit shown in Fig. 4 was built. It is very important to investigate the perfor-

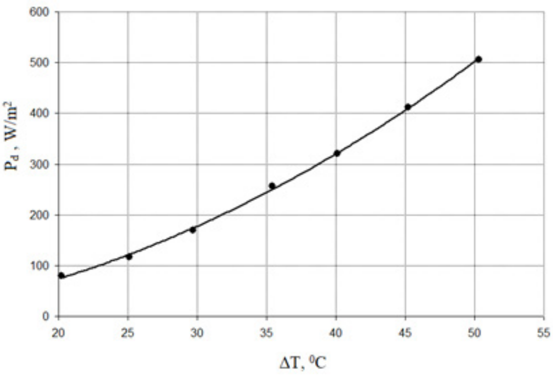

Fig. 5. Surface power density generated in Peltier modules working as TEG vs. temperature difference between the walls of the two boilers between which these modules are placed

Rys. 5. Generowana moc elektryczna na jednostkę powierzchni modułów Peltiera pracujących jako TEG w zależności od różnicy temperatur między ścianami dwóch zbiorników z wodą pomiędzy którymi umieszczono te moduły

mance and reliability of commercial thermoelectric modules, which could be applied in the micro-CHPU.

The above measurement setup (fig. 4) contains four tested modules placed next to each other (50 mm × 50 mm size single module) and two steel tanks (boilers) with a capacity of approximately 2.1 dm^3 each. The water pressure is reduced to approx. 0.2 bar – a pressure reducer is used before connecting to the water supply (waterworks). The sides of these modules were coated with thermal grease. An electric heater was placed inside tank 1 and was supplied from electricity grid via a transformer (it gives galvanic separation and voltage reduction) and a solid state relay. The heater imitates the heat produced in the combustion chamber. Thanks to this, a cheap and uncomplicated measurement system was built, which allows for small-scale testing of various solutions that will then be used in the micro-CHPU. While the water in tank 1 is heated, the heat flux travels to the colder tank (to tank 2) via the thermoelectric modules. The temperature was measured using two DS18B20 sensors in a water-proof casing (Dallas Semiconductor / Maxim). These sensors were attached to the walls of the boilers inside them at the point of contact with the Peltier modules. During the experiments, the water temperature varied from 14˚C to 72˚C in tank 1 and from 14˚C to 20˚C in tank 2. The measurement system in fig. 4 makes it possible to determine the surface maximum power density generated in Peltier modules working as TEGs vs. The temperature difference of the tanks walls (between which they were placed) is shown in fig. 5.

In order to obtain the maximum electric power in the modules for each of the temperature differences, the load resistance must be appropriately adjusted. Therefore, a dedicated electronic unit has been constructed that tracks the optimal operating point of the thermoelectric generator (Peltier modules in this case). The unit is a kind of DC/DC voltage converter, where the input resistance is matched. It will be discussed in another paper in the field of electronics. The measuring system was controlled by Arduino Leonardo board and driven via a laptop.

The measurement points in the temperature difference range 20˚C – 50˚C are well approximated by a power function (eq.1)

$$P_d = k \cdot \Delta T^n \qquad (1)$$

where:

P_d – Surface power density generated in the thermoelectric generator in W/m2

ΔT – temperature difference (in Celsius degrees) between the walls of the two boilers between which these modules are placed

k, n – equation coefficients, k = 0.17(2) and n = 2.04(4)

Since the value of the coefficient n is near 2, it can be roughly assumed that the generated power increases with the square of the temperature difference. If the heat exchange surface between tanks is equal to 1 m2 and the temperature difference is 50 ˚C, these modules generate electric power of about 500 Watts. The above results indicate that Peltier modules perform very well as TEGs. This gives a great application potential in thermal biomass processing. Lowering the cost of the micro-CHPU device will make the final product easier to sell and more popular. The next stage of the research is the completion of the prototype. Fig. 6 shows a simplified schematic of the micro-CHPU prototype, which is currently under construction. The device in its basic version consists of two boilers (tanks) and a matrix of Peltier modules between them.

The first boiler will be heated by the heat collector from the combustion chamber. The second boiler will heat up from the first as a result of the heat flux passing through the thermoelectric modules. The water temperature in the tanks is always lower than 100˚C (less than the boiling point). Consequently, the temperature in the thermoelectric modules does not exceed the permissible values. In the micro-CHPU prototype (Fig.6), boiler 1 (hot water tank) with the capacity of 50 liters and boiler 2 (cold water tank) with the capacity of 14 liters will be used. In practice, boiler 2 is a thin cuboid approximately 2.5 cm thick (inside dimension). The contact area of each boiler with thermoelectric modules is 0.5 m^2 in the prototype. The heat flow from tank 1 to tank 2 is, contrary to appearances, very complicated. The water temperature distribution inside the tanks is not uniform. When electric current in thermoelectric modules is generated by the Seebeck effect, a simultaneously flowing electric current causes the Peltier effect. It is a kind of a negative feedback loop (a kind of dynamic effect) that significantly reduces the power of the generated

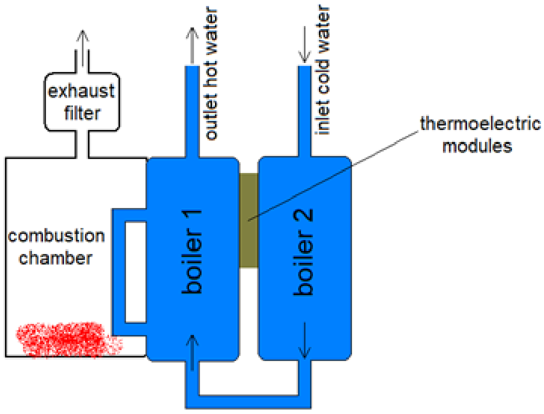

Fig. 6. Simplified schematic of the micro-CHPU prototype which is currently under construction

Rys. 6. Uproszczony schemat konstruowanego prototypu micro-CHPU

current. As a result, the temperature difference between the walls of the thermoelectric modules is smaller than the temperature difference of the water in the tanks - it is not only the result of the finite thermal conductivity of the steel walls. The device will only work properly if the adequate water flow is provided. If the water flow is too low, there will be a significant increase in the temperature in tank 2. This temperature can be calculated from the simplified equation 2 - hence boiler 2 will finally be thermally insulated, and energy losses to the environment are neglected.

$$P_2 = \frac{\Delta E_2}{\Delta t} \approx \frac{(m_w \cdot c_w + m_s \cdot c_s) \cdot \Delta T_2}{\Delta t} \qquad (2)$$

where:

P_2 – heat power reaching tank 2

$\Delta E_2 / \Delta t$ – heat energy ΔE_2 reaching tank 2 in the time Δt

m_w – mass of water in boiler 2

c_w – specific heat of water

m_s – mass of the steel walls of boiler 2

c_s – specific heat of steel

ΔT_2 – temperature increase in tank 2 due to energy reaching this tank.

