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The role, importance and impact of the methane hazard on the safety and efficiency of mining production

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Abstract

Underground mining production is an extremely important process for the economy and carried out in very difficult and complex environmental conditions. The disturbance of the balance of this environment makes it also a very dangerous process. Due to the importance of coal, mainly as an energy raw material, the process of its exploitation is carried out all over the world. The specificity of its production is mainly determined by mining and geological conditions, which determine the method of operation and the selection of machines and devices for this process. One of the most dangerous natural hazards associated with this process are ventilation hazards, including methane hazard. The reason for this threat is methane, an odorless and colorless gas, which becomes a flammable and explosive gas under certain criteria. These features make this gas a huge threat to mining operations. Its huge amounts, contained in coal seams, are released into the mine atmosphere during the exploitation process, causing a very high threat to work safety. Events related to the occurrence of methane are most often the cause of mining disasters, in which people die and the technical and mining infrastructure is destroyed. The reason for the growing methane hazard is the increasingly difficult mining conditions, and mainly the increasing depth of mining, and thus also the increase in methane-bearing capacity of the seams. Taking into account the huge impact of methane hazard on the mining process, the article discusses its impact on the safety and efficiency of this process. The results of the literature review with regard to this risk are presented and the accident statistics are presented. On the basis of actual data, an analysis of interruptions in the exploitation process related to exceeding the permissible methane concentrations was carried out in one of the mines. The problem of limiting the production process due to these exceedances is an important factor reducing the efficiency of this process. The obtained results clearly indicate that the losses resulting from these breaks deteriorate the profitability of the entire process and affect the economic efficiency of the industry. In order to effectively counteract the dangerous phenomena related to the methane hazard and to improve the efficiency of the mining production process, solutions were proposed to improve this state and the directions for further research were proposed.

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1. Introduction

One of the most common natural hazards in underground coal mining is the methane hazard (Matuszewski, 2009). Its cause is methane, an organic chemical compound that is one of the simplest saturated hydrocarbons. At room temperature, this gas is odorless, colorless and lighter than air. In the mine atmosphere, this gas rises under the roof of the excavation. It is also a gas that is inert to the respiration process, but at a higher concentration it can displace oxygen (Łukaszczyk, 2019). In underground hard coal mines, methane occurs in three forms: as free methane, gas dissolved in water, and coal-bound gas (Żyła et al., 2000; Mirek et al., 2013). Coalbed methane is a natural gas accumulated in coal as a result of sorption. Its genesis is related to the process of transformation and carbonization of organic matter (mainly plant matter) from which carbon was formed, under the influence of temperature and pressure, as well as the activity of microorganisms. There are two types of sorption: chemical and physical. The first consists in the formation of a monomolecular layer of a chemical compound on the surface of the carbon skeleton, resulting from the reaction of methane with carbon components. In the case of physical sorption, we can distinguish between: adsorption, which consists in binding methane to the carbon surface as a result of intermolecular forces, and absorption, which means the penetration of methane particles between particles of the carbon skeleton in the diffusion process. The knowledge of the sorption process makes it possible to determine the amount of gas in a given coal bed (Żyła et al., 2000). The total amount of methane contained in the coal seam is called its methane bearing capacity.

Depending on the methane content of the coal seam, four categories of methane hazard have been established. These categories are distinguished for the available seams or their parts, depending on the volumetric amount of natural origin methane contained in the weight unit in the depth of the coal body (Reg. ME, 2016). The description of the categories is presented in Table 1.

Table 1. Methane hazard categories. Own study based on (Rozp. ME, 2016)

Category	Methanol capacity calculated as pure carbonaceous substance
Category I	from 0.1 to 2.5 m^3/Mg
Category II	from 2.5 m^3/Mg to 4,5 m^3/Mg
Category III	from 4.5 m^3/Mg, to 8 m^3/Mg
Category IV*	over 8 m^3/Mg or * sudden outflow of methane or a burst methane and rock.

The operation of decks classified as category II, III or IV is subject to special control rigors. This control concerns: the composition of the mine atmosphere, the use of machinery and equipment, ventilation of mine workings, execution of blasting and drilling works. In addition, mining operations in category IV seams, in accordance with the mining regulations in force, require the use of rock mass methane drainage. In methane seams, the requirements for the machines and devices used are also stricter, due to the possibility of methane explosion during their use (Łukaszczyk, 2020).

