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Analysis of Exploitation Parameters in Drainage Boreholes of the Longwall Demethylation System. Case Study

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INTRODUCTION

In most Polish coal mines, the associated mineral is methane. The presence of methane in coal is related to the coal formation process. It is believed that in coal with low degree of carbonization, methane is formed by the activity of microorganisms while in coals with higher degree of carbonization it is formed by thermal processes of organic matter (Aminian K., 2009, Gaid to Coalbed 1996, Gonet A. et al., 2010). Methane in coal bed occurs as sorbed (adsorbed and absorbed), free and dissolved in water (Bumb A.C., McKee C.R., 1988, Hagoort J., 1988).

Due to the explosive character of air-methane mixtures, the safety regulations for coal mining under methane hazard conditions limit the permissible concentration of methane in the atmosphere of longwall workings to 2%. Maintaining the methane concentration within permissible limits often requires the use of demethylation (Bohan M.P., 2009, Frączek R., 2005, Karacan C.Ö et al., 2011)

In the Polish coal mining industry, the most commonly used demethylation methods are (Bajorski P, Tor A., 2014, Frączek R., 2005, Malina Z., et al., 2006): degasification through drainage boreholes drilled in roof rocks from the main gate of active longwalls:

- methane extraction from sealed old goafs,
- methane extraction from so-called methane galleries, i.e. corridor excavations located in the rock mass above an active longwall and parallel to the longwall’s direction of extraction,
- degasification through drainage boreholes drilled in the bedrock,
- advance degasification through drainage boreholes, used prior to the commencement of mining operations in a specific longwall field.

Selection of degasification method depends on the forecasted methane load of a longwall, which takes into account the outflow of methane from the excavated coal bed, as well as from roof rocks and cap rocks (Badura H. 2001, Badura H.

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2004, Badura H., 2005 , Badura H., 2007a, Badura H. 2007b, Badura H., Jakubów A., 2007, Badura H. et al., 2008, Badura H. et al., 2011, Berger J., et al., 2009, Krause E., Łukowicz K., 2000). The amount of methane released to the mine atmosphere in the area of excavated part of coal bed is also influenced by the amount of daily extraction, daily longwall progress and also the length of longwall (Krause E., Łukowicz K., 2000).

The extracted methane is used to generate thermal and mechanical energy (Łukaszczyk Z., 2019), but a significant amount is discharged into the atmosphere.

Construction and maintenance of the demethanation system is expensive, significantly affecting the price of coal. The issue presented in this paper aims to provide an insight into the problems related to the efficiency of drainage boreholes in the demethanation system in order to optimize this system and reduce the cost of demethanation.

NATURAL CONDITIONS IN THE AREA OF LONGWALL N-0 IN COAL BED 331

Natural conditions in the area of longwall N-0 in coal bed 331 were identified by means of test boreholes and preparatory works: top gate N-0, bottom gate N-0 and raise galleries N-0.

The methane hazard forecast predicted that in the initial 400 m of longwall length, with the assumed extraction of 3000 Mg/day, the total methane emission rate would be 27.19 m^3/min, and in the second, further part of the longwall length – 22.19 m^3/min. The drainage boreholes, for which the analysis presented in the following part of this paper was carried out, were located in the second part of longwall length.

The methane prevention applied during the longwall extraction included:

- supplying an adequate amount of air to the longwall,
- providing fresh air from the extraction gallery N-2 in the coal bed 330/2 to the top gate N-0 in the area of its intersection with the longwall N-0 by means of a fresh air duct,
- use of a ventilation baffle in the top gate N-0 in the area of its intersection with the longwall,
- use of sensors for methane, carbon monoxide, absolute pressure, differential pressure and a stationary anemometer,
- use of demethylation through roof drainage boreholes drilled from the top gate N-0 and connected to the mine’s degasification system.

METHOD OF CONDUCTING DEGASIFICATION IN THE AREA OF LONGWALL N-0

Degasification of longwall region was carried out along with the commencement of mining. The drainage boreholes for the methane drainage system were drilled from the top gate N-0. Several boreholes were drilled from one station and combined with each other to form a set of boreholes connected to the piping of methane drainage system by means of a single tube. The first set consisted of eight drainage boreholes, and the next five boreholes. After extraction of a 400 m long section of the field, the number of drainage boreholes in one set was reduced to four.

Each of the drainage boreholes had a casing pipe about 6 m long at the outlet. The casing pipe was connected to the collector via a valve (gate valve) and a rubber pipe section. The collector outlet stub was connected to the branch pipeline of demethylation system with a section of a steel pipeline. This section contained a measurement orifice and a valve enabling the connection or disconnection of a set of drainage boreholes from the demethylation pipeline. The collector was connected to a drainage device, which discharged water flowing out of the drainage boreholes.

In order to carry out the research presented later in this paper, one of the set of four drainage boreholes, designated as set 31, was additionally adapted to measure the negative pressure (depression), the amount of captured air-methane mixture and the concentration of methane in this mixture in each of drainage boreholes.

Table 1 presents the geometric parameters of drainage boreholes forming the set 31 in question.

Table 1 Geometric parameters of drainage boreholes on the day they were drilled

Borehole name	Angle of inclination in relation to the horizontal	Angle of deviation from roadway axis, degrees	Borehole length, m	Horizontal distance from the bottom of borehole to longwall face, m
TM-4/16	30^0	10^0	80	31.8
TM-5/16	25^0	15^0	80	30.0
TM-6/16	25^0	20^0	80	31.9
TM-7/16	20^0	25^0	80	31.9

MEASUREMENTS OF METHANE AND AIR-METHANE MIXTURE EXTRACTION

The drainage boreholes of set 31 were prepared for the methane extraction when the longwall face was at a distance of 100 m from the location of boreholes. Due to the fact that the drainage boreholes were drilled at different angles to the horizontal and to the longitudinal axis of top gate, the lengths of borehole projections on the horizontal plane were calculated, and then the horizontal distances of borehole bottoms from the longwall face were calculated. The horizontal distances of drainage borehole bottoms from the longwall face given in Table 1 are approximate because both the location of longwall face and drainage borehole outlets were not accurately measured.