For example, if P_2 = 1 kW, $c_w \approx$ 4.2 kJ/kg˚C, $c_s \approx$ 0.49 kJ/kg˚C and water flow speed is at 30 dm³/h, then the temperature in tank 2 increases less than 28˚C. This increase in temperature should be regarded as a critical value. If the temperature of the entering water (in boiler 2) is at 15˚C, it will be heated up to 43˚C with that flow speed. This will decrease the temperature difference between the tanks and reduce the generated electrical power. When the average water flow is lower, it is necessary to use tank 2 with a larger capacity. Summing up, the prototype will give an opportunity to test many technical aspects while commercial Peltier modules are working as thermoelectric modules in the micro-CHPU. At the moment, the micro-CHPU is under construction. The current work is focused on the control system. The main purpose of the control is to maintain the optimal temperature difference between the boilers at the set water flow and output power in the thermogenerators. This is not easy because water-filled boilers are objects of very high inertia and output electric power influences the heat flux taken from boiler 1 and the heat flux reaching boiler 2. The basic fuel burned in the micro-CHPU will be pressed straw (mainly wheat, barley and rye one). Most developing countries have overproduction of straw – for example, in Poland a significant proportion of straw is burned on agricultural land after the harvesting. The conversion of thermal energy into electricity using the thermoelectric effect is generally characterized by low energy efficiency. This is the main reason why the thermoelectric effect is not used on a large scale to generate electricity. Thermal power plants (nuclear, gas, coal) based on thermodynamic processes of water vapor offer much higher efficiency. Unfortunately, these processes are too complicated to build small household generators based on them. Therefore, to obtain high energy efficiency in devices with thermoelectric modules, cogeneration should be used – as in the case of micro-CHPU. The heat flux flowing from boiler 1 to the thermoelectric modules is not dissipated into the environment but comes into boiler 2. The energy losses are low – similar to a typical water boiler (electric or gas). This is a significant difference in comparison to other thermoelectric devices generating electricity from biomass. First of all, commercial thermoelectric devices powered by biomass are designed to work in places without access to the electricity grid. In such devices, the heat flux coming out of the thermoelectric module is dissipated into the environment (air-cooled) and they usually do not contain any boiler (achieving high energy efficiency is not essential). A commercial example of such a device is a biomass stove with a 10 Watts thermoelectric power generator, produced by Thermonamic Electronics, China [43]. It is a biomass stove with thermoelectric modules, dedicated for mobile phone or battery charging and lighting during cooking. Thermoelectric applications for energy harvesting in domestic applications and micro-production units are broadly discussed in paper [44]. The authors show a theoretical model of a biomass thermoelectric generator with a water-flow cooling system. There is a description of the combustion-based thermoelectric conversion system, its physics and various thermoelectric materials. However, there are significant differences between the model analyzed by the authors and the micro-CHPU – in the former model the heat energy that comes out of the coolant is next dissipated into the environment . This results in a significant reduction in energy efficiency but at the same time simplifies the mathematical model in the field of the control system. In paper [45], the authors present a concept of a novel domesticscale integrated wooden pellet-fueled micro-cogeneration. This concept is based on a commercial 20 kW wooden-pellet fueled boiler and three methods of converting heat energy to electricity : indirectly (via mechanical energy) using a rotary steam engine and a Stirling engine, or directly using a domestic thermoelectric cogeneration system. The authors consider applying their concepts to charging an electric car. This concept is somewhat similar to the micro-CHPU presented in this paper. The main difference is that the micro-CHPU is based on commercial and commercially available Peltier modules, the temperature of which never exceeds 100˚C (the water temperature in the boilers is always below the boiling point). This will lower the price and raise the popularity of the final product, which will be easier to repair in the case of failure. An additional advantage of the micro-CHPU is obtaining a valuable fertilizer. Biomass-ash (mainly wheat, barley and rye ash) is a valuable raw material for the production of phosphorus, potassium and calcium-magnesium fertilizers, which are widely used in agriculture [46, 47].

6. Conclusion

Biomass is increasingly used to produce electricity, especially in many developing countries, like Poland. The most efficient method of producing useful energy from biomass is based on burning it in biomass power plants or after mixing with other fuels in coal-fired power plants.

In developing countries, most biomass is still burned in household stoves. These stoves heat houses and water (in a boiler). They have an average or low efficiency and may emit more pollutants into the air during combustion. On the other hand, they are mainly used in rural areas, where the use of CHP power plants does not make sense, because there are high heat losses during the transport via heat pipelines (houses and villages are scattered). In countries such as Poland, large amounts of biomass are burned in household stoves in rural areas, but unfortunately most biomass is wasted - there is overproduction of biomass. When coal-fired power plants are decommissioned, energy production from biomass will decrease significantly. This will reduce the share of biomass in the energy market and cause even more waste of biomass. It should be noted that leaving biomass on the farmland to rot causes formation of carbon dioxide in quantities similar to when burning it in a stove or a power plant. To sum up, refraining from burning biomass will not have a positive effect on the greenhouse effect. The presented paper introduces a new idea – a micro-CHPU (Micro Combined Heat and Power Unit). This solution is based on the thermoelectric effect, during which no noise is produced and no moving components are included. Its operating principle uses the Seebeck effect in commercial Peltier modules. Unlike many other solutions, in the proposed device the heat flux coming out from the thermoelectric modules is not dissipated into the environment, but reaches boiler 2. Currently, the micro--CHPU system is under construction. The obtained results indicate that the Peltier modules work very well as thermoelectric generators. The low price and easy availability of commercial Peltier modules will positively affect the popularity of the micro-CHPU. The previous research has shown that such thermoelectric generators based on Peltier modules are highly reliable and have a long service life. If the micro-CHPU generated a power of 120 - 250 W, this would be more than enough to charge batteries (in the normal charging mode, not the fast one) in an electric agricultural vehicle or in an electric quad. The currently small electric vehicle market is growing rapidly, which will increase the demand for electricity. The application of millions of micro-CHPUs may become a new way of developing the biomass market. Micro-CHPUs can be used anywhere and are not connected to the electricity grid.

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Nowy sposób wytwarzania energii z biomasy w krajach likwidujących elektrownie węglowe

W artykule opisano nowy sposób przetwarzania biomasy przy użyciu urządzeń mikro-CHPU (Micro Combined Heat and Power Unit). Urządzenie mikro-CHPU to nowy pomysł, który pozwala na zamianę energii chemicznej zawartej w biomasie na energię elektryczną do ładowania akumulatorów w małych pojazdach elektrycznych oraz w ciepło użytkowe dla gospodarstw domowych. Do budowy zastosowano komercyjne moduły Peltiera, w których działanie ich zostało odwrócone w celu uzyskania efektu Seebecka. Z przedstawionych wyników badań wynika, że komercyjny moduł Peltiera bardzo dobrze sprawdza się jako generator termoelektryczny. Proponowane urządzenia może okazać się bardzo przydatne w dobie rewolucji, która rozpoczęła się na rynku energii w większości krajów rozwijających się. Obecnie wiele z tych krajów intensywnie zaczyna odchodzić od energetyki opartej na paliwach kopalnych. Bardzo popularną i efektywną metodą wykorzystania biomasy jest mieszanie jej z węglem (w proporcji od 10% do 90%) i spalanie w elektrowni węglowej lub elektrociepłowni. Po zamknięciu tych elektrowni niewykorzystana biomasa mogłaby zostać spalona w urządzeniach mikro-CHPU.

Słowa kluczowe: *biomasa, generator termoelektryczny, mikro-CHPU, moduł Peltiera, zużycie energii pierwotnej, redukcja emisji i odnawialne źródło energii*

Mining Company Management in Case of the Epidemic Emergency

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Abstrakt

The date assumed as the beginning of the pandemic in Poland is March 4 2020, the date of the first confirmed case of the virus. The article presents the actions undertaken by the management of underground hard coal mining plants concerning the risk of epidemic related to SARS-CoV-2. This work shows a set of implemented recommendations, guidelines and decisions which were established after the appearance of the first wave of cases in Poland. What is more, it discusses measures aiming at reducing the risk of spreading the coronavirus among the mineworkers. The suggestions for different variants of the decision-making process concerning the pandemic and which have an enormous impact on the operating expenses of the company are also made.

Keywords: *mining company, epidemic emergency, coronavirus SARS-CoV-2, safety*

1. Introduction

Ensuring safe mine (mining plant) operation and proper working conditions of the employed are the foundations for the functioning of a mining company in terms of its sustainable development. It is particularly important for hard coal mining, where the working environment is shaped by geological and mining conditions, natural hazards and conditions resulting from the specificity of work in underground excavations [Sukiennik et al., 2019b].

Mine operation, whether as an independent unit or a part of a multi-facility mining company, is shaped by the following elements:

- technical and organisational,
- economic,
- social,
- legal.

