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THE EFFECTIVENESS OF THE METHANE DRAINAGE OF ROCK-MASS WITH A U VENTILATION SYSTEM

EFEKTYWNOŚĆ ODMETANOWANIA GÓROTWORU PRZY SYSTEMIE PRZEWIETRZANIA U OD GRANIC

Methane drainage is used in Polish coal mines in order to reduce mine methane emission as well as to keep methane concentration in mine workings at safe levels.

The article describes the method of methane drainage used in longwall D-2 in seam 410. In Poland, coal seams are frequently mined under difficult geological conditions in the roof and in the presence of very high methane hazard. In such situations, mines usually use a system with roof caving and a U ventilation system, which means that methane is drawn off from a tail entry behind the longwall front. In this system, boreholes are drilled from a tailgate and methane is drawn off from behind longwall face.

The article shows the influence of a specific ventilation system on the drainage efficiency at longwall D-2 in seam 410. At this longwall, measurements of methane emission and the efficiency of methane capture were conducted. They consisted in gauging methane concentration, air velocity, absolute air pressure and the amount of methane captured by the drainage system. Experimental data were used to estimate the variations in absolute methane-bearing capacity and ventilation methane, and – most importantly – to gauge the efficiency of methane drainage.

Keywords: methane drainage, ventilation system, effectiveness of methane drainage, methane hazard

Metan występujący w pokładach węgla kamiennego stanowi poważne zagrożenie dla bezpieczeństwa w podziemnych zakładach górniczych. Ograniczenie wypływu metanu do przestrzeni wyrobisk górniczych, w celu niedopuszczenia do przekroczenia dopuszczalnych przepisami górniczymi stężeń metanu w powietrzu przepływającym przez wyrobiska, narzuca stosowanie środków zapobiegających powstaniu zagrożenia w postaci odmetanowania górotworu. Umożliwia ono ograniczenie wypływu metanu do przestrzeni roboczej oraz odsunięcie najwyższych stężeń metanu w głąb przestrzeni zrobowej (Roszkowski i Szlązak, 1999; Szlązak i Korzec, 2010; Szlązak i Kubaczka, 2012; Skotniczy, 2013). Skuteczne odmetanowanie węgla w podziemnych wyrobiskach górniczych nie tylko poprawia bezpieczeństwo, ale również zwiększa wydobycie z wyrobisk eksploatacyjnych (Szlązak i Korzec, 2010; Szlązak i Kubaczka, 2012; Berger i in., 2010).

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W Polsce, roku 2012, eksploatacja prowadzona była w 31 kopalniach, z czego w 21 stwierdzono i rejestrowano wydzielanie metanu, a 15 z nich prowadziło eksploatację w warunkach IV najwyższej kategorii zagrożenia metanowego (Główny Instytut Górnictwa, 2013). W trzech kopalniach prowadzono eksploatację pokładów metanowych jednak nie rejestrowano wydzielania metanu. Obniżanie zagrożenia metanowego poprzez odmetanowanie pokładów przyczynia się do poprawy bezpieczeństwa załóg górniczych oraz ciągłości pracy maszyn zmniejszając liczbę postojów maszyn w wyniku wyłączeń energii elektrycznej po przekroczeniu wartości krytycznych stężenia metanu. Efektywne systemy odmetanowania to także możliwość pozyskiwania metanu, jako naturalnego źródła energii, ale również ograniczanie ujemnych skutków na środowisko naturalne wynikających z odprowadzania metanu do atmosfery.

W artykule opisano metodę odmetanowania górotworu przy wykorzystaniu sytemu przewietrzania U. Jako przykład przedstawiono ścianę D-2 w pokładzie 410. Eksploatacja ściany D-2 prowadzona była w rozpoznanej partii złoża na głębokości od 888 m do 1047 m, w pokładzie 410 o miąższości od 1,2-2,2 m. Mapę pokładu 410 wraz z lokalizacją ściany D-2 przedstawiono na rysunku 1.

Maksymalna zmierzona metanonośność pokładu 410 wynosiła 9,508 m^3CH_4/Mg csw. Prognoza metanowości bezwzględnej ściany D-2 w pokładzie 410 przewidywała maksymalne wydzielanie się metanu w ilości 36,78 m^3/min. przy postępie 7,25 m/d (wydobycie 3000 Mg/dobę). Udział poszczególnych warstw w wydzielaniu metanu przedstawia się następująco:

- z pokładu wybieranego – 25%,
- z warstw podbieranych – 42%,
- z warstw nadbieranych – 33%.