The process of desorption, which is the reverse of sorption, makes it possible to determine what amounts of gas leave the coal at a given time. This knowledge is important from the point of view of the safety and continuity of the coal production process, because it allows to identify places particularly exposed to methane emission and eliminate them through intensive ventilation.

Methane is released into the mine workings as a result of disturbing the balance of the rock mass in the process of its exploitation. Drilling of corridors in the deposit as well as operational activities, such as mining, annealing or degassing of the seams, disturb the sorption equilibrium as a result of lowering the pressure of the gas contained in the deposit. As a result, there is a slow release of methane, which forces the gas to migrate towards the mine workings. Free methane flows into the workings, causing an explosion and fire hazard as well as an oxygen-free atmosphere (Łukaszczyk, 2019). It is this type of gas that poses a huge threat to the mining staff, and can also cause the discontinuity of coal production and huge material losses (Matuszewski, 2009). Table 2 summarizes the events related to the methane hazard in 2008-2022. The analyzed data show that during this period there were 45 events in which a total of 180 people suffered, including 45 fatal (WUG, 2022).

Table 2. List of events related to the methane hazard in hard coal mines. Own study based on (WUG, 2022)

year	number of events	number of light accidents	number of serious accidents	number of fatal accidents
2008	2	13	5	8
2009	3	13	25	20
2010	1	2	0	0
2011	3	2	9	3
2012	0	0	0	0
2013	7	6	0	0
2014	4	10	15	5
2015	3	4	0	0
2016	5	1	0	0
2017	3	0	0	0
2018	2	0	0	0
2019	4	0	0	0
2020	3	3	0	0
2021	3	0	0	0
2022	2	20	7	9
SUM	**45**	**74**	**61**	**45**

With the right concentration of methane and the right amount of oxygen, this gas and air create a flammable or explosive mixture. At a concentration of up to 5%, methane burns out smoothly in contact with a thermal source. At a gas concentration in the range of 5.0% - 15%, methane forms an explosive mixture with the air. The strongest explosion occurs with a methane mixture of 9% concentration and oxygen content over 12%. We call this concentration stoichiometric. Above 15% methane, the mixture is flammable. Of course, for any of these events to occur, an energy impulse must occur. The exact explosion limits are shown in the Coward methane explosion triangle shown in Fig. 1.

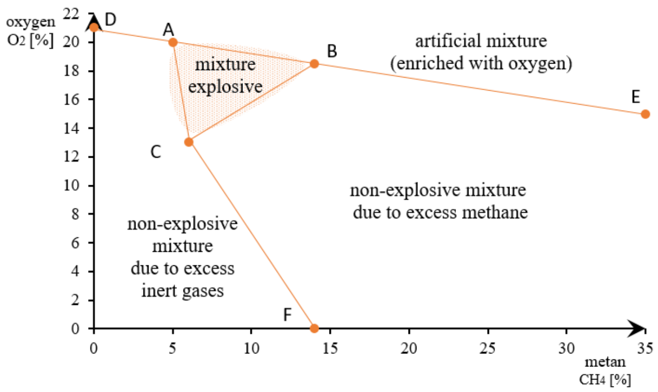

Fig. 1. Coward's triangle of explosiveness. Own study based on (Coward et al. 1952)

The area enclosed by the ABC triangle defines the concentration range for which an explosive mixture of methane is formed. In the remaining spaces, non-explosive mixtures are formed due to too little or too much methane or oxygen. It is impossible to obtain a mixture of methane and air in the area above the explosion triangle. The status of the mixture in any given space may change dynamically, for example as a result of: limiting or increasing the air supply to workings, changing the ventilation system, reorganizing mining works or changing the technology of exploitation.

Depending on the maximum concentration of methane that may occur in the excavation, there are three levels of methane explosion hazard:

- degree "a" in the case when the accumulation of methane in the air greater than 0.5% is excluded,
- stage "b" if, under normal ventilation conditions, the accumulation of methane in the air greater than 1.0% is excluded,
- degree "c" if, even in normal ventilation conditions, the accumulation of methane in the air may exceed 1.0%.

The present concentration of methane determines the preventive measures to be taken in order to combat the methane hazard. In the excavation where the concentration of methane in the air is more than 2%, the electrical network is immediately shut down and the machines and devices are immobilized, which results in the interruption of the production process, and thus a decrease in the efficiency of this process. In such a situation, the traffic supervisor is notified and additional measurements are made in order to determine the cause of exceeding the methane concentration in the air, the size of the accumulation of methane and the places of methane outflow. In the excavation, where the concentration of methane in the air is more than 3%, people are additionally withdrawn from the endangered workings and the entrances to the endangered workings are secured. The main preventive action is to actively combat the accumulation of methane according to the rules defined by the manager of the mining plant operations. The return of people to the workings and the resumption of interrupted works are permissible only when the methane concentration in the air is less than 2.0% (Szlązak et al. 2010; Rozp. ME, 2016).