The outlet of each borehole was equipped with a valve (gate valve), which enabled connection or disconnection of the borehole from the methane drainage network and regulation of negative pressure in drainage boreholes.

The drainage boreholes forming a single set were connected to the so-called collector with rubber hoses. The collector outlet was connected to collection pipeline with a steel pipe. A part of pipeline connecting the set of boreholes with a collection pipeline was the so-called measurement section, equipped with a measurement orifice. In everyday practice, measurements of the amount of captured air-methane mixture, as well as of methane concentration in that mixture are conducted for the whole set of boreholes. Additionally, the methane concentration in a mixture captured through individual drainage boreholes is measured. Gas for analysis is collected by puncturing with a needle the rubber hose connecting the drainage borehole with the collector. If the methane concentration in drainage borehole is too low (below 30%), the vacuum in the borehole is reduced with a gate valve at the outlet of borehole.

Measurement orifices were additionally installed in the drainage boreholes of borehole 31 to connect the individual boreholes to collector, which allowed to control the flow rate of gaseous mixture out of the individual boreholes.

Measurements of the amount of air-methane mixtures and methane concentrations in individual boreholes of set 31, as well as for the whole set, were carried out for 49 days. The distance of a set of boreholes from the longwall face on the first day of measurements was about 100 m, while on the last day it was 5 m.

Figures 1 and 2 show the development of air-methane and methane mixture extractions by drainage borehole TM-4/16.

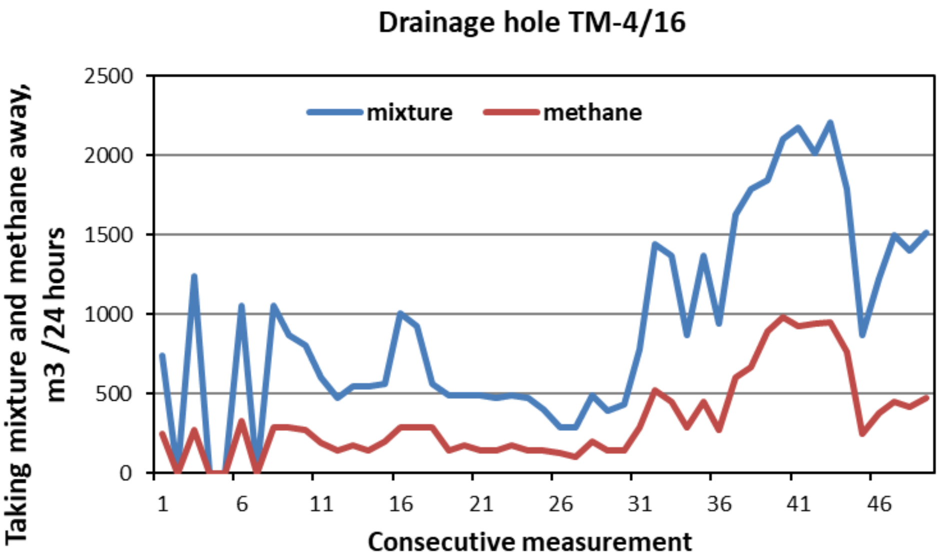

Fig. 1 Methane and air-methane extraction shown by successive measurements

During the whole measurement period, there were 4 days (days 2, 4, 5 and 7) on which methane concentration in the mixture captured by the borehole was sufficiently lower than 30% to cause the methane concentration in captured mixture to drop below the permissible value. As a result, the borehole TM-4/16 was inactive on those days.

Values of statistical coefficients calculated only for the period when the borehole was active are presented below.

The correlation coefficient between the applied depression (negative pressure) in the borehole and the amount of mixture extracted through the borehole is r = 0.42 (moderate correlation (Zelias A., 2000)), and between the depression and the amount of methane extracted r = 0.35 (clear but low correlation).

The lowest methane concentration in the captured mixture was 22% and the highest 48%. An average value of methane concentration in the mixture extracted from the borehole, calculated for the time of connecting the borehole to the methane drainage network, was about 36%.

The correlation coefficient between methane concentration in a borehole and the applied depression is about r = -0.06, which means that there is practically no relationship between these parameters.

On the other hand, there is a moderate correlation between the distance from the drainage borehole outlet to the longwall and the mixture flow and methane flow rate. In both cases, the correlation coefficient is about r = -0.63. This means that, in general, the amount of captured mixture and methane increased as the distance from longwall to drain borehole outlet increased, but this relationship is not clear. This is also evidenced by the graphs of mixture and methane extraction shown in Figures 1 and 2.