Managing mine company, and in fact, managing the risks associated with operating in such an environment, is a serious challenge for the company or mine managers and engineers and technicians. The risk does not only assess the probability of occurrence of hazards resulting from conducting mining works but, above all, the effects generated by these hazards [Sukiennik et al., 2019a].

This is due to the geological and mining conditions and the adapted technological specificity of the mining production process It is carried out within the area of a disturbed rock mass, mostly involving high pressure and resulting from it seismic, gas (especially concerning methane), fire and water hazards. Therefore, the threat to the safety of the employees working in underground excavations arises from many factors [Konopko, 2010]. The influence of geological and mining factors on the risk of work safety in underground mines has been the subject of numerous studies carried out for many decades. This is the reason why these issues are described in literature and regulated by many formal and legal acts, often in great detail.

At the end of 2019 in China, and in March of the following year in Poland, the epidemic emergency associated with the spread of the coronavirus SARS-CoV-2, causing acute respiratory disease COVID-19, emerged. It was acknowledged to be very easily transmitted from one person to another. The virus is mainly transmitted by the droplets created, when a person infected coughs, sneezes and exhales. These droplets are too heavy to float in the air, so they fall quickly on surfaces. Then a person may become infected after touching the contaminated surface followed by touching their eyes, nose or mouth.

The risk of a severe course of the coronavirus disease appeared to be serious and led to making high-level decisions concerning the announcement of the state of epidemic emergency in the Republic of Poland commencing 14 March 2020 and the state of epidemic commencing 20 March 2020 [Regulation 2020a, 2020b, 2020c]. According to the above-mentioned regulations, radical measures concerning isolation of the inhabitants of our country were implemented. The isolation involved mainly the large scale, temporary suspension of their activities, especially closures of many businesses, offices, schools and retail outlets. Whenever it was possible, the so-called remote working system was implemented.

This created a dilemma – what decisions to make and what will be the consequences for mining companies and mines? These decisions were left to be made by the coal companies and mines managements. These had to be made having insufficient information concerning a threat of this kind, which actually "only just" emerged. Therefore, what decisions need to be made (as soon as possible) with regard to the functioning of mines, without having any reliable knowledge about the sources of the spread of the threat itself and methods of preventing it? And the knowledge of the risks involved is essential at each mining company management level. Although it would be more favourable to implement decisions that would involve "no risk", the basis of the security concept involves "acceptable risk". If it is adopted in relation to a mining company, it is necessary to anticipate and predict the possibility of occurrence of a risk. This term should be understood as a risk included between the desired upper and lower levels of safety taking into account a set of necessary criteria. In this case, the criteria should concern epidemic emergency in relation to the employees.

The scale of the problem may be evidenced by the fact that by the 10th July 2020, more than 6,500 employees of all mines located in Silesia (less than 9% of all employees) were infected with the coronavirus. The only mine where no case of infection has been reported is LW Bogdanka SA located in the Lublin Province.

2. Issues concerning making decisions concerning hazards present in a mining plant (mine)

Although there are many definitions of the term "management", for the purpose of this work it can be assumed that, in the management system of a mining company, there are five management functions: planning, organising, leading, inspecting and improving. However, the management process often involves complex networks of management and executive activities. The whole process consists of three stages: selection and analysis of source data (1), decision-making planning (2) and decision-making (3). The last of these stages involves a very high level of responsibility on the part of the decision-maker as the effects of their decisions, in most cases, might be "extremely costly".

The mining production process consists primarily of a selection of the applicable technology for mining the deposit while maintaining occupational safety. Concerning the management of a mining company and its individual mines, particularly vital are decisions involving [Dubiński et al., 2017]:

- ensuring high standards of occupational safety,
- implementation of modern technical and technological solutions for deposit mining,
- ensuring the required quality of commercial coal produced,
- protection of the mining area where the effects of the carried out mining and the natural environment may be visible.

Additionally, from an economic point of view, the mining production process should be efficient, or at least not generate financial losses. Such requirements for mining production are shown in Figure 1.

In hard coal mining, the basis for decision-making are the laws, regulations, guidelines and various rules and procedures developed. In many cases, those are established based on the past experience and are often supported by scientific research. These regulations are, or at least should be, well known to individual decision-makers. This allows for proper management of a mine and a mining company - proper, i.e. in a way that ensures the highest possible level of safety and avoids unjustified risks concerning mining production.

There is no alternative concerning occupational safety related to the conditions of currently occurring and recognised risks, both natural and resulting from the technologies used. The most important document on basis of which mining plants operate is Mining Law [Act, 2011] which contains provisions stating that:

- "Mining plant operations shall be performed in pursuance of the provisions of law, in particular in pursuance of the mining plant operations plan and in compliance with mining principles",
- "A mining plant operations plan shall specify: (...) detailed projects required in order to ensure: (...) public safety, fire safety, safety to persons in a mining plant, in particular occupational health and safety projects...".

Then, on the basis of this act, a number of regulations were developed, which define in detail the principles for safe mining in the case of the occurrence of specific hazards. The two most important regulations are:

- Regulation of the Minister of Energy of 23 November 2016 on detailed requirements for operation of underground mining plants (Regulation, 2016)
- Regulation of the Minister of Environment of 29 January 2013 on natural hazards in mining plants where, inter alia, the following hazards: rock bursts, methane, gas and rock eruptions, coal dust explosion, climate-related and water hazards [Regulation, 2013].

The regulations specify the ways of measuring the intensity of individual hazards, classifying them into appropriate classes, categories or degrees, and also specify the number of principles and guidelines on how to carry out mining in case of their occurrence. One should note that failure to comply with the established requirements shall lead to taking appropriate disciplinary measures or even penal consequences.

Many of the introduced principles led to a decrease in efficiency understood as the ratio of the amount of expenditure to the achieved effects [Durlik, 1993]. In a mining company (mine), the achieved effects include primarily the amount of extraction. Depending on the type of hazard and its scale, it may be necessary to:

- incurring increased expenditures on taking relevant preventive measures concerning each of the hazards

and/or

- reduction of the amount of extraction due to the slower advancement of work at a face due to the hazard related to rock bursts, methane or gas and rock eruptions.

As mentioned above, there is no alternative nor price for occupational safety. The principles established for mining are always implemented in case of occurrence of any hazard. If the expenditures proved mining deposits, outcrops or their parts to be unprofitable, the alternative for decisions made does not only involve abandoning them but discontinuing work in the entire area.

However, how to make rational decisions facing unknown threat? In this case, the problem is to determine how and using which parameters to diagnose the status, how to adopt an action plan and how to implement it. In general, depending on the point of view, the assessment of the same phenomenon, process or subject vary considerably. The correctness of decisions made depends on many factors, including the reliability of available data, predicted conditions of an epidemic, mining

Fig. 1. Features of standard for carrying out mining production process. Source: own study based on [Dubiński et al., 2017]

Rys. 1. Cechy modelowego prowadzenia procesu produkcji górniczej

and technical situation in a mines, knowledge and experience of a company's management and mine management. For this reason, decisions made voluntarily are subject to great risk.

3. Measures taken concerning the existing epidemic emergency

As opposed to other hazards, in the case of an epidemic emergency caused by the SARS-CoV-2 there are no specific procedures that could be strictly followed in the operation of a mining company. For example, the Website of the Republic of Poland provides only five general guidelines [www.gov.pl/web/koronawirus]:

1. Regularly wash your hands with soap and water.
2. Cover your mouth and nose with your bent elbow or tissue when you cough.
3. Avoid touching your eyes, nose and mouth.
4. Stay at least 2 meters from other people
5. Stay home.

Rules formulated in such way imply that the primary mean of protection against becoming infected is to keep a distance from other people or even to avoid any contact at all. Implementation of such rules is absolutely not feasible in mines where the limited space of shaft hoist cages, underground means of transport and excavations, where a large number of people work, make it impossible to maintain two-meter space between people.

