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METHANE – FUEL GAS. OPPORTUNITIES AND THREATS

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INTRODUCTION

The intensive restructurization of hard coal mining in Poland since the beginning of the 1990s (Lukaszczyk Z., 2017) is inevitably related to the decommissioning of subsequent mines (Lukaszczyk Z., Popczyk M. 2017), most of which are characterized by high methane content. With the descent of mining to ever greater depths, the mines of the Upper Silesian Coal Basin have become highly methane mines (Łukaszczyk Z., 2019). The total amount of methane is composed of the amount emitted directly to the ventilation air in mines (ventilation methane) and included in the demethylation system, isolated from the ventilation air. Along with the depth, there was an increase in methane content in coal deposits, forcing the need to increase the intensity of demethylation (Badura H., Łukaszczyk Z. 2020). Methane from the demethylation system is only partially utilized. In case of its use, the safety aspect is maintained. However, the question arises as to what to do with the methane after its extraction and removal to the surface. An important issue is also methane, which could not be extracted by demethylation. This gas, along with the used ventilation air, is released irreversibly into the atmosphere. In the paper, attention was drawn both to the threats resulting from the direct emission of methane to the atmosphere and the opportunities for its economic use.

Polish underground mining is characterized by complex geological and mining conditions and a number of threats (Łukaszczyk Z. 2019, Łukaszczyk Z., Badura H. 2017). The majority of hard coal mines in Poland, including all mines belonging to Jastrzębska Spółka Węglowa S.A. are highly methane mines. This means that the air flowing out of mine shafts contains a certain concentration of methane, the size of which depends on the amount of air and the amount of methane flowing into it, which is emitted into the mine excavations. The concentration of methane in air shafts, in accordance with the currently binding regulations (Regulation) cannot exceed 0.75%. The part of methane present in the rock mass, thanks to the application of demethylation system, is captured in the pipelines of demethylation system and discharged to the surface (Berger J.,

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Nawrat S. 2011), which limits the amount of methane flowing into the ventilation air. This methane is utilized to some extent.

Methane from coal deposits is also emitted after decommissioning of the mines and can be used economically (Łukaszczyk Z. 2019, Nawrat S. el al. 2011). The potential for discoverable methane resources from decommissioned hard coal mines increases along with the decommissioning of subsequent mines.

The total amount of methane that is released per minute into the mine's excavations and into the demethylation system is called absolute or total methane (Kozłowski B, Grębski Z. 1982). The amount of methane emitted in a specific period of time in the mine (e.g. during one year or month) converted into a ton of extraction in that period is called relative methane. The amount of methane emitted to the ventilation air converted into a unit of time is called ventilation methane. The amount of methane included in the demethylation system converted into a unit of time is called the methane content of the demethylation system or in other words the methane content of demethylation.

The methane content of mines is variable in time, which is caused by the uneven methane content of coal deposits and surrounding rocks in the deposit space, as well as the intensity of exploitation (Badura H. 2003; Roszkowski J., Szlązak N. 1999).

METHANE EMISSIONS FROM ACTIVE MINES

In 2019, 806.949.7 thousand m^3 of methane (absolute methane content) was released from the rock mass under the influence of hard coal mining, which means that on average 1.535.3 m^3 of this valuable fuel gas (SRK 2020) was released per minute. In 2015-2019, the amount of methane released per ton of extracted net coal (relative methane content) ranged from 12.9 to 14.5 m^3 CH_4/t. In 2019 it was 13.09 m^3/t. In turn, the average methane demethylation efficiency in 2019 was 37.5%, i.e. an increase of 2.9% compared to 2018. The average efficiency of the utilization of extracted methane in 2019 amounted to 62.8% (decrease by 1.3% in relation to 2018) (WUG 2020).

The total methane emission to the atmosphere in 2019 amounted to over 611 million m^3, of which over 506 million m^3 in ventilation and over 105 million m^3 in surface methane released after extraction at demethylation stations (Data ARP in Katowice).

UTILIZATION OF METHANE EXTRACTED IN SURFACE DEMETHYLATION STATIONS

Methane from coal deposits is a very valuable fuel – with a calorific value of about 50 MJ/kg and, on the other hand, a greenhouse gas with greenhouse potential 23 times higher than carbon dioxide (Annual EU Greenhouse Gas Inventory and Inventory Report 2019). The total amount of methane extracted in surface demethanation stations of hard coal mines in Poland in 2019 was 300.773.5 thousand m^3, of which only 195.556.2 thousand m^3 were utilized and the rest was emitted irreversibly to the atmosphere. It should be noted that the methane extraction with demethylation system, as well as the demand for methane utilization products (mainly heat) were not stable. Also not all mines, to a large extent regardless of their management, are not adequately equipped with installations for methane disposal. For these reasons, only a part of the methane captured by the demethylation system was used productively. According to the analyzed data, hard coal mines used only 47 110.1 thousand m^3 of extracted methane for their own needs, from which they produced 147 488 MWh of electricity and 435 029 GJ of thermal energy, while they sold 148 446.1 thousand m^3 of this valuable fuel to industrial customers. Figure 1 graphically presents the quantities of methane extracted and utilized in 2019.