Ściana D-2 w pokładzie 410 przewietrzana była systemem U z doświeżaniem za pomocą wentylatora i lutniociągu. Powietrze do ściany D-2 w pokładzie 410 w ilości ok. 1500 m^3/min doprowadzone było chodnikiem nadścianowym D-2. Dodatkowo w rejon skrzyżowania wylotu ze ściany D-2 z chodnikiem podścianowym D-2, za pomocą lutniociągu doprowadzone było około 500 m^3/min.

W przypadku odmetanowywania pokładów sąsiednich niezbędne jest określenie strefy desorpcji wywołanej eksploatacją ściany. Otwory drenażowe powinny być zlokalizowane tak, aby znajdowały się w strefie odprężonej, natomiast nie przecinały strefy zawału bezpośredniego. W polskich warunkach geologicznych dobre wyniki daje wyznaczanie kątów nachylenia otworów drenażowych zgodne z pracą (Flügge, 1971), a przedstawionych na Rys. 2.

Rozmieszczenie otworów drenażowych w rejonie badanej ściany przedstawiono na rysunku 4 ich parametry techniczne zaś w tabeli 1. Parametry techniczne planowanych otworów drenażowych z chodnika nadścianowego i podścianowego D-2 przedstawiono w tabelach 2 i 3.

Celem artykułu było pokazanie jaki wpływ na efektywność odmetanowania ściany D-2 w pokładzie 410 miał dobór systemu przewietrzania U. W ścianie D-2 w pokładzie 410 przeprowadzono badania wydzielania metanu i jego ujęcia systemem odmetanowania. Badania polegały na pomiarach stężenia metanu, prędkości powietrza, ciśnienia barometrycznego i ilości ujmowanego metanu systemem odmetanowania. Pomiary prowadzono w oparciu o czujniki metanometryczne i prędkości powietrza umieszczone w ścianie D-2 w pokładzie 410. Rozmieszczenie czujników przedstawiono na rysunku 6. Niezależnie od tego dokumentowano postęp i wielkość dobowego wydobycia ze ściany. Czujniki, na podstawie których określano stężenia metanu kontrolowane były okresowo poprzez porównanie ich wskazań z mieszankami wzorcowymi, natomiast czujniki prędkości powietrza sprawdzano poprzez porównywanie ich wskazań z pomiarami chwilowymi wykonywanymi w miejscu ich zabudowy anemometrami ręcznymi.

Badania prowadzono w okresie od 01.04.2013 roku do końca października (28.10.) 2013 roku. W omawianym czasie, na podstawie pomiarów, dokonano bilansu dziennego ilości wydzielającego się metanu w rejonie eksploatacji. Jednocześnie obliczono dzienną wielkość wydobycia, postępu i wybiegu ściany. Dodatkowo w zadanym okresie czasu określono przebiegi zmian stężenia metanu na czujnikach metanometrycznych, prędkości i ciśnienia barometrycznego na wylocie z rejonu. Numery czujników, na podstawie których dokonywano obliczeń oraz ich lokalizację przedstawiono w tabeli 4.

Uzyskane dane oraz ilość metanu ujęta odmetanowaniem posłużyły do określenia przebiegu zmienności metanowości wentylacyjnej, bezwzględnej, a także określenia efektywności odmetanowania (Rys. 7-10).

W celu przeprowadzenia oceny statystycznej wyników sporządzono wykresy ramkowe wyznaczonych na podstawie pomiarów wielkości na wybiegu eksploatowanych ścian (Rys. 11-13). Dodatkowo dla ściany wykreślono zależność wydobycia od wybiegu (Rys. 14).

Analiza statystyczna obejmowała również określenie przebiegu zmienności ilości metanu ujętego odmetanowaniem i jego efektywności od wydobycia (Rys. 15, 16) i od metanowości bezwzględnej (Rys. 17 i 18), a także efektywności odmetanowania od metanowości wentylacyjnej (Rys. 19), stężenia

metanu od odmetanowania (Rys. 20) i ilości metanu ujętej odmetanowaniem od ciśnienia barometrycznego powietrza (Rys. 21).