2. Mining production efficiency

Methane trapped in the rock mass, rocks and coal is released at almost every stage of coal production and transport. The technology of this production, according to the definition of the workability of the rock, consists in detaching the lumps of coal from the body of the mining wall. For this purpose, longwall shearers, streams or explosives are used. Small pieces of coal go directly to the scraper conveyors and then to the belt conveyors, which are transported to the shaft. Larger lumps are crushed in mining crushers. The mined coal is brought to the surface by means of vertical shafts. At each of these stages, the coal grinds, cracks and crumbles, releasing the methane contained in it.

After selecting the coal, a free space is created, which is filled by the fall of roof rocks (it is rarely filled with filling). In the process of the collapse of tropic rocks, a very important role is played by the mechanized mining housing, which is part of the mechanized longwall complex. Commonly used in Poland, the caving system causes the formation of rock rubble behind the mining support, which is a porous and permeable medium. Due to these features, methane can accumulate in goaf from the overhead and / or underneath decks and from the coal left behind. This methane, depending on the ventilation system used, can be displaced deep into the goafs or get out to mine workings. The behavior of this methane also depends on the ventilation parameters of the air in mining excavations. Unfortunately, methane may also play a significant role in its concentration in longwall and under-wall workings. According to the regulations in force, 5 m / s is allowed as the maximum air velocity in the wall. Methane, as a gas lighter than air, accumulates in the upper part of the wall, most often at the entrance to the overwrap. It is in this zone that the most dangerous concentrations of this gas occur. The most important methane concentration sensor is also installed there. Fresh air, on the other hand, is transported from the bottom (under-wall heading) up (over-wall heading), so that the methane is safely removed from the exploitation area.

One of the most important problems is the infarction line already mentioned. Rocks fall uncontrollably, creating goafs of varying permeability. This can result in sudden outflows of sometimes large amounts of methane into the working space. In this situation, the methane sensor may react to exceeding the permissible methane concentration in this area. Exceeded concentrations may last for a very short time, however, activities related to the restoration of working conditions significantly extend the downtime of the production process. These shutdowns ultimately reduce the efficiency of mining production.

Efficiency is a concept that is quite difficult to define unequivocally. In the literature, you can find synonyms such as efficiency, effectiveness, productivity and efficiency. However, the terms are not always interchangeable. Efficiency should be used to determine the amount of production that is actually being achieved. Effectiveness describes the degree of accomplishment of the company's goals. Productivity means the quantity of production obtained from a unit of a given resource. On the other hand, the concept of efficiency can be described as the ratio of production to inputs (Romanowski, 2017). Although efficiency and effectiveness do not always measure and mean the same, efficiency can be represented as the ratio of the effect obtained to the expenditure incurred:

$$E=e/n \tag{1}$$

where:

E – efficiency, e – effects, n – outlays.

Another popular interpretation of efficiency is the percentage approach to the degree of utilization of the machine park. The measure of effectiveness is then the OEE Overall Equipment Effectiveness indicator, combining (in the form of a product) indicators of availability, use and quality (Brodny, 2015, Loska, 2017, Romanowski, 2017): The method of calculating the OEE indicator is presented in Table 3.

Table 3. Components of the OEE. Own study based on (Loska, 2017)

$OEE = A \cdot E \cdot Q \quad (2)$		
A - Availability	**E – Efficiency**	**Q – Quality**
$A = APT/PBT \quad (3)$	$E = \frac{PRI}{\left(\frac{APT}{PQ}\right)} = \frac{PRI \cdot PQ}{APT} \quad (4)$	$Q = \frac{GQ}{PQ} \quad (5)$
APT – Actual Production Time PBT – Planned Busy Time	PRI – Planned Run time per Item PQ - Quantity of manufactured Products APT – Actual Production Time	GQ - Quantity of Good products PQ - Quantity of manufactured Products

Despite the commonness of such an approach to calculating the efficiency of machines, in practice there are various approaches to determining its value and interpreting the results. An example is the division into global and technical OEE. In the first case, the planned machine working time (PBT) does not take into account the production plan and the resulting load. In the second case, PBT is determined based on the existing production plan. Regardless of the chosen approach, specific production data are required to determine the value of the indicator, and the correctness of the calculated indicator largely depends on the quality and reliability of the data obtained (Brodny, 2015, Loska, 2017, Romanowski, 2017).