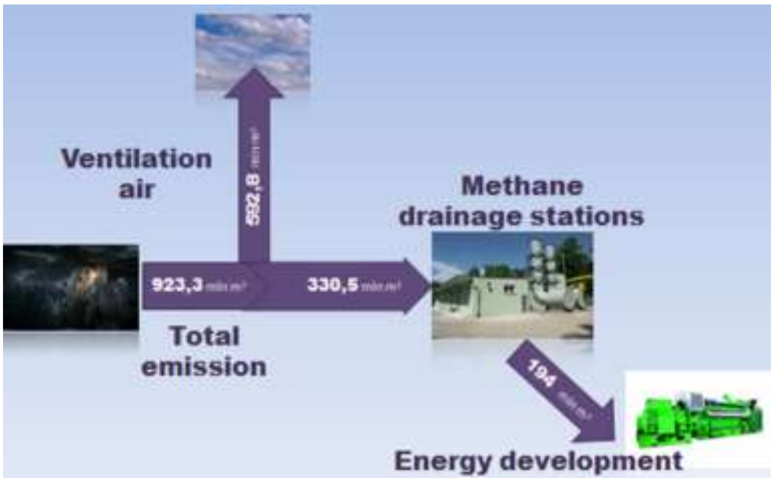

Fig. 1 Total methane emissions and utilization in 2019

Source: Own elaboration

The presented material shows that the inclusion of methane in the process of mine demethylation should be increased, especially during the exploitation demethylation or the introduction of new technologies of advance demethylation. Moreover, a detailed analysis of the reasons for not using 100 % of the extracted methane in the process for which the mines incurred high costs should be carried out. It can be estimated that the value of this unused fuel could amount to PLN 100 to 200 million.

METHANE FROM AIR SHAFTS – VAM

The vast majority of this valuable energy resource was emitted irreversibly into the atmosphere. Methane from coal deposits is emitted to the atmosphere with air through air shafts. The calorific value of methane-air mixture, which is the mixture of methane and air discharged through air shafts from hard coal mines into the atmosphere depends mainly on the concentration of methane, as presented in Table 1.

The basic – very large barrier for the use of methane for energy purposes, is its low concentration in the ventilation air amounting to about 0.3% on average in Poland – which gives a very low calorific value of the mixture with air amounting to about 0.15 MJ/kg and, according to the regulations, the maximum concentration of methane in the shaft may be 0.75%, which gives a calorific value of about 0.375 MJ/kg.

Table 1 Methane concentration and calorific value

Methane concentration in the air in the shaft, %	Calorific value of gas MJ/m^3 100% CH_4 = 35,73 MJ/m^3	Calorific value of gas MJ/kg 100% CH_4 = 51,04 MJ/kg
0.0	0.0	**0.0**
0.1	0.03573	**0.04980**
0.2	0.07146	**0.09959**
0.3	0.10719	**0.14993**
0.4	0.14292	**0.19919**
0.5	0.17865	**0.24898**
0.6	0.21438	**0.29874**
0.7	0.25011	**0.34885**
0.8	0.28584	**0.39838**
0.9	0.32157	**0.44818**
1.0	0.35730	**0.49797**
1.1	0.39303	**0.54777**
1.2	0.42876	**0.59757**
1.3	0.46449	**0.64737**
1.4	0.50022	**0.69717**
1.5	0.53595	**0.74696**
1.6	0.57168	**0.79676**
1.7	0.60741	**0.84656**
1.8	0.64314	**0.89636**
1.9	0.67887	**0.94616**
2.0	0.71460	**1.00013**

Source: Own elaboration

The concentration of methane in the air-methane mixture intended for combustion may be increased by adding methane extracted mainly from the demethylation of coal deposits or by appropriate changes in the amount of air output in the mine.

Scientific research and practical experience, especially in recent years, has allowed to develop many devices and technologies enabling economic use of the extracted methane in heating and power installations.