Przeprowadzone obserwacje w rejonie ściany D-2 prowadzonej systemem U od granic pozwalają na następujące stwierdzenia:

- W trakcie biegu ściany zmianie ulega wydatek ujmowanego metanu oraz efektywność odmetanowania. Na etapie rozruchu ściany zarówno metanowość bezwzględna, jak również ilość metanu ujmowanego przez odmetanowanie uzyskiwały niższe wartości. Po okresie rozruchu ściany parametry te wzrastały i utrzymywały się na względnie stałym poziomie w czasie eksploatacji ściany. Wzrosła również efektywność odmetanowania.
- W czasie prowadzenia ściany stwierdzono wzrost ujęcia metanu systemem odmetanowania wraz z narastaniem metanowości bezwzględnej w rejonie.
- Zmiany wydobycia nie wpływały jednak na zmiany wydatku ujmowanego metanu.
- Analiza zmiany ilości ujmowanego metanu na tle zmian ciśnienie powietrza mierzonego w wyrobiskach nie wykazała zmian ilości metanu ujmowanego przez system odmetanowania. Ilość metanu ujęta systemem odmetanowania w całym badanym okresie utrzymywała się na stałym poziomie. Ten system odmetanowania nie jest czuły na zmiany ciśnienia powietrza. Otwory drenażowe nie posiadają bezpośredniego połączenia ze strefą oddziaływania otworów.

Słowa kluczowe: odmetanowanie, system przewietrzania U, efektywność odmetanowania, zagrożenie metanowe

1. Introduction

The need to reduce methane emissions into excavations in order to prevent exceeding the permissible levels of methane concentration in the air flowing through excavations makes it necessary to apply rock-mass methane drainage as a preventive measure. It enables reducing methane emissions into the working area and shifting the areas with the highest concentration of methane to the back of the cavity caused by the extraction (Roszkowski & Szlązak, 1999; Szlązak & Korzec, 2010; Szlązak & Kubaczka, 2012; Skotniczy, 2013). Effective methane drainage in underground excavations not only improves safety, but also increases coal output from mine workings (Szlązak & Korzec, 2010; Szlązak & Kubaczka, 2012; Berger et al., 2010).

In 2012, mining in Poland was conducted in 31 mines; in 21 of them, methane-bearing seams were mined and methane emissions were observed and recorded (Central Mining Institute, 2013). In three mines, methane-bearing seams were mined, but no methane emission was recorded. Reduction of methane hazard by means of coal seam degasification helps to improve work safety of miners as well as guarantees continuous machinery work by limiting the number of standstills resulting from switch-offs caused by exceeding critical values of methane concentration. In addition, effective methane drainage makes it possible to obtain methane as a natural source of energy, but also to reduce the negative influence on the environment caused by releasing methane into the atmosphere.

In 2012, annual coal output from gassy seams in Poland amounted to 59.4 mln Mg (75 percent of the output); as for non-gassy seams, it amounted to 19.8 mln Mg (25 percent of the output). The total amount of methane released from the rock-mass subjected to exploitation was 828.2 mln m^3, which gives an average emission of 1571.5 $m^3 CH_4$/min (Central Mining Institute, 2013).

2. Geology and mining conditions of the mined longwall

The exploitation of longwall D-2 took place in the developed part of the deposit at the depth ranging from 888 to 1047 m, in seam 410 whose thickness varied between 1.2 and 2.2 m. The roof strata were the following: gray shale, laminated, solid (0.0-2.0 m), sandy shale, interlayered with fine-grained solid sandstone (0.0-9.7 m), unsorted sandstone, solid (0.0-25.0 m), with occasional layers of sandy shale, coal n/d (0.0-1.0 m), sandy shale turning into unsorted sandstone (~30 m), shale (~1 m), coal seam 409/5 (~0.0-0.5 m), shale (~0.5 m), sandy shale (~1.50-5.50 m), shale (~2 m), fine-grained sandstone (~3 m), and coal seam 409/4 (3.10-3.50 m).

The bottom of the seam consisted of the following strata: shale with sand and numerous imprints of Carboniferous plants (0.0-1.2 m), coal seam n/d (0.5 m), sandy shale, solid, turning into fine-grained sandstone (~10 m), very solid with occasional layers of sandy shale, and seam 411/1 with a thickness of 0.25-0.50 m.