In mining enterprises, telemetry systems are responsible for the correctness and completeness of collected data. These systems fulfill many functions, such as (Łukaszczyk, 2019, Stecuła, 2017):

- measure the concentrations of gases and other physical parameters,
- inform about the local value of the measured parameter and alarm about exceeding the threshold values,
- turn off the electricity supply of machines and devices locally,
- transmit the measurement results to the surface,
- visualize, record and archive measurement data,
- they signal damage to selected system component

Due to the methane hazard, the most important function of the telemetry system is the disconnection of electricity in the event of exceeding the permissible methane concentrations. The purpose of this activity is to prevent the initial ignition or explosion of methane resulting from the operation of electrical machinery and devices. Pursuant to the regulations in force, the electricity of machines and devices operating in the area of hard coal production is disconnected when the methane concentration is exceeded 2%.

For the purpose of this research, data was obtained from one of the currently functioning mining enterprises. On their basis, the analysis of events related to the exceedance of the permissible methanol concentrations was performed. A selected fragment of the obtained data is presented in Fig. 2.

The analyzed research period covered 30 working days. During this time, there were 82 events related to exceeding the permissible methane concentration. The most frequent cause of these events was the increased release of methane as a result of the fall of roof rocks in the cave. The total time of the violations that occurred was slightly over 40 hours. However, the time related to the restoration of appropriate working conditions and the commissioning of machinery and equipment amounted to over 121 hours. The results of the analysis of the obtained data are summarized in Table 4.

Particularly disturbing is the fact that even the shortest occurrence of exceeding the permissible methane concentration generates long interruptions of the entire mining production process. However, it is difficult to determine a reliable relationship between the time of exceedances and the time of restoring working conditions. The shortest time of exceeding the 2% methane concentration, lasting only 5s, caused the process to be stopped for only 9 minutes and 15 seconds. On the other hand, the exceeding of 7 seconds stopped the operation process for 5 minutes and 21 seconds.

7	L. p	Nr	Adres Zabudowy	Próg	Czas prze	wył. energ	Ma	Przyczyna
8	1	516	Up.Vlz bad./504 do 10m na płn. od frontu śc.	2,0%	0:00:13	0:30:46	3,2	wzmożone wydzielanie CH4 po odpaleniu MW
23	16	602	łz badawczy, pokład 504- do 6m od czoła przodka wyrob.w miej. najw.nagrom	2,0%	0:22:40	0:26:47	1,3	zakłócenie wentylacji - prace na lutniociągu
70	63	405	Up.Vlz bad.pokład 504, do 2m na płn.od linii likwidacji wyrobika.	2,0%	0:00:05	0:05:51	2,1	wzmożone wydzielanie CH4 - urabianie
95	88	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:06	0:08:43	2	wzmożone wydzielanie CH4 - urabianie
96	89	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:10	0:10:38	1,3	wzmożone wydzielanie CH4 - opad skał stropowych w zawale
121	114	516	Up.Vlz bad./504 do 10m na płn. od frontu śc.	2,0%	0:03:01	0:14:12	2,1	wzmożone wydzielanie CH4
132	125	405	Up.Vlz bad.pokład 504, do 2m na płn.od linii likwidacji wyrobika.	2,0%	0:00:05	0:20:01	2,1	wzmożone wydzielanie CH4 - rabunek
139	132	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:05	0:13:11	2	wzmożone wydzielanie CH4 - opad skał stropowych w zawale
145	138	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:10	0:10:06	2	wzmożone wydzielanie CH4
159	152	405	Up.Vlz bad.pokład 504, do 2m na płn.od linii likwidacji wyrobika.	2,0%	0:00:31	8:04:42	2,1	wzmożone wydzielanie CH4
160	153	405	Up.Vlz bad.pokład 504, do 2m na płn.od linii likwidacji wyrobika.	2,0%	0:00:04	0:29:11	2	wzmożone wydzielanie CH4 - opad skał stropowych w zawale
161	154	405	Up.Vlz bad.pokład 504, do 2m na płn.od linii likwidacji wyrobika.	2,0%	0:00:16	0:04:46	2,1	wzmożone wydzielanie CH4 - opad skał stropowych w zawale
162	155	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:03:47	0:07:43	2,7	wzmożone wydzielanie CH4 - opad skał stropowych w zawale
163	156	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:08	0:12:36	2,1	wzmożone wydzielanie CH4 - opad skał stropowych w zawale
170	163	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:06	0:08:57	2,3	wzmożone wydzielanie CH4 - rabunek
175	168	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:05	0:06:12	2	wzmożone wydzielanie CH4 - rabunek
176	169	511	Up.Vlz bad./504 na ociosie przeciwleg. do wyrob. śc., na wys.okna ściany.	2,0%	0:00:05	0:06:32	2	wzmożone wydzielanie CH4 - opad skał stropowych w zawale

Fig. 2. A fragment of the obtained data from a mining company.