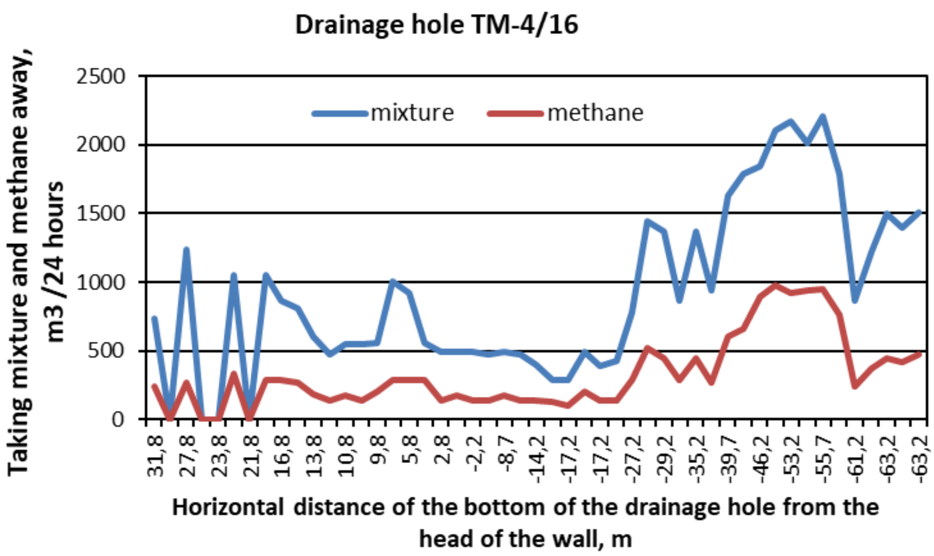

Fig. 2 Methane and air-methane extraction depending on the horizontal distance from the bottom of drainage borehole to the longwall

During the first seven days of measurements, methane was captured by the borehole for three days. The mixture flow on these days ranged from 734 m^3/day to 1238 m^3/day, and the methane flow ranged from 245 m^3/day to 331 m^3/day.

In the period from the 8th to the 30th day, the mixture capture ranged between 432 m^3/day and 1051 m^3/day, while the methane extraction ranged from 101 m^3/day to 288 m^3/day. The average mixture extraction during this period was 572 m^3/day.

From the 20th day of borehole's existence, its part was located above the exploited space of coal bed (Fig. 2). This fact is evidenced by negative values of the distance from the bottom of drainage borehole to the longwall face.

In the final period, from the 31st to the 49th day, the amount of captured mixture ranged from 778 m^3/day to 2203 m^3/day, and of captured methane from 228 m^3/day to 979 m^3/day. Strong increase of methane extraction in borehole TM-4/16 can be explained by covering longer and longer part of the borehole with stress-relieved zone, which is formed above the extracted space of coal bed. A sudden decrease in extraction of both a mixture and methane in the final period of borehole's existence and a sudden drop in methane concentration in the extracted mixture in spite of reduced vacuum in borehole were most probably caused by unsealing the borehole from the roadway side as well as from the collapse side.

Assuming that flow rate of air-methane mixture and methane concentration were constant in the period between measurements, 44957 m^3 of air-methane mixture and 16 128 m^3 of methane were captured during the whole borehole exploitation period. The maximum extraction of air-methane mixture per day was 2203 m^3, including 979 m^3 of methane.

Figures 3 and 4 present trends in air-methane and methane extraction through drainage borehole TM-5/16

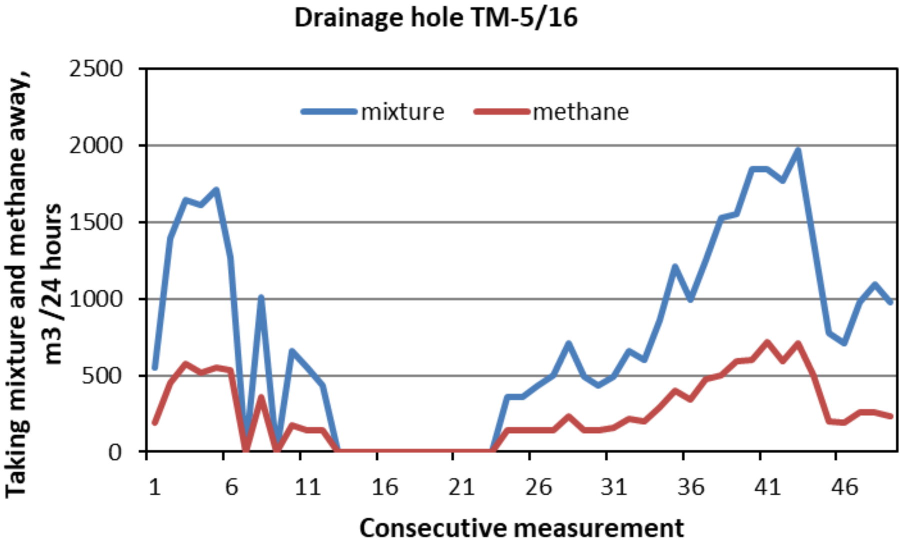

Fig. 3 Methane and air-methane extraction shown by successive measurements

During the whole measurement period, 13 days occurred on which the borehole M-5/16 was inactive (number of active days – 36). As above, further analysis concerns only days when the borehole was active.

The correlation coefficient between the applied depression (negative pressure) in the borehole and the amount of mixture captured by the borehole is r = 0.43 (moderate correlation) and between the depression and the amount of methane captured r = 0.40 (moderate correlation).

The lowest methane concentration in the captured mixture was 22% and the highest was 39%. A weighted average value of methane concentration in the mixture captured by the borehole, calculated for the time of connecting the borehole to methane drainage network, was about 32%.

The correlation coefficient between methane concentration in the borehole and the applied depression is r = 0.17, thus there is practically no relationship between these parameters.

There are also no correlations between the distance of drainage borehole outlet from the longwall and the mixture flow rate (r = -0.15) and the distance of drainage borehole outlet from the longwall and the methane flow rate (r = -0.10).