It is possible to distinguish between the basic directions of scientific and industrial research enabling economic use of methane:

- methane concentration (increasing concentration) by purifying (removing) air and other gases,
- methane combustion from ventilation air in boilers along with other fuels such as coal,
- oxidation in reversible reactors for heat production,
- oxidation in reversible and flow catalytic reactors for heat production,
- combustion in gas turbines.

Numerous research and development studies carried out in recent years have led to the development of many technologies and devices that enable the utilization of methane from ventilation air as fuel.

The developed installations allow the operation of devices when the concentration of methane in the ventilation air is as high as 0.1-0.2% (only maintaining autothermia without additional energy effect).

For practical applications in which methane concentration changes over time using the developed methods, methane concentration of 0.5% is required.

Directions of scientific and industrial research enabling economic use of methane from ventilation air, as a fuel mainly for heat generation may include:

– co-combustion of methane from ventilation air in boilers with other fuels such as coal,
– oxidation of methane from ventilation air in reversing reactors,
– oxidation of methane from ventilation air in catalytic and flow catalytic reversing reactors,
– direct combustion of methane from ventilation air in gas turbines.

Technologies used to utilize or dispose of methane from VAM may include:

✓ thermal flow and reversible TFRR reactors (VOCSIDIZER),
✓ catalytic flow and reversible CERR reactors,
✓ catalytic flow reactors CFR,
✓ gas turbines CGT,
✓ turbines with catalytic combustion CCGT,
✓ hybrid turbines for methane-air-carbon mixture.

EXTRACTION AND ECONOMIC USE OF METHANE FROM DECOMMISSIONED MINES

Methane extraction is inseparably related to the current analysis not only of the history of coal mining or the structure of mine, but above all, it requires taking into account geological factors, which as the examples show, are often characterized by considerable uncertainty.

Currently in Poland only 5 of the decommissioned mines (“Morcinek”, “Żory”, “Moszczenica”, “Śląsk” and “Krupiński”) conduct effective methane extraction, although methane resources in the gas tanks of the decommissioned mines are estimated at several million m^3 (Barchański B., Kostorz J. 1999). For example, the amount of 100 % of methane extracted and utilized energetically only from three decommissioned mines: “Morcinek”, “Żory” and “Moszczenica” amounted to about 13.5 million m^3 in 2017, which was nearly 6.5% of methane extracted and utilized from the active mines in the same year as shown in Tables 2, 3, 4.

Table 2 Methane extraction from “Żory-1” deposit

Year	Gas volume (m^3)	Methane volume 100% CH_4 (m^3)
2010	1 949 675	1 720 792
2011	4 176 419	3 605 518
2012	2 962 958	2 417 751
2013	3 653 349	3 082 983
2014	2 880 554	2 544 416
2015	4 180 928	3 632 825
2016	4 401 523	3 661 553
2017	6 477 242	3 244 990
2018	6 785 894	2 697 649

Source: Own elaboration based on data obtained from GAZKOP-1 Sp. z o.o.

In 2010-2018, GAZKOP-1 extracted a total of 26 608 477 m^3 of 100% CH_4 from the “Żory-1” deposit.

Table 3 Methane extraction from “Kaczyce 1” deposit

Year	Gas volume (m^3)	Methane volume 100% CH_4 (m^3)
2004	1 753 934.70	1 631 213.01
2005	4 305 496.70	4 082 975.56
2006	3 544 183.50	3 341 476.55
2007	2 579 427.20	2 409 234.18
2008	279 489.00	264 076.98
2009	30 831.00	29 596.00
2010	38 576.10	37 142.09
2011	32 091.00	30 576.00
2012	24 305.00	23 323.00
2013	18 851.00	18 164.00
2014	23 702.00	22 756.99
2015	1 365 196.10	1 275 421.41
2016	2 277 616.00	2 160 639.01
2017	2 406 950.20	2 291 221.49
2018	1 316 422	1 228 816
2019	1 286 876	1 198 948

Source: Own elaboration based on data obtained from Karbonia S.A.

In total, in 2004-2019, the company extracted from the deposit (underground energy warehouse) 20 045 580.26 m^3 of 100% CH_4.

Table 4 Methane extraction from “Moszczenica” deposit

Year	Gas volume (m^3)	Methane volume 100% CH_4 (m^3)
2008	14 819 400	9 303 500
2009	15 987 300	9 591 800
2010	15 436 000	9 844 300
2011	14 547 800	9 118 800
2012	11 900 200	8 701 600
2013	12 044 200	8 756 800
2014	12 669 300	9 039 900
2015	12 641 300	9 049 900
2016	10 397 100	7 339 800
2017	11 551 000	7 586 200
2018	13 786 300	8 732 300
2019	13 172 400	8 865 200

Source: Own elaboration based on data obtained from SRK S.A. – Jastrzębie Branch.