On 24 March 2020 the secretary of state in Ministry of State Assets met with the presidents of the coal companies via teleconference during which the guidelines to be followed in mines, concerning the spread of coronavirus, were developed. The most important guidelines implemented during work in individual mining plants were:

- reducing the number of work shifts and reducing the work time to six hours,
- limiting the number of people entering the shaft hoist cage and transported using transport equipment by half,
- appointing crisis management centres that decide, depending on the turn of events, on the current decision-making in a company and its mines,
- introducing screening among employees of mines with highest number of cases.

For employees entering mines, temperature measurement points were established. In some mines testing of thermal cameras in order to remotely measure the temperature of people entering them was started.

Further guidelines on procedures were developed by the Team for Managing Crisis in Underground Mining Plants (Polish: Nadzwyczajny Zespół ds. Zagrożeń w Podziemnych Zakładach Górniczych) appointed by the President of the State Mining Authority. These include, among others:

- imposing the obligation on the mining plant operation managers to develop and implement new principles for transporting people using shaft hoists and in underground excavations, along with procedures for disinfecting shaft hoist cages, mine rail cars and other means of transport,
- the obligation to develop, for each mine and their operation, procedures concerning suspected or confirmed cases of SARS-CoV-2,
- appropriate organisation of the use of baths and other places located on the surface of the mines where there are concentrations of people,
- preparation for each mine one or two places where sufficient amounts of disinfectants will be stored,
- the need to place strong emphasis on the use of appropriate protective clothing and other personal protective equipment (masks, goggles, gloves) by employees.

Initially, attempts were made to limit the number of employees working at the same time by reducing the number of shifts and minimising the number of employees working in particular posts. The aim of such actions was to make disinfection of some posts and baths possible as well as reducing the number of employees working in one place at the same time.

However, these actions did not bring the expected results and in view of the increasing number of confirmed cases among employees, the managers of individual companies made decisions to limit the work of some mines by suspending mining for several days. Still, the number of infected continued to grow rapidly, so this time, a radical decision was made (by the government) to completely suspend the work in twelve selected mines for three weeks. At that time, only employees checking fire safety of underground excavations went to work. Since 6 July 2020, all mines have been operating normally and now it will be possible to assess whether these actions will help to stop the spread of the virus.

4. Decision-making process in an epidemic emergency

According to numerous studies conducted all over the world on the fight against the threats posed by SARS-CoV-2, there is no chance of its natural extinction. Until an effective vaccine is developed, there is no other way to slow down the spread of the pandemic than to limit the contact between individuals. Therefore, the management of mining companies must adopt such an assumption when making decisions related to their operation.

However, the radical step of stopping the operation of mines cannot be the basis for the proposed solutions. Due to the danger of deformation of underground excavations (including, in particular walls in which the built-in machinery and equipment may be destroyed) and initiation of spontaneous fires caused by coal spontaneous ignition, such a solution cannot be taken into account. It is necessary to find other methods to reduce the number of people in underground excavations. For this purpose, each mine should carry out an in-depth technical and economic analysis of the possibilities of:

1. limiting the number of people working at the face of a mine,
2. limiting the number of faces concerning works mining both drifts and headings, as well as determining the economic effects of such action,
3. decommissioning a certain number of excavations and basic elements, especially shafts and fore-shafts.

The principles and technologies for carrying out certain works often, among others, provide for employing the minimum number of people necessary for their safe operation. Therefore, the procedure aiming at the reduction of the number of people working at faces of a mine cannot involve reducing this number below the required minimum. However, in many cases, there are possibilities to implement modern technical solutions, allowing to reduce this number almost completely. For example:

- using electro-hydraulic controllers for sections of powered supports carried out by only one operator located at a main gate,
- using full visualisation and automation for controlling conveyors transporting mined minerals,
- using a container system for transporting materials - containers loaded on the surface can be transported directly to the face of a mine without the need to reload them on the main transport road.

Another method of reducing the number of employees involves increasing the concentration of production. In many mines, the current amount of extraction is obtained from several simultaneously active longwalls and, considering the average annual., there can be even up to 5 of those. Performing appropriate analyses would provide data on whether there are technical possibilities to increase the extraction from certain longwalls in such a way that the total amount of extraction required could be obtained from fewer longwalls. Another issue that needs to be investigated by means of economic analyses is the possibility of reducing operating expenses for the required efficiency of production to be achievable in the case of a smaller amount of extraction from fewer longwalls. Concerning this issue, the companies and mines management play a particularly important role. According to the research on:

- market situation – coal marketing opportunity and its price,
- the amount of expenses to be incurred in order to carry out the required works safely,

the decisions made should involve the determination of the very minimum amount of extraction necessary to maintain the efficiency of operation, the number of stopes, equipment needed to mine them, and the number of employees needed to carry out the works.

Addressing the third issue mentioned above, it should be highlighted that currently spatial structure of many mines is overly expanded. This most often concerns the remaining structures used in the period when the extraction of hard coal by the mining industry was more than three times higher than currently. Only parts located peripherally were decommissioned when conducting restructuring activities in the functioning mines, and no changes in the areas of carrying out mining were made. As a result, today there are mines with 7 and 8 shafts and more than 10 levels. If those are maintained but not used during mining, those only generate unnecessary expenses. The regulations require for each excavation to be maintained in a condition which does not threaten the safety and be periodically inspected. Their decommissioning would contribute to reducing both operating costs and the number of employees necessary.

5. Summary and conclusions

The SARS-CoV-2 pandemic caused a shock to the world economy. Production companies, including hard coal mining industry in Poland, were particularly affected by it. Such a situation is the result of the recognition of a new, mass threat to the health and life of mineworkers. Company managers, responsible for the safety of their employees, were almost immediately forced to introduce dramatic changes in the organisation of work in companies.

The first actions performed in the mining plants were mainly related to adapting the activities to the national law resulting from the regulations introducing, first, the state of epidemic emergency, and then the state of the epidemic. At the same time, the mines implemented the recommendations of the Chief Sanitary Inspectorate concerning rules for proper hygiene (e.g. social distancing, disinfection, wearing mask). Due to the further increase in the number of coronavirus cases, organisational changes were made to reduce the number of employees, e.g. in shaft hoist cages or transport machines. In many plants, mass screening was carried out and in some periods, mining was completely suspended. The difficult, from an economic point of view, decisions resulted in bringing the situation under control and stopping the increase of infections by the beginning of July 2020. However, it should be stated that the "remote working" promoted and introduced in many industries is not feasible for implementation in underground mining companies. Therefore, in case of the next wave of the epidemic, previously observed events should be expected to occurr. Nonetheless, the introduced procedures and experienced gained while fighting the first wave of the epidemic will undoubtedly allow for more effective crisis management.

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Zarządzanie przedsiębiorstwem górniczym w warunkach zagrożenia epidemicznego

Pojawienie się pierwszego potwierdzonego przypadku koronawirusa w dniu 4 marca 2020 roku przyjmuje się jako datę rozpoczynającą pandemię w Polsce. W artykule przedstawiono działania podjęte przez kierownictwa podziemnych zakładów węgla kamiennego w związku z zagrożeniem epidemicznym koronawirusem SARS-CoV-2. Zaprezentowano zbiór wdrożonych rekomendacji, wytycznych i decyzji, które zostały podjęte z chwilą pojawienia się pierwszej fali zachorowań w Polsce. Dodatkowo omówiono praktyczne działania w celu minimalizacji ryzyka zarażenia pracowników kopalń koronawirusem. Wskazano także propozycje różnych wariantów przebiegu procesów decyzyjnych związanych z panującą pandemią, które mają decydujący wpływ na koszty funkcjonowania przedsiębiorstwa.