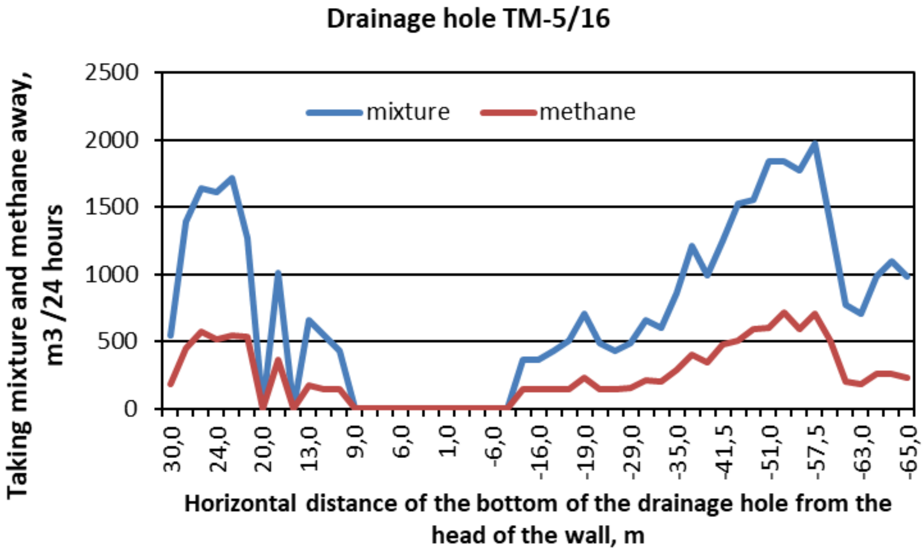

Fig. 4 Methane and air-methane extraction depending on the horizontal distance from the bottom of drainage borehole to the longwall face

Figure 3 shows that the extraction of air-methane mixture and methane occurred in three clearly visible stages. The first stage covered a period of first 13 days.

During the first period, the mixture extraction increased from 547 m^3/day on the 1st day to 1.713 m^3/day on the 5^{th} day. Similarly, methane extraction increased from 187 m^3/day to 576 m^3/day on the 3^{rd} day and then decreased to 547 m^3/day on the 5^{th} day.

On the 6^{th} day, the mixture extraction decreased to 1267 m^3/day and the methane extraction decreased to 533 m^3/day. On the 7^{th} day, the mixture and methane extraction dropped to zero.

On the 8^{th} day, the mixture extraction increased to 1008 m^3/day and methane to 360 m^3/day, only to decrease again to 0 on the following day.

On the 10th day of borehole operation, the amount of captured mixture increased to 662 m^3/day and methane to 173 m^3/day, after which the amount of air-methane mixture and methane decreased to drop to zero on the 13th day.
In the second stage lasting from the 13th to the 23rd day (11 days), the mixture and methane extraction was zero.
From the 24th to the 43rd day, the air-methane mixture and methane extraction had an increasing trend with slight fluctuations. On the 43rd day, the mixture extraction was 1973 m^3/day and the methane extraction was 706 m^3/day.
After reaching the maximum, the extraction of mixture and methane decreased strongly to reach values of 706 m^3/day and 63 m^3/day, respectively, on the 46th day, and then increased slightly to reach values of 979 m^3/day and 230 m^3/day on the last day, the forty-ninth day.
During the period from the 13th to the 23rd day of operation, the methane release into the drainage borehole was too low and keeping the borehole active would lead to an air-methane mixture in the whole set of boreholes with too low methane concentration. Figures 3 and 4 show that there was a period of lack of methane inflow to the drainage borehole, not only when the bottom of borehole TM-5/16 was located above the coal bed casing, but also when it was located above the excavated part of coal bed (from the 20th day of borehole existence).
Extraction by borehole TM-5/16 of an air-methane mixture with the required methane concentration was commenced only when the bottom of borehole was approx. 14 m above the selected area of coal bed. During the whole period of borehole TM-5/16 exploitation, 36619 m^3 of air-methane mixture was captured, which contained about 12168 m^3 of methane. The maximum daily extraction of mixture was 1973 m^3, the minimum was 360 m^3, and the average was 1017 m^3. Maximum daily extraction of methane through this borehole was 720 m^3, the minimum was 144 m^3 and the average was 338 m^3.
Data on methane extraction by borehole TM-6/16 are presented in Figures 5 and 6.

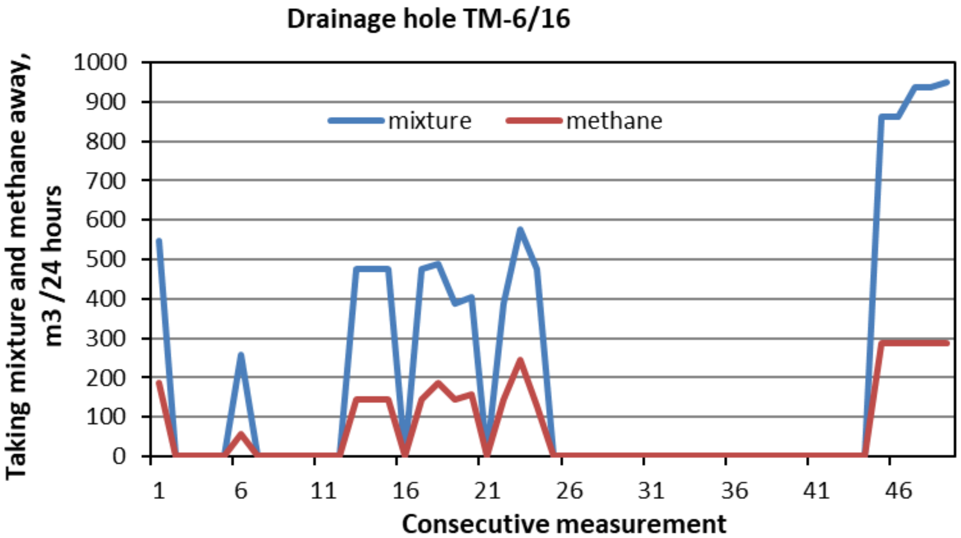

Fig. 5 Methane and air-methane extraction shown by successive measurements

The number of active days in drainage borehole TM-6/16 is 17, which is the lowest in comparison with the number of active days in other boreholes.