Figure 1 shows a map of seam 410, in which the localization of longwall D-2 is indicated. The longwall was extracted using a diagonal system from the boundaries of the field. The head-

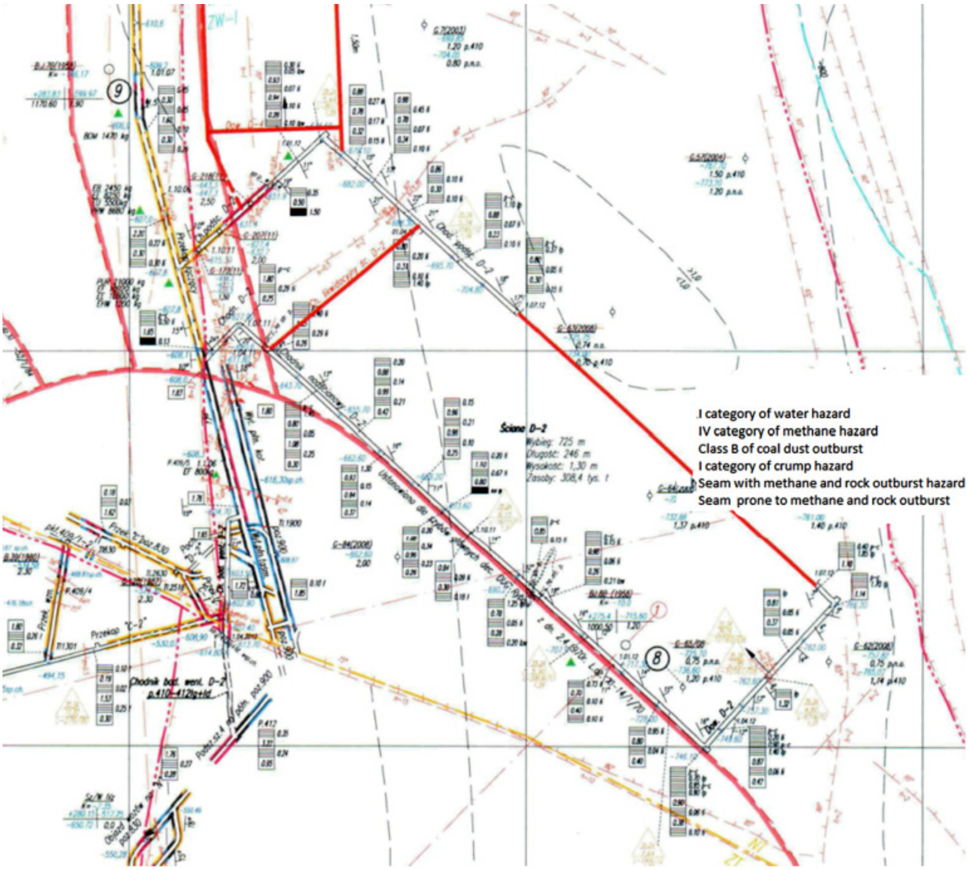

Fig. 1. A map of seam 410 in the area of longwall D-2

ings were drilled using supports with the profile V29-V36 and 0.6 to 0.8 m wide, depending on the geology and mining conditions; wherever a heading crossed a fault or a geological disruption, its supports were reinforced. In the headings, wider spaces or recesses were made to accommodate transformers, transporting devices, assembly rooms, etc. A plow system was implemented to extract the longwall.

The highest recorded methane content in seam 410 was 9.508 m^3CH_4/Mg ccs. According to the forecast of absolute methane-bearing capacity, the maximum predicted amount of released methane was 36.78 m^3/min at the rate of advance 7.25 m/d (coal output 3000 Mg/d).

The distribution of methane release in percentage terms was as follows:

- 25 percent from the mined seam
- 42 percent from underworked strata
- 33 percent from overworked strata.

Longwall D-2 in seam 410 was ventilated using a U system with additional air supply provided by a ventilator and an air duct. The longwall D-2 in seam 410 was supplied with ca. 1500 m^3/min via the upper entry D-2. An additional amount of air (500 $m^{3/}$min) was directed via an air duct to the crossing of the face end and the bottom road.

The return air from longwall D-2 was directed to shaft IV at the level 900 via the bottom road D-2.