Table 4. Summary of the results of the analysis of break times caused by exceeding the permissible methane concentrations in the longwall Own study

Analyzed number of events	**82**
The sum of the time of exceeding the permissible concentrations	**40h 41 min**
Total downtime of the mining production process	**121h 40 min**
The difference in the time of exceedances and downtime of the production process	**80h 59min**
Longest overshoot time permissible methane concentration	**7h 42 min**
Shortest crossing time permissible methane concentration	**5 s**
The longest downtime of the coal production process	**19 h 30 min**
The shortest downtime of the coal production process	**2 min 8 s**
Average duration of the exceedance permissible methane concentration	**49 min**
Average downtime of the hard coal production process	**1h 48 min**
The longest recovery time	**13h 48 min**
The shortest time to restore working conditions	**2 min**
Decline in efficiency due to downtime (availability of machines)	**22%**

Another proof of the lack of systematization of the restoration of working conditions is the fact that 6 events occurred, which lasted exactly the same, namely 8 seconds, and each of them was the cause of stopping the process, and these stops lasted, respectively: 3min 47s, 2min 8s, 20min 2s, 13min 8s , 6min 20s and 6min 53s.

In order to illustrate the differences in the discussed times of exceeding the permissible methane concentrations and breaks in the hard coal production process, a list of these events was prepared, which is presented in Fig. 3.

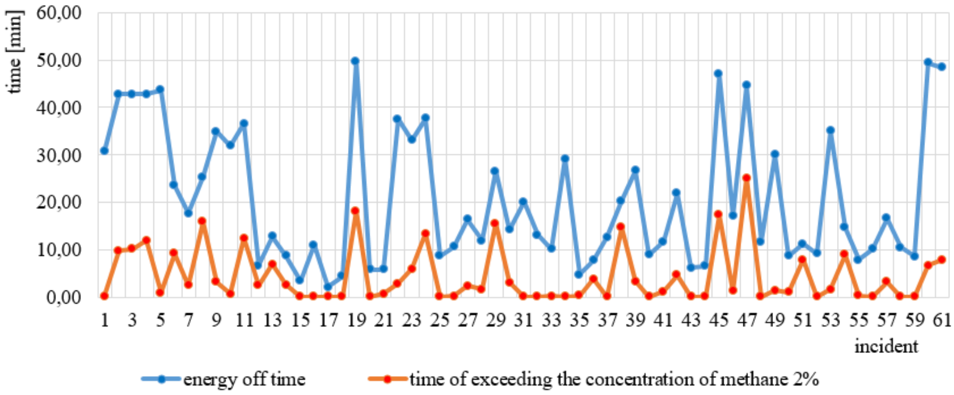

Fig. 3. List of selected exceedance times permissible methane concentrations and breaks in the production of hard coal

In order to maintain the legibility of the drawing, the events with downtime not exceeding 60 minutes were listed.

Such frequent downtime of the mining production process is caused by preventive measures (disconnection of power supply) aimed at ensuring safety in mining excavations during the occurrence of exceeded allowable methane concentrations. This safety is very important for the health and even life of employees and for ensuring the functionality of the mining infrastructure. However, it is disturbing that the occurrence of these events causes a reduction in the efficiency of the entire mining process. When analyzing the discussed data in relation to efficiency (as the value of OEE index), one can notice a decrease in the availability of machines in the mining production process by 6% and their use by 18%. These components determine the final efficiency of the analyzed process, which in this case fell by 22%.

It is worth mentioning that the decrease in efficiency is associated with a decrease in hard coal production, and thus affects the efficiency of the entire process. In the case of the mining industry, it is associated with large economic losses.