The correlation coefficient between the applied depression in the borehole and the amount of mixtures captured is r = 0.48 (moderate correlation) and between the depression and the amount of methane captured is r = 0.33 (clear but low correlation). The correlation coefficient between methane concentration in the borehole and the applied depression is r = -0.61, which means that the concentration of captured methane decreased along with depression.

Taking the above into account, it can be concluded that an increase in depression resulted in an increase in the flow rate of methane captured, but at the same time the methane-air mixture was poorer in methane.

The lowest methane concentration in the captured mixture was 20% and the highest 43%. The weighted average value of methane concentration in the mixture captured by a borehole was about 30%.

Correlations were found between the distance from drainage borehole outlet to longwall and mixture flow rate (r = -0.91 – very strong correlation) and the distance from drainage borehole outlet to longwall and methane flow rate (r = -0.87 – significant correlation).

As for the previous boreholes, the capture of methane by borehole TM-6/16 can be divided into three periods (Fig. 5). The first period, lasting from the 1st to the 24th measurement, is characterized by intervals in methane extraction. It can be divided into five productive sub-periods separated by four non-productive sub-periods. The first productive sub-period is the first day of connecting the borehole to methane drainage system. The flow rate of captured air-methane mixture is 547 m^3/day and methane 187 m^3/day, with methane concentration at 34%. This is followed by a four-day non-productive sub-period. The 6th day is the second productive sub-period. It captured 259 m^3/day of mixture and 58 m^3/day of methane, and the methane concentration was 20%. The second non-productive sub-period consists of 6 days. It is followed by a three-day productive sub-period. The mixture and methane extractions were constant at 475 m^3/day and 144 m^3/day, respectively. The methane concentration was 30% on the first 2 days and 28% on the 3rd day. The 16th day was the third non-productive period. The fourth productive sub-period includes four days. The captured air-methane mixture flow rate ranges from 389 m^3/day to 475 m^3/day, and the captured methane flow rate ranges from 144 m^3/day to 187 m^3/day. Methane concentrations during this period ranged from 27% to 39%. The 21st day is the fourth non-productive period. However, the next three days form the fourth productive sub-period. The flow of captured air-methane mixture ranges from 389 m^3/day to 576 m^3/day, and methane from 130 m^3/day to 245 m^3/day. Methane concentrations during these days ranged from 28% to 43%.

This period is followed by the second period – non-productive. It consists of 20 days.

A correspondingly high flow of methane into borehole TM-6/16 occurred on the 45th day of borehole’s existence and lasted until the final, 49th day. The air-methane mixture extraction ranged from 864 m^3/day to 950 m^3/day. Methane extraction was constant at 288 m^3/day. This period is characterized by a relatively low concentration of methane in the captured air-methane mixture, ranging from 26% to 28%.

As can be seen from Figure 6, during the entire second, non-productive period, the bottom of drainage borehole was located above the extracted space.

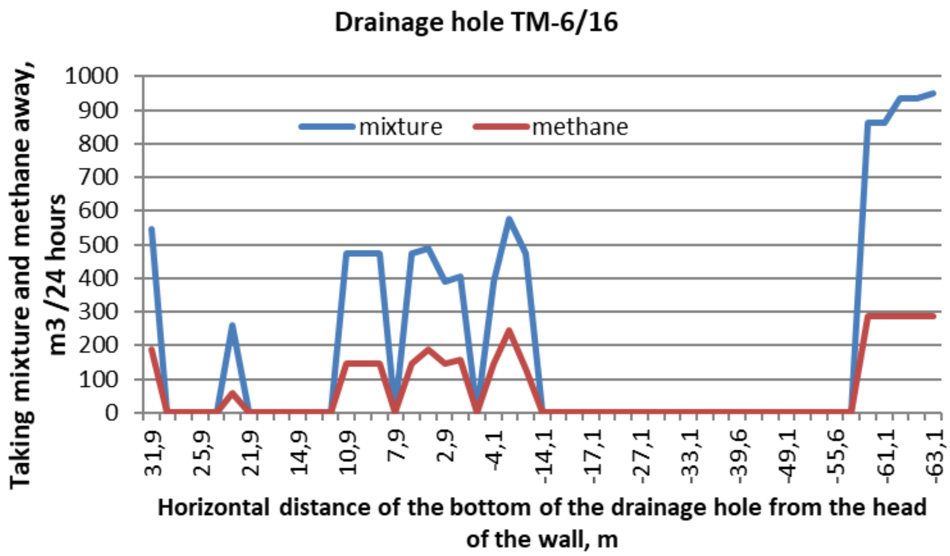

Fig. 6 Methane and air-methane extraction depending on the horizontal distance from the bottom of drainage borehole to the longwall face

During the whole exploitation period of borehole TM-6/16, there were captured 9979 m^3 of air-methane mixture, which contained about 3269 m^3 of methane. The maximum daily extraction of mixture was 950 m^3, the minimum was 259 m^3 and the average was 587 m^3. Whereas, maximum daily extraction of methane by this borehole was 288 m^3, the minimum was 58 m^3, and the average was 192 m^3. Data on methane extraction from borehole TM-7/16 are presented in Figures 7 and 8.