In 2008-2019, SRK S.A. extracted a total of 105 930 100 m^3 of 100% CH_4 from “Moszczenica” deposit.

All the above data show how significant and important the use of methane from the tanks created after the decommissioning of mines is. This process should already be considered and developed at the stage of mine decommissioning project. The degree of methane utilization from decommissioned mines in Poland is low, which is caused, among others, by long and cumbersome, from the administrative point of view, procedures to obtain concessions for exploration, identification and exploitation of methane from these mines by entrepreneurs.

Methane extraction from decommissioned hard coal mines (“Morcinek”, “Żory”, “Moszczenica”) confirmed that this methane can be used as a local energy source. Utilization of this valuable raw material for energy purposes requires an ongoing analysis of the energy price market (Łukaszczyk Z., 2019).

Increased consumption of methane deposited in the underground gas tanks of the decommissioned mines should have a positive impact on the use of this fuel in the Upper Silesian Coal Basin.

The creation of a local energy market should be pursued through the implementation of appropriate economic incentives dedicated to both entrepreneurs and its potential consumers. The consumers may be encouraged by the legal qualification of methane from coal deposits as “green fuel” (Łukaszczyk Z., Badura H. 2017).

The European Union’s climate policy, expressed in support of projects using low-carbon energy sources, may be an opportunity to implement more projects related to methane extraction and economic use.

The utilization of methane resources from decommissioned hard coal mines, taking into account the geological, technical and economic conditions of extraction, should result in obtaining significant economic effects beneficial for entrepreneurs, municipalities and the State Treasury, and above all, beneficial effects for the environment.

THREAT

There are many indications that the emission of mine methane into the atmosphere may be subject to EU ETS or equivalent regulations in the near future. The August project on the future EU methane strategy (POLITICO 2020) states that “the EU considers forcing an actual cessation of any routine release or combustion of gas from mining shafts in the EU energy sector by 2025” and will encourage international suppliers to comply with these strict standards. The final version is expected later this year.

In such a case, the fees would significantly increase the costs of hard coal mining and thus eliminate first of all the extraction of coal in high-methane mines. In an extreme hypothetical case, it could be a cost of emission rights amounting to over PLN 1 million (Łukaszczyk Z. 2019).

Taking into account the above, it is worth to do everything, by all possible means, to limit the emission of methane to the atmosphere as much as possible and not to intensify the climate changes.

In view of the justified, growing pressure to maximally limit the emission of greenhouse gases into the atmosphere and the emphasis on energy efficiency, the use of methane from coal deposits becomes fully justified.

CONCLUSIONS

Methane from coal deposits is a very valuable ecological fuel. Given its resources and the fact that it belongs to the group of greenhouse gases, it should be maximally extracted and economically utilized both from active and decommissioned mines. Methane is extracted from the tanks of decommissioned mines and the technology of its inclusion should be prepared already at the stage of mine decommissioning project.

It is necessary to amend the Geological and Mining Law – in the scope of further simplification of the "open door" procedure to obtain concessions for exploration, identification and extraction of methane from coal deposits by entrepreneurs in order to simplify and accelerate the concession process carried out in the Ministry of Environment. In addition, the mining companies should launch industrial installations for the production of compressed natural gas – methane from coal deposits (CNG-MPW), which is not used as a result of mine demethylation for communication and local energy.

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Abstract.
Since the beginning of the 1990s, there has been an intensive restructuring of hard coal sector in Poland. In this process, successive mines are being decommissioned, most of which are characterized by considerable methane content. The vast majority of hard coal mines in Poland, including all the mines belonging to Jastrzębska Spółka Węglowa S.A. are highly methane mines. This means that the air flowing out of the mine shafts contains a certain concentration of methane, the size of which depends on the amount of air and the amount of methane-filled air, which is emitted into the mine excavations. In 2019 alone, nearly 807 million m^3 of methane was released from the rock mass affected by mining, out of which only 195.6 million m^3 were used economically. This publication presents and characterizes projects involving the extraction and economic use of methane from both active and decommissioned mines. The paper also points out the legal and administrative conditions in which projects related to methane extraction and utilization can be implemented. The paper presents measurable benefits from demethylation not only in terms of improving the safety of coal extraction, but mainly economic and ecological aspects. Above all, attention was paid to the fact that the vast majority of methane was irreversibly emitted to the atmosphere to the detriment of the natural environment.

Keywords: methane, methane extraction, energy efficiency, environmental charges, greenhouse gases