3. The method of drilling drainage boreholes from the parallel headings

In order to implement methane drainage in adjacent seams, it is necessary to determine the boundaries of the desorption zone created by exploiting the longwall. Drainage boreholes should be positioned in the decompressed zone without overlapping with the goaf area. Under the geological conditions prevalent in Poland, accurate results of calculating the slope angles of drainage boreholes are achieved by using the method described in (Flügge, 1971) and presented in Figure 2.

The angles in Figure 2 refer to boreholes drilled in a direction parallel to the longwall face. Their inclination is approximately the same as the desorption angle. In case when boreholes are oblique relative to the longwall face, the values need to be adjusted accordingly. If boreholes are drilled from a parallel heading, it is necessary to take into account the width of the pillars separating the headings and to ensure that as much of the length of the borehole as possible remains in the decompressed zone.

The length of the borehole is determined by geological conditions, primarily by the position of the methane-bearing coal seams. As long as it is technically feasible, it should be aimed that the boreholes reach all the seams in the decompressed zone (desorption zone). The altitude of the desorption zone depends on the length (*L*) of the longwall.

Using the notation from Figure 2, the altitude of the desorption zone can be calculated with the following formula:

$$h_g = L \cdot \frac{\mathrm{tg}\beta \cdot \mathrm{tg}\varepsilon}{\mathrm{tg}\beta + \mathrm{tg}\varepsilon} \tag{1}$$

where β and ε denote desorption zone angles.

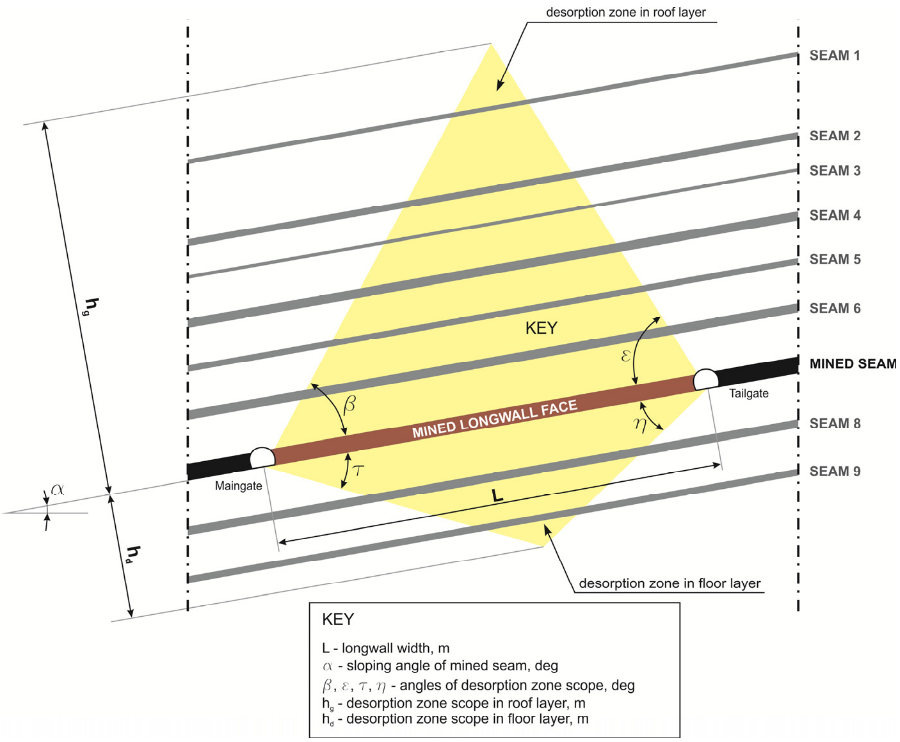

Fig. 2. Determination of methane desorption zone in a longwall during mining (Flügge, 1971)

According to Figure 2, the slope angles between the desorption area and the level of the seam in a degasification area at a vertical plane will be calculated as follows:

for the bottom road:

$$\beta = \delta_d - \alpha$$

and for the upper entry:

$$\varepsilon = \delta_d + \alpha$$

where: α — slope angle of the mined seam, deg.

As for the floor strata, the corresponding alternate angles are considered. Because the release of gases from the bottom layers is smaller than the calculated desorption zone would suggest, only half of the value of the desorption angles is assumed: $\tau = \dfrac{\beta}{2}$, $\eta = \dfrac{\varepsilon}{2}$.