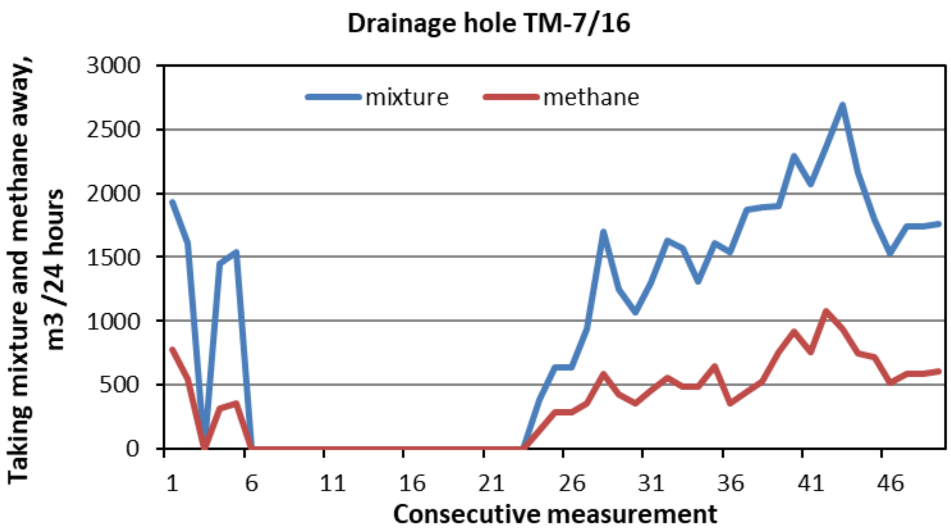

Fig. 7 Methane and air-methane extraction shown by successive measurements

During the whole operation period of borehole MT-7/16, there were 19 non-productive days (number of active days – 30). The values of statistical coefficients presented below are based only on data collected on days when the borehole was active.

The correlation coefficient between the applied depression in the borehole and the amount of mixtures captured is r = 0.55 (moderate correlation), while between the depression and the amount of methane captured is r = 0.38 (strong but low correlation). The correlation coefficient between methane concentration in the borehole and the applied depression is r = -0.26, which means that an increase in depression in the borehole caused a decrease in methane concentration in the captured mixture.

Taking the above into account, it may be concluded that an increase in depression in the borehole in question resulted in an increase in the flow of methane captured, but at the same time the air-methane mixture was poorer in methane.

The lowest methane concentration in the captured mixture was 22%, while the highest was 40%. The weighted average value of methane concentration in the borehole mixture was about 34%.

There are correlations between the distance from drainage borehole outlet to longwall and mixture flow rate (r = -0.40 – moderate correlation) and the distance from drainage borehole outlet to longwall and methane flow rate (r = -0.44 – moderate correlation).

Also in the case of analyzed borehole, it is possible to distinguish three basic periods of activity.

The first period includes the first 5 days. In the first 2 days of borehole's existence, the air-methane mixture and methane extraction was significant. On the 1st day, the mixture flow rate was about 1930 m^3/day and the methane flow rate was 778 m^3/day, while on the 2nd day – 1613 m^3/day and 547 m^3/day, respectively.

On the 3rd day, the mixture and methane extraction was zero.

On the next 2 days, the air-methane mixture extraction increased first to 1454 m^3/day and on the following 5th day to 1540 m^3/day. Methane extraction was 317 m^3/day and 360 m^3/day on these days.

The second period includes 18 days when the borehole was shut down due to insufficient methane concentrations.

The third and final period includes 26 days, from the 24th to the 49th day of the borehole's exploitation. The total flow rate of air-methane mixture captured by borehole MT-7/16 during this period is 41357 m^3/day and of methane 14688 m^3/day. The minimum value of the mixture flow is 339 m^3/day, maximum value is 2693 m^3/day and average value is 1591 m^3/day. The maximum methane extraction was 1080 m^3/day, the minimum was 144 m^3/day, and the average was 565 m^3/day.

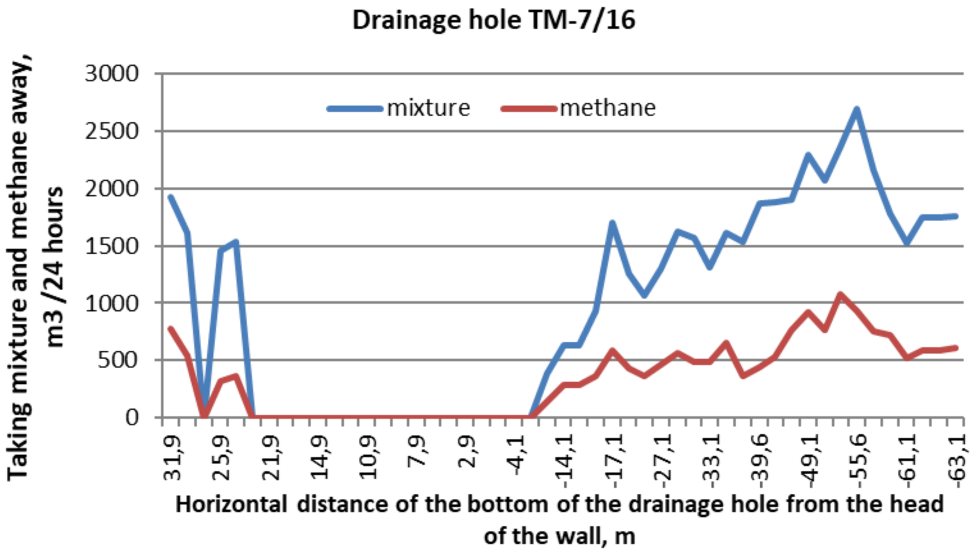

Fig. 8 Methane and air-methane extraction depending on the horizontal distance from the bottom of drainage borehole to the longwall face

The most productive, third period of the borehole's existence began when the bottom of borehole was above the excavated space at a distance of about 12.5 m. During the whole exploitation period, 47894 m^3 of air-methane mixtures were obtained through borehole TM-7/16, including 16690 m^3 of methane. The maximum withdrawal of air-methane mixture during the whole period was 2693 m^3/day, whereas the maximum withdrawal of methane was 1080 m^3/day.