Słowa kluczowe: *przedsiębiorstwo górnicze, zagrożenie epidemiczne, koronawirus SARS-CoV-2, bezpieczeństwo*

Selection and Calculation of Air Cooling Solutions in Underground Coal Mines in Vietnam

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Abstrakt

Currently, Vietnamese underground mines have been exploited down to -500 m and, in the near future, they will be exploited deeper. The exploitation of coal of seams has an negative impact on a workers environment. The increase in the depth of coal seam exploitation causes is the increase of adverse microclimate factors such as temperature, moisture, heat radiation. According to the current Vietnamese laws, coal deposits can be mined in a condition when air temperature does not exceed 30oC, although this rule is not always observed, especially during summer. The article show how reducing the adverse impact of climate factors in the mines and calculating the parameters which reduce the temperature on an example in one of underground coal mines in Vietnam.

Keywords: *air temperature, air humidity, air cooling, thermal power of cooler*

1. Introduction

In underground mines, in addition to technical hazards resulting from technological processes, there are also natural threats related to the rock mass surrounding the excavation (water, gas, gas and rock burst, gas and dust explosions and climatic hazards). The air flow temperature is the main factor shaping the climate in headings. The prevailing microclimate determines the working conditions of mining crews in workplaces. Working in difficult climatic conditions, especially in hot environments, is often associated with acute ailments which are caused by disturbances of water-mineral balance with impaired thermoregulation of the body. It causes decreasing in such functions of the human body as the ability to perceive, concentrate, pay attention, perceptiveness and work efficiency [1, 2, 3]. Air parameters significantly reduce the efficiency of mineral extraction, which contributes to reduce in the economic efficiency of the underground mining plant.

Factors influencing the character of the air temperature in the excavation are: sources of moisture, depth of exploitation and related air compression in the air intake shafts and heat flow from the rock mass to the air. Moreover, an increase in air temperature causes the temperature oxidation of coal and additional technological heat sources (electromechanical devices) [4, 5]. Another factor affecting the deterioration of climatic conditions air humidity is often exceeding 85%.

The main methods of combating temperature threat in underground mines include the classic ventilation methods and artificial air cooling methods. In this article, the authors analyse a solution of reducing the adverse impact of climatic factors on the state of air in the heading of coal mines in Vietnam, involving an utilization of local cooling equipment.

2. Microclimate parameters in underground hard coal mines in Vietnam

Most of the underground mines of the Vietnam National Coal – Mineral Industries Holding Corporation Limited (VINACOMIN) had completed the mining of deposits over the sea level since 2019, such mines include Vang Danh, Thong Nhat, Nam Mau, Ha Lam, Khe Cham III, Khe Cham II-IV, Mao Khe and Nui Beo. The annual average production in these mines is around 1,500,000 Mg. Vietnamese underground mines are shallow mines which extract coal deposits up to 300 m below ground, e.g. Nui Beo, Ha Lam, Mao Khe, Khe Cham III. Deepest mines include Khe Cham II-IV, reaching to 500 m below ground. In these mines, the annual average production in the wall is output, and it is over 500,000 Mg, e.g. in the Ha Lam mine the wall 11-1-17 of coalbed 11 about 600,000 Mg is extracted, and the wall 7-2-1 of coalbed 7 about 1,200,000 Mg of coal per year.

In the next few years, VINACOMIN will accelerate the implementation of mechanization for mining from seams by longwall systems and spoil transport, such as the use of mechanized mining technology, longwall shearers will be used and the excavated belt transport system will be modernized. Mechanization will also be used to transport people and materials.

Vietnamese underground mines use a ventilation system based on main ventilation fans, the so-called central suction system.

Mining operations in Vietnam are governed by Regulation No. 03/2011/TT-BCT of the Ministry of Industry and Trade, according to which the air velocity in the wall and heading faces cannot be less than 0.25 m/s. In mines with methane hazard categories III and IV air current speed cannot be below 0.5 m/s (in faces with an 15° incline or coal deposits is thicker than 2 m as well as face headings with a length up to 100 m). Air velocity cannot exceed: 4 m/s in coal excavations, 8 m/s for tunnel headings, 10 m/s – for air crossings, 12 m/s in shafts and fore-shafts while transporting people and 15 m/s in air ducts [6]. Table 1 presents the volumetric air stream and its velocity in selected underground mines in Vietnam.

According with Vietnamese regulations (03/2011/TT-BCT), air temperature at the working site cannot exceed 30oC [6]. In the most cases in underground mines in Viet-

Tab. 1. Examples of air velocity and volum delivery in selected mines in Vietnam

Tab. 1. Temperatura i wilgotność powietrza w badanych wyrobiskach kopalń podziemnych w Wietnamie

No.	Heading name	Volum air stream [m³/s]	Cross-sectional area of the heading [m²]	Air velocity [m/s]
A	Ha Lam mine			
1	Wall -150 / -160, zone III, coalbed 11	6.9	5.2	1.33
2	Wall 10-2, zone III, coalbed 10	6.0	5.1	1.18
3	Wall CGH 7-3-1	24.0	10.4	2.31
B	Vang Danh mine			
1	Bottom road of wall CII-8-3, coalbed 8, Canh Ga zone	4.6	4.5	1.02
2	Air-heading of wall CII-8A-2, coalbed 8A, Canh Ga zone	5.4	4.8	1.13
3	Air-heading level +106, coalbed 6, Gieng Vang Danh zone	13.2	5.5	2.40
C	Thong Nhat mine			
1	Bottom road of wall KT7	6.7	4.8	1.40
2	Air-heading of wall KT8	11.0	8.5	1.29
3	Bottom road of wall KT9	11.2	6.6	1.70

Tab. 2. Air temperature and humidity in selected headings of underground mines in Vietnam

Tab. 2. Temperatura i wilgotność powietrza w wybranych wyrobiskach kopalń podziemnych w Wietnamie

No.	Heading name	Air parameters	
		Temperature [°C]	Relative humidity [%]
A	Mao Khe mine		
1	Air-heading, level -80, coalbed 8	29.0	83
2	Carrying heading, level -80 of wall I, coalbed 8, east	30.6	87
B	Vang Danh mine		
1	Carrying cross-heading, level -50 F11-F12, zone II - Gieng Canh Ga	28.9	88
2	Carrying heading, level +60 of wall CIII-8A-2 - Gieng Vang Danh	28.0	88
C	Nam Mau mine		
1	Air-heading of wall I-9-5	29.5	94
D	Ha Lam mine		
1	Wall CGH 7-3-1	33.5	93
1	Wall CGH 11-1-17	32.4	90
E	Thong Nhat mine		
1	Cross-heading, level +18	29.9	94
2	Carrying heading , level +8, PV4C	29.2	93
F	Ha Long mine		
1	Roadway -50 - V11B -CB Cam Thanh	28.6	88
2	Wall -20/+40 V11B -Cam Thanh	28.8	88
G	Khe Cham mine		
1	Carrying heading of wall 14.5.2.A, coalbed 14.5	28.5	75
2	Air-heading, level -152 of wall 14.5.3.1, coalbed 14.5	29.0	82
H	Quang Hanh mine		
1	Air-heading, level -200 of wall 7.13, coalbed 7 TT	29.0	92
2	Carrying heading level -50 of wall 7.1, coalbed 7 ĐN	28.5	90

nam, the air temperature is maintained at the level of the above standards. However, during summer, when the external air temperature exceeds 35°C, hot air is supplied to the working site through the ventilation system, resulting in air temperature higher than 30°C. Table 2 presents air temperature and relative humidity values in selected Vietnamese mines.

As it is shown in Table 2, air temperature above 30oC is found in several headings of the Ha Lam and Mao Khe mines, in which walls mechanized complexes of high electrical power were used, and which emit an additional heat stream to the flowing air.