3. Proposed solutions and further research directions

Underground hard coal mining continues to be one of the priority sectors of the Polish economy. This sector generates over 85 thousand. jobs in mines and about 400 thousand. jobs in the vicinity of the mining industry. Mining plays a key role in Poland's energy policy, in the broadly understood national energy sector. It is worth mentioning that Poland has rich coal resources, which for many years may be a stabilizer of the energy security of the country and the European Union. However, it should be remembered that the production of hard coal belongs to one of the most difficult and dangerous industries. Currently, coal seams in Poland are highly methane. As a result, excavations in these seams and the very process of their exploitation are exposed to high methane emissions. As a result of coal mining and disturbance of the equilibrium in the rock mass, there may therefore be high concentrations of methane in mining excavations. Such concentrations may ignite or explode methane. Both of these phenomena are among the most dangerous in mining, posing a huge threat to the entire mining process (Olszewski, 2017; Palka, 2021).

In order to ensure work safety and the efficiency of the coal production process, it is necessary to diagnose and forecast phenomena accompanying mining production. In terms of ventilation hazards, undoubtedly one of the most dangerous, conducting direct research of these phenomena in real conditions is very difficult and dangerous, as well as expensive, which significantly limits the possibilities of their conduct. In many cases, such research is practically impossible to carry out, and the course of many unfavorable phenomena can be described on the basis of their effects only roughly. For this reason, model studies are very important, as they enable the analysis of many phenomena based on various types of models that are able to reproduce real conditions with increasing accuracy (Brodny et al. 2021; Tutak, 2021).

Currently, one of the most frequently and widely used methods for modeling ventilation hazards is numerical fluid mechanics. The CFD method can be used to study phenomena related to the flow of liquids and gases, mass and heat transfer, as well as combustion processes. It consists in solving a system of differential equations that describe the analyzed phenomena. CFD is based on the equations describing the pressure and flow velocity fields - on the continuity equation and the Navier-Stokes equations. Numerical fluid mechanics also enable the analysis of complex physical processes such as: heat conduction, convection, coupled heat exchange between liquids and solid materials surrounding them, and radiation. The main goal of the CFD method is to determine the reality using an appropriate mathematical model and to visualize what will happen under certain circumstances (Xu G, 2017; Wendt, 2008). The possibility of using the CFD technique in forecasting the distribution of methane concentration in workings has been described in numerous scientific papers (Brodny at al., 2015; Małachowski, 2015; Brodny at al., 2016; Brodny at al., 2017; Brodny at al. , 2018; Tutak et al., 2018a; Tutak et al., 2018b).

Another interesting form that enables the analysis of ventilation conditions is the use of artificial intelligence in the problems of diagnosing and forecasting gas hazards in mining. In the literature, the most frequently mentioned in this field are artificial neural networks, expert systems and evolutionary algorithms (Knosal, 2002; Lipski et al. 2014). The current state of knowledge and access to modern IT and programming tools allow the implementation of advanced systems in mining. A significant advantage of these systems is the ability to quickly respond to changes in methane emission and the possibility of continuous learning based on subsequent measurement data imported by the system. The process of continuous improvement enables obtaining reliable results, and thus can effectively support the management process of the ventilation system of a given area of hard coal production (Broja et al., 2015; Mróz et al., 2016). Due to the dynamic development of technology, the availability of advanced application solutions and computer hardware, it seems reasonable to invest and conduct research towards a wider use of modern solutions in mining production processes and to support their work with additional analyzes and tests.

4. Summary

Underground hard coal production is essential for the development of the economy and the shaping of global markets. Thus, it is necessary to further efficiently exploit this raw material. However, the multi-year restructuring of mines has led to the concentration of extraction, which in practice means the necessity to deepen the mining exploitation areas, and thus the intensification of unfavorable and dangerous phenomena. As a result of the deepening of the workings and the exploitation of deeper and deeper seams, an increase in their methane-bearing capacity is observed, which directly influences the increase of the methane hazard. As a result of the activities carried out during the coal production process, the rock mass structure is disturbed and methane is released to the areas covered by the exploitation. The occurrence of exceeding the permissible methane concentrations is the most common cause of interruptions in the coal production process, which significantly reduces its efficiency. Even minor exceedances lasting a few seconds suspend the production process for a few or even several minutes. The time necessary to restore working conditions after the occurrence of such an event significantly reduces the availability and use of mining machines. It should be remembered that both of these factors have a direct impact on the efficiency of the entire process.