The analyses carried out above show that the total period of methane extraction through drainage boreholes can be divided into three periods:

- the first period is characterized by intervals of fairly large methane extraction separated by periods of no sufficient amount of methane inflow to drainage boreholes, which resulted in the necessity of short-term shutdowns of these boreholes. The number of days in this period was different for individual boreholes and ranged from 5 to 24. A characteristic feature of this period is that boreholes TM-4/16, TM-5/16 and TM-7/16 were all located above the coal body, before the longwall face, while borehole TM-6/16 was located above the coal body during the first 19 days, and during the last 5 days of this period part of the borehole was already above the extraction area of the longwall field;
- the second period is characterized by a strong decrease in methane inflow to the boreholes, as a result of which three out of four boreholes had to be shut down from exploitation. The length of the second period varied for each borehole and ranged from 11 to 33 days. From the second period onwards, a portion of each borehole was located above the selected area of coal bed;
- the third period was characterized by a strong increase in the amount of captured methane, with the maximum methane extraction occurring between the 41st and 45th day of extraction in a particular drainage borehole.

During the first period, 850 m^3CH_4 was captured by borehole TM-4/16, 3629 m^3CH_4 was captured by borehole TM-5/16, 1829 m^3CH_4 was captured by borehole TM-6/16, and 2002 m$^3CH_4$ was captured by borehole TM-7/16. In total, 8310 m$^3CH_4$ was captured during the first period.

In the second period, borehole TM-4/16 captured 4349 m$^3CH_4$. The remaining boreholes were inactive.

During the third period, 10930 m$^3CH_4$ was captured by borehole TM-4/16, 8539 m$^3CH_4$ by borehole TM-5/16, 1440 m$^3CH_4$ by borehole TM-6/16 and 14688 m$^3CH_4$ by borehole TM-7/16. In total, 35597 m$^3CH_4$ was captured during the third period.

During the whole operation period, 44957 m^3 of air-methane mixture and 16128 m^3 of methane were captured by borehole TM-4/16, 36619 m^3 of mixture and 12168 m^3 of methane by borehole TM-5/16, 9979 m^3 of mixture and 3269 m^3 of methane by borehole TM-6/16, and 47894 m^3 of mixture and 16690 m^3 of methane by borehole TM-7/16. These data show that extraction of both air-methane mixture and methane differs significantly among individual boreholes.

In total, the amount of captured mixtures is 139449 m^3, captured methane is 48255 m^3, and the average methane concentration calculated on this basis is 34.6%.

Apart from measurements conducted in individual boreholes, collective measurements of the amount of mixtures and methane extraction were carried out along the measuring section connecting the collector of drainage boreholes of a set 31 with a branch methane drainage pipeline. Results of these measurements are shown in Figure 9.

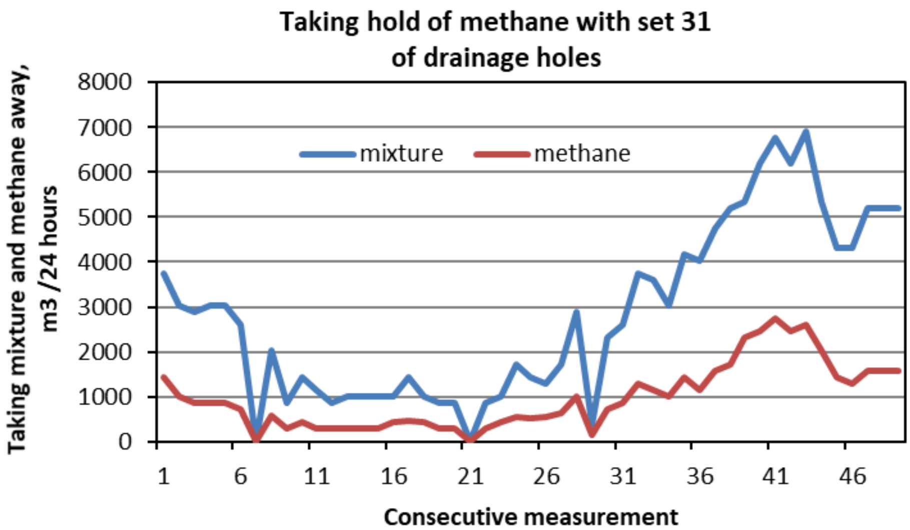

Fig. 9 The methane and air-methane mixture extraction throughout the active period of a set 31 of drainage boreholes

Figure 9 shows that only on two days, i.e. on the 7th and 21st day, zero air-methane mixture was captured by the whole set of boreholes.

On productive days, the lowest daily amount of captured air-methane mixture was 389 m^3 and methane was 144 m^3, the maximum daily mixture extraction was 6912 m^3 and methane was 2736 m m^3/min.

During the whole period, on one day the methane concentration in the captured mixture was below 30% and reached 25% (on the 11th day). The average value of methane concentration in the mixture was 33.9% and the maximum value was 42%.

Figure 9 shows the methane and air-methane mixture extraction throughout the active period of a set 31 of drainage boreholes, and Figure 10 shows the methane concentration in the captured mixture.

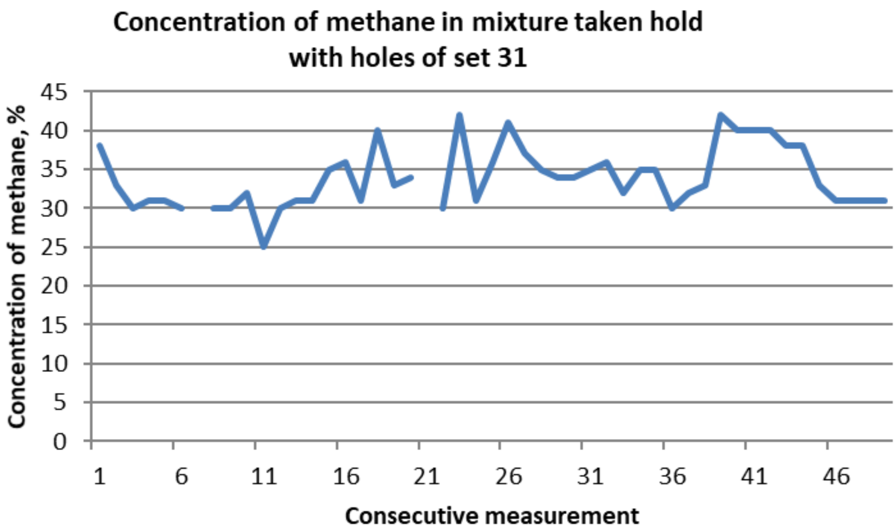

Fig. 10 Methane concentration in the air-methane mixture in the measurement section of a set 31 of drainage boreholes