3. Analysis and selection of solutions to reduce air temperature in underground hard coal mines in Vietnam

In order to improve climatic conditions in underground headings, mining companies mainly use traditional methods of headings ventilation, with air cooling methods being used in selected mines and operating areas. The traditional methods of improving climatic conditions in mines are such that do not require cooling equipment. The effective ventilation of headings may improve climatic conditions, taking into account some requirements as followings [7, 8, 9] :

- Limiting fresh air humidification in downcast shafts and headings, simplification of the ventilation network and, consequently, directing a broader stream of fresh air to walls and headings,
- Proper exposure and cutting of the deposit, shortening the air supply paths and spoil haulage,
- Selecting an optimum longwall ventilation system,
- Tight insulation of cave-in workings (limiting air flow through workings),
- Avoiding serial ventilation of longwall headings,
- Locating the spoil haulage from the longwall in the used air current,
- Proper design of heading length, especially of longwalls, to account for the ventilation system's efficiency

To improve climatic conditions, the methods mentioned above are also used to limit moisture evaporation from watercourses by covering them, resulting in a decrease of air humidity. These methods do not always bring the assumed effect of lowering the air temperature to the permissible values at the workplace of the mining crew due to restrictions introduced by safety regulations, e.g. the maximum airflow speed in excavations, the risk of gas and dust explosion. Therefore, it is necessary to use other methods including the use of cooling equipment.

Air conditioning equipment can operate in the indirect or direct system. These devices include an evaporator, which is an air cooler combined with a machinery assembly consisting of a water-cooled condenser, an expansion valve (Fig. 1

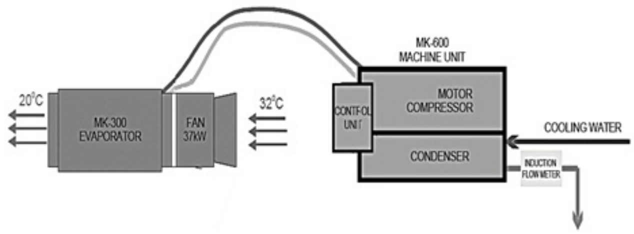

Fig. 1. Air cooler diagram

Rys. 1. Schemat chłodziarka powietrza

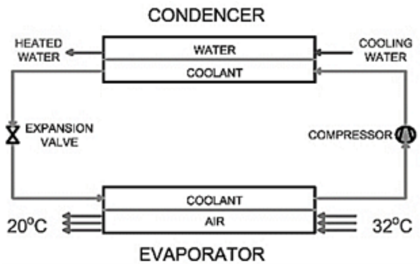

Fig. 2. Principle diagram of the operation of the air cooler

Rys. 2. Schemat zasadniczy działania chłodziarki powietrza

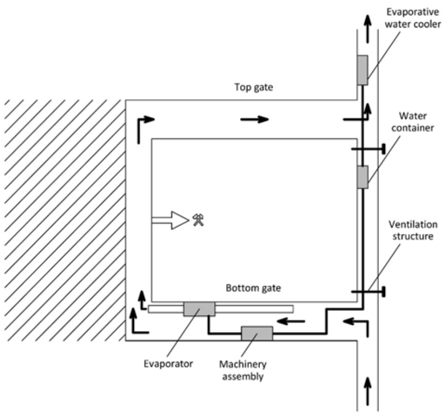

Fig. 3. Local air conditioning diagram

Rys. 3. System klimatyzacji lokalnej

and 2). The evaporator and the condenser are connected with elastic wires to the coolant circulation. Direct action chillers cool the air stream with an evaporator located directly in the cooled air stream, while heat is collected from the condenser in an open or closed system with the use of technological water (by the water from the fire-fighting system). In a closed system, the stream of heat received from the condenser is discharged via the water into the circulating air current in the evaporative water cooler. In the indirect operation system, the heat stream taken from the air in the excavation via water is directed to the evaporator and then it is collected by the water from the condenser. The correctness and efficiency of the air cooling process in the excavation ensure sufficient heat collection from the condenser.

Currently, there are three trends in the technology of air conditioning in mining headings used to reduce air temperature in workplaces: local, group or central air conditioning [10].

In hard coal mines, local air cooler with a capacity of up to about 350 kW is used primarily to cool the air in hollow excavations ventilated by ventilation pipes. Such devices are also used to cool the air in bottom gates.

In a group air-conditioning system, cooling aggregates with a cooling capacity of 1 to 3 MW can be used as individual or combined. Cooling aggregates, depending on the conditions in a given mine, are usually located near the downcast shafts, from which the cooled water is transported by insulated pipelines to the local air coolers. The main advantage of group air conditioning systems is the possibility of implementing many variants of the arrangement of air coolers. Group air conditioning systems are very often used in Polish underground mines in combination with local air coolers.

In central air-conditioning systems, the location of cooling aggregates together with their cooling system is possible on the surface or underground, or on the surface and underground (combined system). Central air conditioning systems use cooling aggregates that cool water, which is pumped into local water air coolers. The cooling capacity of such a system reaches up to 10 MW. In Poland, central air conditioning systems are used e.g. in KWK Pniówek, KWK Budryk and in the mines belonging to KGHM Polska Miedź S.A.

In hard coal mines in Vietnam, in order to actively reduce the air temperature, a local air-conditioning system should

Tab. 3. Air temperature in the CGH 7-3-1 wall at the Ha Lam mine in 2019.

Tab. 3. Temperatura powietrza w ścianie CGH 7-3-1 w kopalni Ha Lam w 2019 r.

Heading name		Months											
		1	2	3	4	5	6	7	8	9	10	11	12
Bottom gate CGH 7-3-1	°C	28.2	28.5	29.7	30.9	30.2	31.3	31.4	31.6	31.6	30.6	29.8	29.3
Wall CGH 7-3-1	°C	29.9	30.3	31.1	31.5	32.2	32.9	33.4	33.5	33.4	33.3	31.2	30.5
Top gate CGH 7-3-1	°C	30.5	30.9	31.3	32.0	33.7	33.4	34.7	34.5	34.4	33.8	32.5	30.9
Volumetric air stream	m^3/s	22.2	22.8	21.8	22.3	23.2	22.5	22.8	21.6	22.7	22.1	22.4	22.7
Surface temperature	°C	23.5	29.3	30.5	35.0	34.9	37.2	35.8	35.3	31.1	30.3	27.2	25.3

Tab. 3. Air temperature in the CGH 7-3-1 wall at the Ha Lam mine in 2019.

Tab. 3. Temperatura powietrza w ścianie CGH 7-3-1 w kopalni Ha Lam w 2019 r.

No.	Parameter	Symbol	Unit	Value
1	Cross-sectional area of the heading	A	m^2	11.2
2	Heading perimeter	B	m	13
3	Heading length	L	m	536
4	Dry-bulb temperature	t_s	°C	31.6
5	Wet-bulb temperature	t_w	°C	30.8
6	Relative humidity	φ_d	%	88
7	Air pressure	p	Pa	103,977
8	Average air speed across the heading cross-section	w_d	m/s	2.0

be used, which among the mine air-conditioning systems has the lowest investment costs. The scheme of such a system is shown in Figure 3.

4. Calculating of air temperature after using an air cooler for wall No. 7-3-1 in the Ha Lam mine

The CGH 7-3-1 wall is located on bed 7 in the Ha Lam mine in Vietnam. The wall was launched on October 20, 2018. The capacity of this wall is 1,200,000 Mg/year. The CGH 7-3-1 wall is at the deepest mine level of -265.8 m. The mining and transport devices used have high electrical power: longwall shearer – 600 kW, armoured face conveyor – 630 kW and 400 kW, belt conveyor in the bottom gate – 500 kW. During operation, the air temperature in the wall often exceeds 30°C, especially in summer (table 3 and figure 4). Traditional ventilation solutions were used to reduce climate risk and reduce air temperature, but they were still ineffective. Therefore, another solution was to apply the method of artificial air cooling, consisting in lowering the air temperature in the bottom road before it is led to the longwall.