The resulting formula for calculating the desorption area for floor strata is as follows:

$$h_d = L \cdot \frac{\mathrm{tg}\,\eta \cdot \mathrm{tg}\,\tau}{\mathrm{tg}\,\eta + \mathrm{tg}\,\tau} \tag{2}$$

Figure 3 illustrates where drainage boreholes are drilled when a U system of longwall ventilation is used. In this system, air is supplied via the bottom road, passes through the longwall

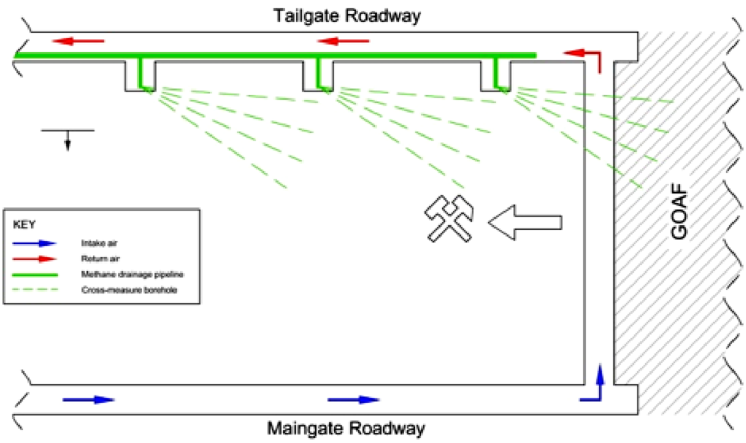

Fig. 3. A U ventilation system

and is directed to the longwall front along the solid coal. Drainage boreholes are drilled from the overlying (ventilation) heading and are liquidated as the exploitation front moves on.

After the headings had been drilled, drainage boreholes were made; their placement is shown in Figure 4. The boreholes were drilled in four bunches (KM 333, KM 353, KM 373, KM 400); their length ranged from 60 to 120 m and their diameter was 65 mm. At each station, there were five boreholes in each bunch, drilled into the roof strata and into the floor strata.

The technical parametres of drainage boreholes are presented in Table 1.

TABLE 1

The technical parametres of the drainage boreholes in the area of longwall D-2 in seam 410

Borehole no.	Borehole	Borehole diameter, mm	Borehole length, m	Deviation from the right angle, °	Inclination, °
1	TM29/12	65	60	23 to the left	15
2	TM30/12	65	70	8 to the left	15
3	TM31/12	65	80	7 to the right	17
4	TM32/12	65	100	22 to the right	20
5	TM33/12	65	120	32 to the right	20
6	TM151/12	65	80	23 to the left	-45
7	TM152/12	65	80	8 to the left	-45
8	TM153/12	65	80	7 to the right	-45
9	TM154/12	65	120	22 to the right	-35
10	TM155/12	65	120	32 to the right	-35
11	TM441/12	65	120	42 to the right	20

The drainage boreholes were then connected to a methane drainage pipeline with a diameter of 200 mm, installed in incline D-4 in seam 409/4. Despite creating negative pressure in the methane drainage station, no methane was collected as there was no decompression zone in seam 410. Methane concentration in the drainage boreholes fluctuated between 3 to 9 percent. This was caused by the absence of a decompression zone in the area where the boreholes were drilled. It had not been possible to capture methane from the boreholes drilled in incline D-4 in seam 409/4 until the extraction in longwall D-2 in seam 410 started and the area around the boreholes became decompressed. In May 2013, the amount of captured methane fluctuated between 0.5 and 3.0 m^{3}CH$_4$/min, while methane concentration was between 30 to 55 per cent.

The two drainage boreholes drilled from the upper entry D-2 in seam 410 did not yield the predicted amount of methane because the direction of ventilation in longwall D-2 had been reversed to prevent temperature hazard.