It can be concluded from Figure 9 that from the first to the seventh day of methane extraction of the whole set 31 of drainage boreholes, the amount of methane decreases significantly to reach zero on the 7th day. The maximum flow rate of captured methane occurred on the 1st day and was 1440 m^3, while on the 6th day it was 720 m^3. The average value of methane extraction for six days was 960 m^3.

Then, from the 8th to the 20th day, the amount of methane varies from 576 m^3/day to 288 m^3/day, with an average value of about 336 m^3/day.

On the 21st day of mining, the methane flow rate was zero.

From the 22nd day, there is a clear upward trend of methane extraction and reaches a maximum of 2736 m^3/day on the 41st day. The methane extraction then decreases to finally reach 1548 m^3/day.

The methane flow rate captured in the first 21 days of set 31 was 10382 m^3. This represents approximately 22% of methane extraction over the entire period of set existence. It follows from the above that the methane extraction during this period was significant, which leads to the conclusion that drilling drainage boreholes at a considerable distance from the longwall face significantly increased the efficiency of methane drainage.

According to the measurements for the whole set 31, the total flow rate of captured air-methane mixture is 138485 m^3, and of captured methane is 47448 m^3.

Whereas, the sums of mixture and methane flow rates calculated from the data for individual drainage boreholes show that the total mixture flow rate is 139449 m^3 and the methane flow rate is 48255 m^3.

Comparison of the total air-methane mixture and methane extraction calculated from the collective measurements and those resulting from the sum from individual boreholes shows that they differ significantly, with the values resulting from the sum being larger. The amount of mixture resulting from measurements for the whole set 31 of drainage boreholes is smaller by 964 m^3, and the amount of methane is smaller by 807 m^3. These differences are due to the measurement methodology. The total measurement errors resulting from measurements conducted for individual drainage boreholes are the sum of errors made for each borehole. This sum is larger than the measurement error carried out on the collective section of all the drainage boreholes, between the collector and branch pipelines of demethylation network.

Figure 10 presents methane concentration in the flow rate of air-methane mixture in the measurement section of a set 31 of drainage boreholes.

On the 2nd day, the methane concentration was undetermined due to the closure of all boreholes in a set 31.

On the 1st day, the methane concentration was less than 30% (was 22%). On the 25th day the methane concentration was in the range (30%, 35%) and on the 11th day in the range (35%, 40%). Methane concentrations above 45% occurred on the 3rd day, with 41% on the 1st day and 42% on the 2nd day.

CONCLUSIONS

On the basis of analysis of the demethylation efficiency in four drainage boreholes, forming the set 31, the following statements and conclusions can be formulated:

1. Drainage boreholes for which the demethylation efficiency analysis was conducted were drilled 100 m in front of the longwall face. The lengths of boreholes were equal and amounted to 80 m. The boreholes had different inclination to the horizontal and deviation from the longitudinal axis of ventilation roadway.
2. Three periods are evident in the methane extraction of individual boreholes comprising the set 31. In the first period there are days when methane extraction was significant, but there were also days with zero methane extraction. In the second period, methane extraction was low in one of the boreholes and zero in the others. In the third period, methane extraction had an upward trend to a maximum and then declined.
3. Occurrence of non-productive second period is related to a strong decrease in filtration properties of roof rocks, associated with the presence of so-called exploitation pressure wave.
4. Decrease in the demethylation productivity in the third period was related to the proximity of longwall face to a distance of 5 m from the set of

boreholes and occurrence of a crack zone in the rock mass above the excavated part of coal bed and in front of longwall face.

5. Duration of each period varied from borehole to borehole.
6. For the whole set of boreholes it is also possible to distinguish three periods of captured methane output: the first one of considerable but quickly decreasing output, the second one of low output and the third one of considerable average output. The first and second periods lasted a total of 21 days. The third period lasted from day 22 to day 49.
7. Total methane extraction during the first and second periods was about 22% of the total methane extraction. However, it constituted 28% of all captured methane in the third period. This means that it is advisable to drill drainage boreholes at a considerable distance from the longwall face, as the safety conditions of extraction will improve and the costs of methane utilization will be significantly reduced.
8. It is advisable to measure the methane output for all of the methane drainage boreholes in a set every certain number of sets. This will allow for optimizing the inclination angles and number of drainage boreholes as well as adjusting them to the current geological conditions and rock mass methane bearing capacity.

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Abstract: In hard coal mines with methane, there is often a need to apply demethylation in order to keep the methane concentration not exceeding 2% in the ventilation air. The basic demethylation method in longwall areas is through drainage boreholes made in the roof rocks of the coal bed, from top gate, in front of the longwall. The drainage boreholes are usually made in bundles, in a fan-shaped arrangement, with several boreholes in each bundle. The paper presents the results of measurements and tests of the efficiency of a bundle of four drainage boreholes drilled approximately 100 m in front of the longwall face. The efficiency of individual boreholes was analyzed in time and depending on the distance of borehole outlets from the longwall face. It was found that there is a large variation in the extraction of air-methane mixture by individual drainage boreholes, as well as large differences in the efficiency of individual drainage boreholes during the longwall extraction process.

Keywords: hard coal mine, degasification, methane concentration, drainage boreholes