In order to reduce the air temperature in the CGH 7-3-1 wall excavation, the TS-300 cooler from the Polish manufacturer Termospec Co. was used. The air cooler will be installed at the inlet of the bottom gate (536 m from the wall inlet). The direct action TS-300 cooler uses R407C refrigerant. The cooler consists of two separate units connected by flexible conduits. The first includes the refrigerant compressor, electric motor, condenser, expansion valve and control and monitoring system. The second unit is the refrigerator evaporator which is an air cooler. Directly in front of the evaporator is a lute fan, in this case WLE 803B forcing air flow through the cooler. Table 4 contains technical data and results of measurements of air parameters at the inlet to the heading.

Equations from (1) to (7) were used to determine the thermodynamic parameters of the cooled air.

Partial pressure of water vapour p_w:

$$p_w = \varphi\, p_{wn} \quad \text{(Pa)} \tag{1}$$

where:
p_{wn} – saturated vapour pressure, Pa
φ – relative humidity, -.

$$p_{wn} = 610.6 \times 10^{\frac{7.5 t_s}{(237.29 + t_s)}} \quad \text{(Pa)} \tag{2}$$

t_s – dry-bulb temperature, °C

Specific humidity of air, xd:

$$x_d = 0.622 \frac{p_w}{p - p_w} \quad \text{(kg/kg)} \tag{3}$$

where:
p – air pressure, Pa

Humid air density, ρ_d:

$$\rho_d = \frac{(1+x) p_{wn}}{462(0.622+x)T} \quad (\text{kg/m}^3) \tag{4}$$

where:
T – air temperature in the duct, $T = t_s + 273.15$ (K);
t_s – dry-bulb temperature, °C

Mass flow rate of humid air $\dot{m}_d$.

$$\dot{m}_d = \dot{V} \rho_d \quad \text{(kg/s)} \tag{5}$$

where:
V – volumetric flow rate of air, m^3/s, V=Aw
A – cross-sectional area, m^2
w – air velocity in the heading, m/s.

Mass flow rate of dry air $\dot{m}_{sd}$.

$$\dot{m}_{sd} = \frac{\dot{m}_d}{1+x} \quad \text{(kg/s)} \tag{6}$$

Specific enthalpy of air h_d:

$$h_d = 1.005 t_s + x(1.926 t_s + 2500) \quad \text{(kJ/kg)} \tag{7}$$

Taking into account the calculated air parameters at the inlet to the refrigerator fan, at the inlet to the evaporator and the nominal thermal power of the TS-300 cooler, the air temperature at the outlet from the evaporator was determined. The air flow leaving the evaporator is a mixture of the part of the air that has been cooled to the maximum in the cooler,

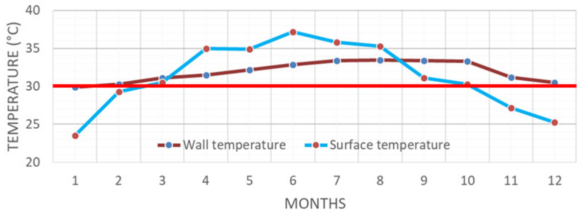

Fig. 4. Air temperature change diagram for wall CGH 7-3-1
Rys. 4. Wykres zmian temperatury powietrza w ścianie CGH 7-3-1

obtaining the temperature of the wall of the cooler and the part that has not completely cooled. Then, the cooled stream of air is mixed with the stream of air flowing in the heading (next to the air-conditioning machine). By indicating by tmk and xmk, respectively, the temperature and specific humidity of the air at the outlet of the evaporator, when it is saturated, on the basis of [11] you can write:

$$\begin{cases} x_{mk} = x_{\mathrm{nmk}} = \dfrac{379.793\times10^{\frac{7.5t_{mk}}{t_3+237.29}}}{p-610.6\times10^{\frac{7.5t_{mk}}{t_3+237.29}}} \\ t_{mk} = \left\{\dfrac{1}{C_p+C_{\mathrm{pw}}x_{mk}+C_{\mathrm{ww}}\cdot[(1-b_f)x_c+b_fx_2-x_{mk}]}\right\}\cdot \\ \{(1-b_f)[C_pt_c+C_{\mathrm{pw}}t_cx_c+r_px_c]+b_f[C_pt_2+C_{\mathrm{pw}}t_2x_2+r_px_2]-r_px_{mk}\} \end{cases} \quad (8)$$

where:
b_f – TS-300 evaporator's bypass coefficient calculated from the formula – according to [12],

$$b_f=0.01364/60\ Q_p-0.03507 \quad (-) \quad (9)$$

Q_p – volume air flow at the evaporator inlet, m³/s
C_p – specific heat of dry air at constant pressure, kJ/(kg.K),
C_{pw} – specific heat of steam at constant pressure, kJ/(kg.K),
C_{ww} – specific heat of water, kJ/(kg.K),
r_p – latent heat of water evaporation, kJ/kg,
t_c – temperature of the conventional part of the cooled air at the evaporator outlet, °C
x_c – specific humidity of the contracted part of the cooled air at the evaporator outlet, kg of steam/kg of dry air,
t_2 – temperature of air at the evaporator inlet, $t_2 = t_s+\Delta t$, °C
Δt – increase of air temperature as a result of fan operation, °C. It can be determined from the dependence [13]:

$$\Delta t = \frac{\Delta_p}{\rho_d c_p 10\eta} \quad (kg/s) \quad (10)$$

x_2 – specific air humidity at the evaporator inlet equal to the specific air humidity xd at the fan inlet, kg/kg
η – fan efficiency,%. According to [13], it can be calculated for the WLE 803B fan from dependence:

$$\eta=-6.4676Q_p^2+75.427Q_p-162.32 \quad (11)$$

Δ_p – total pressure of the fan, Pa. Based on [13], the pressure of the lute fan is equal:

$$\Delta_p=-456.43Q_p^2+4883.2Q_p-8875.4 \quad (12)$$

If the air mixture does not reach saturation at the evaporator outlet, where $(1-b_f)\ x_c+b_f\ x_2 \geq x_{nmk}$, its temperature and humidity can be determined by solving the system of equations (13):

$$\begin{cases} x_{mk} = (1-b_f)x_c+b_fx_2 \\ t_{mk} = \dfrac{1}{c_p+c_{\mathrm{pw}}x_{mk}}\begin{Bmatrix}(1-b_f)[c_pt_c+c_{\mathrm{pw}}t_cx_c+r_px_c]+ \\ +b_f[c_pt_2+c_{\mathrm{pw}}t_2x_2+r_px_2]-r_px_{mk}\end{Bmatrix} \end{cases} \quad (13)$$

The air temperature tc and the specific humidity xc (corresponding to the parameters of the cooler wall) are calculated from the equations (14) or (15) below. Equation (14) applies to the condition (16) that cools air with condensation of water vapor on the surface of a recuperative heat exchanger, which is the evaporator of a TS-300 cooler. For dry air cooling (x2 <xc), the system of equations (15) is solved [11]:

$$\begin{cases} x_c = x_{\mathrm{nc}} = \dfrac{379.793\times10^{\frac{7.5t_c}{t_c+237.29}}}{b-610.6\times10^{\frac{7.5t_c}{t_c+237.29}}} \\ t_c = \dfrac{t_2(c_p+c_{\mathrm{pw}}x_2)+r_p(x_2-x_c)-\frac{N}{(1-b_f)Q_m}}{c_p+c_{\mathrm{pw}}x_c+c_w(x_2-x_c)} \end{cases} \quad (14)$$

$$\begin{cases} x_c = x_2 \\ t_c = t_2 - \dfrac{N}{(1-b_f)Q_m(c_p+c_{\mathrm{pw}}x_2)} \end{cases} \quad (15)$$

$$x_2 \geq x_c \quad (16)$$

wherein:
Q_m – dry air mass flows in the evaporator:

$$Q_m=(Q_p\ \rho_2)/(1+x_2)\ (kg/s) \quad (17)$$

ρ_2 – air density at the evaporator inlet, kg/m³
N – evaporator's thermal power of the TS-300 refrigerator, kW.