Uncontrolled accumulation of methane can also cause ignitions or explosions of this gas and coal dust. Most often these are catastrophic phenomena, in which employees die and the mining infrastructure is irretrievably destroyed. Their direct research is very limited or even impossible. Such possibilities are provided by model studies and computer simulation. One of the most advanced methods of modeling these phenomena is CFD. In terms of ensuring the safety and thus the efficiency of the hard coal production process, this method seems to be an excellent solution. Research, in which various methods can be combined, also offers enormous potential. Better and better industrial automation systems or automatic methane measurement systems practically continuously recording ventilation parameters in mining excavations create the possibility of using these data sets and using them in modeling the phenomena occurring.

Assuming that in the near future, hard coal mining will continue to remain one of the most important sectors of the world economy, it is reasonable to undertake all research and actions to ensure the safety and thus effectiveness of this industry.

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Reference

Brodny, J., Tutak, M., 2018. Analysis of Methane Hazard Conditions in Mine Headings. Technical Gazette 25, 1, 271-276.

Brodny, J., Tutak, M., 2016. Determination of the zone endangered by methane explosion in goaf with caving of longwalls ventilated on “Y” system. Management Systems in Production Engineering, 4(24), 247-251.

Brodny, J., Tutak, M., 2015. Numerical analysis of airflow and methane emitted from the mine face in a blind dog heading. Management Systems in Production Engineering, 2(18), 110-118.

Brodny, J., Tutak, M., 2017. Symulacja numeryczna jako narzędzie wspomagające ocenę zagrożenia metanowego w kopalni węgla kamiennego. Zeszyty Naukowe Politechniki Śląskiej, Seria Organizacja i Zarządzanie, 100, 45-59,

Brodny, J., 2015. Koncepcja wykorzystania modelu efektywności całkowitej do analizy pracy maszyn górniczych. Systemy Wspomagania w Inżynierii Produkcji.

Brodny, J., Tutak, M., 2021. Applying computational fluid dynamics in research on ventilation safety during underground hard coal mining: A systematic literature review. Process Safety and Environmental Protection 151, 373-400.

Broja, A., Małachowski, M., Felka, D., 2015. Monitorowanie parametrów odmetanowania w kontekście ich wpływu na wartości metanowości w rejonie ściany. Konferencja Naukowo-Szkoleniowa: Zasilanie, telemetria i automatyka w przemyśle wydobywczym „Innowacyjność i bezpieczeństwo” EMTECH 2015, 274-283.

Coward, H.F., Jones, G.W., 1952. Limits and flammability of gases and vapors, US Bureau of Mines Bulletin 503.

Knosala, R., 2002. Zastosowanie metod sztucznej inteligencji w inżynierii produkcji. Wydawnictwo Naukowo-Techniczne, Warszawa.

Lipski, J., Pizoń, J., 2014. Sztuczna inteligencja w inżynierii produkcji. W: Monografia Innowacyjne metody w inżynierii produkcji, 11-24, Politechnika Lubelska, Lublin.

Loska, A., 2017. Analytical model of the exploitation policy assessment of technical network systems-case study. Systemy Wspomagania w Inżynierii Produkcji, 6.

Łukaszczyk, Z., 2020. Methane - fuel gas. Opportunities and threats. New Trends in Production Engineering. Sciendo.

Łukaszczyk, Z., 2019. Zagrożenie metanowe - przegląd literatury. Systems Supporting Production Engineering, 8(1), Górnictwo-perspektywy i zagrożenia, 300-313.

Małachowski, M., 2015. Zastosowanie oprogramowania wykorzystującego obliczeniową mechanikę płynów CFD do analiz zjawisk wentylacyjnych w kopalniach. Konferencja Naukowo Szkoleniowa: Zasilanie, telemetria i automatyka w przemyśle wydobywczym „Innowacyjność i bezpieczeństwo” EMTECH, 284-296,

Matuszewski, K., 2009. Najważniejsze zagrożenia powodujące katastrofy w polskich podziemnych zakładach górniczych. Bezpieczeństwo Pracy: nauka i praktyka, 25-28.

Mirek, A., Katan, D., 2013. Zagrożenie metanowe w polskim górnictwie węgla kamiennego w ostatnim dwudziestoleciu i perspektywy kształtowania się poziomu tego zagrożenia w najbliższych latach. Materiały Szkoły Eksploatacji Podziemnej, Kraków 2013.

Mróz, J., Broja, A., Felka, D., Małachowski, M., 2016. Struktura systemu monitorowania i analiz on-line zaburzeń oraz zagrożeń metanowych w sieci wentylacyjnej kopalni. Przegląd Górniczy, 9, 28-36.

Olszewski, J. 2017. Znaczenie górnictwa węgla kamiennego dla gospodarki i regionów oraz bariery jego funkcjonowania, GIPH, Surowce dla gospodarki Polski, Kraków, 2017.

Palka, D., 2021. A methane emission from hard coal mines in Poland in 2009-2019 and its business use, Proceedings of the 37th International Business Information Management Association Conference IBIMA.

Romanowski, M., Nadolny, K., Bałasz, B., 2017. Metody analityczne w ocenie efektywności procesów produkcyjnych. In Innowacje w zarządzaniu i inżynierii produkcji.

ROZPORZĄDZENIE MINISTRA ENERGII z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych

Stecuła, K., Brodny, J., Tutak, M., 2017. Informatics platform as a tool supporting research regarding the effectiveness of the mining machines’work; CBU International Conference Proceedings, 5.

Szlązak, N., Korzec, M., 2010. Zagrożenie metanowe oraz jego profilaktyka w aspekcie wykorzystania metanu w polskich kopalniach węgla kamiennego. Górnictwo i Geoinżynieria, 34, 163-174.

Tutak, M., Brodny, J., 2018a. Analysis of the Impact of Auxiliary Ventilation Equipment on the Distribution and Concentration of Methane in the Tailgate, Energies. 11, 3076, DOI: 10.3390/en11113076.

Tutak, M., Brodny, J., 2018b. Prognozowanie rozkładu stężenia metanu w wyrobiskach górniczych z wykorzystaniem badań modelowych oraz pomiarów w warunkach in situ. Automatyzacja Procesów Dyskretnych. Teoria i Zastosowania, 1, 219-228, Wydawnictwo Politechniki Śląskiej, Gliwice.

Tutak, M., 2021. The Application of Numerical Methods and IT Tools to Environment and Safety Engineering. A special issue of Sustainability (ISSN 2071-1050), Environmental Sustainability and Applications.

Wendt, J.F., 2008. Computational fluid dynamics: an introduction. Springer Science & Business Media, 5-15.

Wyższy Urząd Górniczy, Niebezpieczne zdarzenia – metan, 2022, dostęp online 20.05.2022 (www.wug.gov.pl/bhp/zdarzenia)

Xu, G., Luxbacher, K.D., Ragab, S., Xu, J., Ding, X., 2017. Computational fluid dynamics applied to mining engineering: A review. International Journal of Mining, Reclamation and Environment, 31(4), 251-275.

Żyła, M., Praca zbiorowa: Układ węgiel kamienny-metan w aspekcie desorpcji i odzyskiwania metanu z gazów kopalnianych. Nauka i Technika Górnicza, Uczelniane Wydawnictwo Naukowo-Dydaktyczne AGH, Kraków 2000.

甲烷危害的作用、重要性和影响 关于采矿生产的安全和效率

關鍵詞
采矿生产过程
流程效率
硬煤开采
甲烷危害
数值建模
和模拟

摘要
地下采矿生产对经济来说是一个极其重要的过程，并且在非常困难和复杂的环境条件下进行。这种环境平衡的扰乱使得它也是一个非常危险的过程。由于煤炭的重要性，主要作为能源原料，其开采过程在世界各地进行。其生产的特殊性主要取决于采矿和地质条件，这些条件决定了该过程的操作方法和机器设备的选择。与此过程相关的最危险的自然危害之一是通风危害，包括甲烷危害。造成这种威胁的原因是甲烷，一种无色无味的气体，在一定标准下会变成易燃易爆气体。这些特征使这种气体对采矿作业构成巨大威胁。其大量存在于煤层中，在开采过程中会释放到矿井大气中，对生产安全造成极大威胁。与甲烷发生相关的事件通常是采矿灾难的原因，其中人员死亡，技术和采矿基础设施被破坏。瓦斯危害增加的原因是开采条件越来越困难，主要是开采深度的增加，煤层的瓦斯承载能力也随之提高。考虑到甲烷危害对采矿过程的巨大影响，文章讨论了其对这一过程的安全性和效率的影响。介绍了有关该风险的文献回顾结果和事故统计数据。在实际数据的基础上，对其中一个矿山进行了与超过允许的甲烷浓度有关的开采过程中断的分析。由于这些超标而限制生产过程的问题是降低该过程效率的重要因素。获得的结果清楚地表明，这些中断造成的损失恶化了整个过程的盈利能力，并影响了行业的经济效益。为了有效应对与甲烷危害相关的危险现象，提高采矿生产过程的效率，提出了改善这种状况的解决方案，并提出了进一步研究的方向。