Mass stream of air flowing through the excavation (next to the air-conditioning machine) m_1:

$$\dot{m}_1 = (\dot{V}-\dot{V}_{mk})\rho_d \quad (kg/s) \quad (18)$$

where :
V_{mk}– air volume flow at the fan inlet, $V_{mk}=Q_p$, m³/s

Mass stream of air flowing through the air conditioning machine m_{mk}, kg/s,

$$\dot{m}_{mk} = \dot{V}_{mk}\rho_d \quad (kg/s) \quad (19)$$

Specific enthalpy of air at the cooler outlet h_{mk}:

$$h_{mk}=1.005t_{mk}+x(1.926t_{mk}+2500) \quad (kJ/kg) \quad (20)$$

Tab. 5. Results of calculations of the air temperature in the excavation after using the air-conditioning machine

Tab. 5. Wyniki obliczeń temperatury powietrza w wyrobisku po zastosowaniu maszyny klimatyzacyjnej

Parameter	Symbol	Unit	Value
Partial pressure of water vapour	p_{wd}	Pa	3,907
Specific humidity of air	x_d	kg/kg	0.024
Humid air density	ρ_d	kg/m³	1.17
Moist air mass stream	$\dot{m}_d$	kg/s	26.2
Dry air mass flow	$\dot{m}_{sd}$	kg/s	25.6
Specific enthalpy of air	h_d	kJ/kg	93.9
Temperature of air at the evaporator outlet	t_{mk}	°C	8.1
Specific air humidity at the evaporator outlet	x_{mk}	kg/kg	0.0065
The air volume flow at the evaporator inlet	V_{mk}	m³/s	7.08
Specific enthalpy of air at the evaporator outlet	h_{mk}	kJ/kg	24.62
Mass stream of air flowing through the air-conditioning machine	$\dot{m}_{mk}$	kg/s	8.29
Mass stream of air flowing through the excavation (next to the air-conditioning machine)	$\dot{m}_1$	kg/s	17.93
Specific air humidity after mixing air streams	x_m	kg/kg	0.019
Specific enthalpy of air after mixing air streams	h_m	kJ/kg	72.00
Dry-bulb temperature after mixed air stream	t_{sm}	°C	24.3
Partial pressure of water vapour in the exhaust air	p_{pwm}	Pa	3,030.8
Wet-bulb temperature after mixed air stream	t_{wm}	°C	24.2

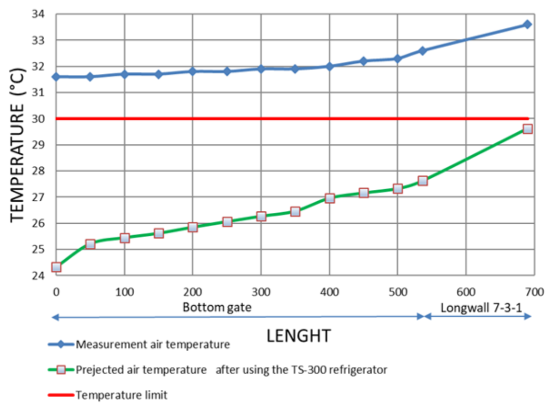

Fig. 5. The graph of air temperature changes before and after using the air conditioning machine in the bottom gate of the CGH 7-3-1 longwall

Rys. 5. Wykres zmian temperatury powietrza przed i po zastosowaniu maszyny klimatyzacyjnej w chodniku podścianowym i ściany CGH 7-3-1

Specific air humidity after mixing air streams in the excavation, x_m:

$$x_m = \frac{\dot{m}_d x_d + \dot{m}_{mk} x_{mk}}{\dot{m}_d + \dot{m}_{mk}} \quad \text{(kg/kg)} \tag{21}$$

Specific enthalpy of air after mixing air streams in the excavation h_{mk}:

$$h_m = \frac{\dot{m}_d h_d + \dot{m}_{mk} h_{mk}}{\dot{m}_d + \dot{m}_{mk}} \quad \text{(kJ/kg)} \tag{22}$$

Dry-bulb temperature mixed in the excavation, t_{sm}:

$$t_{sm} = \frac{h_m - 2500 x_m}{1.005 + 1.926 x_m} \quad \text{(°C)} \tag{23}$$

Partial pressure of water vapor in the air in the excavation p_{wnm}:

$$p_{wm} = \frac{p x_m}{0.622 + x_m} \quad \text{(Pa)} \tag{24}$$

Wet-bulb temperature (t_{wm}) of mixed air streams is determined by iterative methods on the basis of an equation:

$$p_{wm} = 610.6 \times 10^{\frac{7.5 t_{wm}}{237.29 + t_{wm}}} - 6.77 \times 10^{-4}(t_{sm} + t_{wm})p \quad \text{(Pa)} \tag{25}$$

The results of the calculations are presented in the table 5.

On the basis of the calculated temperature of air in the excavation behind the cooler, the authors carried out a forecast of the air temperature in bottom road of the CGH 7-3-1 wall using the J. Voss method [14]. The value of the projected temperature at the outlet of the wall CGH -7-3-1 is less than 30°C and is 29.6°C. Figure 5 presents a graph of changes in air temperature before and after using an air-conditioning machine in bottom road of the CGH 7-3-1 wall.

5. Summary

Ventilation in underground mines in Vietnam meets the requirements for the flow and air velocity in the underground excavation in accordance with the regulations of the Ministry of Industry and Trade. According to the regulation, the temperature at the workplace in the underground mine should not exceed 30°C. However, in summer, in Vietnam, the outside air temperature is high and is above 35°C, this causes an unfavorable increase in the air temperature in underground excavations.

To minimize the adverse effects of climatic conditions on production activities in underground coal mines, ventilation methods are used that are not always sufficient. In order to lower the air temperature at workplaces, the Vietnamese mines began to use air cooling methods using local, direct-acting air coolers.

In the CGH 7-3-1 wall of the Ha Lam mine, the air temperature in summer often exceeds the permissible value of 30°C. To lower the air temperature in the wall a direct-acting air cooler type TS-300 from Termospec Co. was used. According to calculations, the air temperature in the excavation was reduced to 24.3°C. Figure 5 shows a gradual increase in the air temperature in the excavation, but it does not exceed 30°C at the inlet to the longwall excavation. The use of the compressor system allowed to reduce the air temperature, which at the inlet to the wall reached 29.6°C and the same improve the climatic conditions in this excavation. The use of a second air cooler would allow a further reduction air temperature in the excavation.

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Dobór i obliczenia rozwiązań chłodzenia powietrza w podziemnych kopalniach węgla w Wietnamie

Obecnie wietnamskie kopalnie podziemne zostały wyeksploatowane do -500 m, w najbliższej przyszłości będą eksploatowane głębiej. Eksploatacja ma negatywny wpływ na środowisko. Działalność eksploatacji w wyrobiskach powoduje wzrost niekorzystnych czynników mikroklimatycznych, takich jak temperatura, wilgotność, promieniowanie cieplne. Zgodnie z obowiązującym wietnamskim prawem, złoża węgla mogą być eksploatowane w warunkach, gdy temperatura powietrza nie przekracza 30°C, chociaż nie zawsze jest to przestrzegane, zwłaszcza latem. W artykule przedstawiono rozwiązanie ograniczania niekorzystnego wpływu czynników klimatycznych w kopalniach oraz obliczenie parametrów obniżających temperaturę powietrza na przykładzie podziemnych kopalń węgla w Wietnamie.

Słowa kluczowe: *p\temperatura powietrza, wilgotność powietrza, chłodzenie powietrza, moc cieplna chłodnicy*