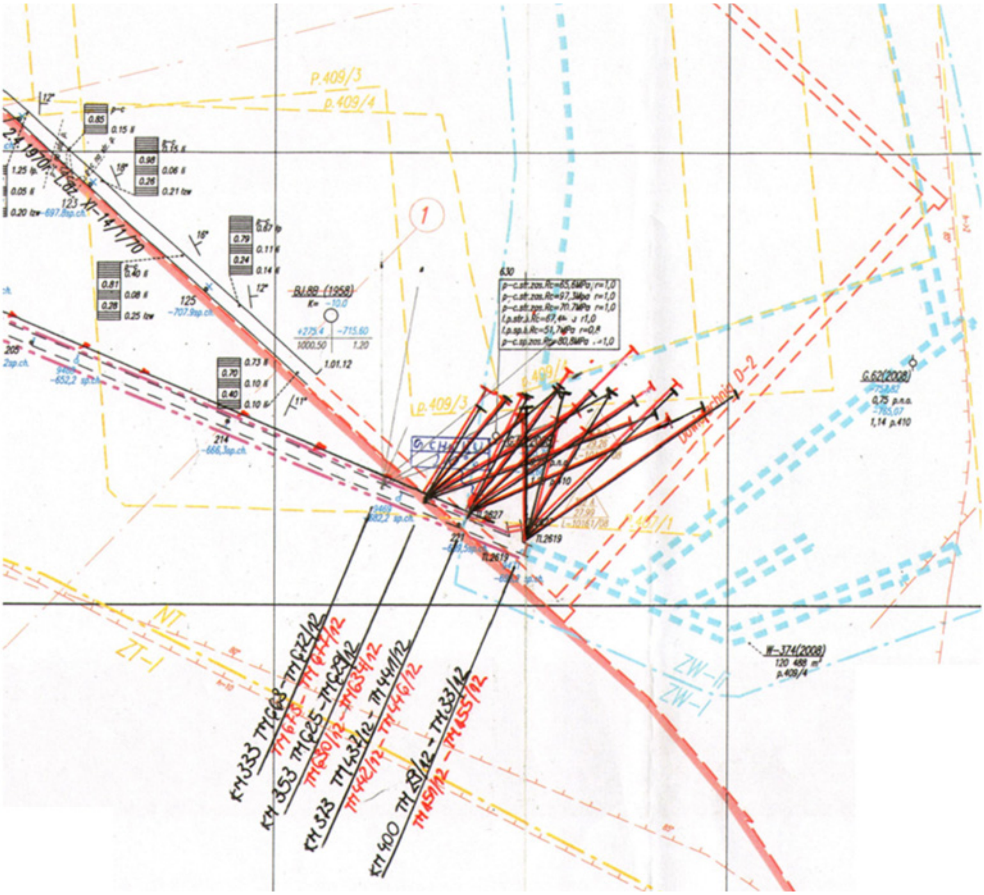

Fig. 4. The placement of drainage boreholes in the area of longwall D-2 in seam 410

After the ventilation system had been modified, drainage boreholes were designed and drilled in the bottom road D-2 (Fig. 5). The boreholes were drilled in bunches of four, separated by a distance of 18 m. During exploitation, four or five methane capture points operated at the face of longwall D-2, draining ca. 8 m^{3}CH$_4$/min, the value of methane concentration being above 50 percent. The parametres of the boreholes are listed in Tables 2 and 3.

TABLE 2

Technical parametres of the drainage boreholes to be drilled from the upper entry D-2 in seam 410

Bore-hole no.	Deviation of the borehole from the axis of the heading onto the longwall face, °	Deviation of the borehole from the axis of the heading onto the longwall face (optimal), °	Inclination of the borehole, °	Optimal inclination of the borehole, °	Borehole length, m	Optimal borehole length, m
1	18÷22	20	+11÷+13	+12	85÷95	90*
2	22÷26	24	+15÷+17	+16	85÷95	90*
3	26÷30	28	+19÷+21	+20	85÷95	90*
4	30÷34	32	+25÷+27	+26	85÷95	90*
5	34÷38	36	+17÷+19	+18	85÷95	90*

* The optimal borehole length is 60 m (±5 m) in the first bunch and 75 m (±5 m) in the second

TABLE 3

Technical parametres of the drainage boreholes to be drilled from the bottom entry D-2 in seam 410

Bore-hole no.	Deviation of the borehole from the axis of the heading onto the longwall face, °	Deviation of the borehole from the axis of the heading onto the longwall face (optimal), °	Inclination of the borehole, °	Optimal inclination of the borehole, °	Borehole length, m	Optimal borehole length, m
1	22÷26	24	+19÷+21	+20	85÷95	90*
2	26÷30	28	+23÷+25	+24	85÷95	90*
3	30÷34	32	+27÷+29	+28	85÷95	90*
4	34÷38	36	+31÷+33	+32	85÷95	90*

* The optimal borehole length is 60 m (±5 m) in the first bunch and 75 m (±5 m) in the second

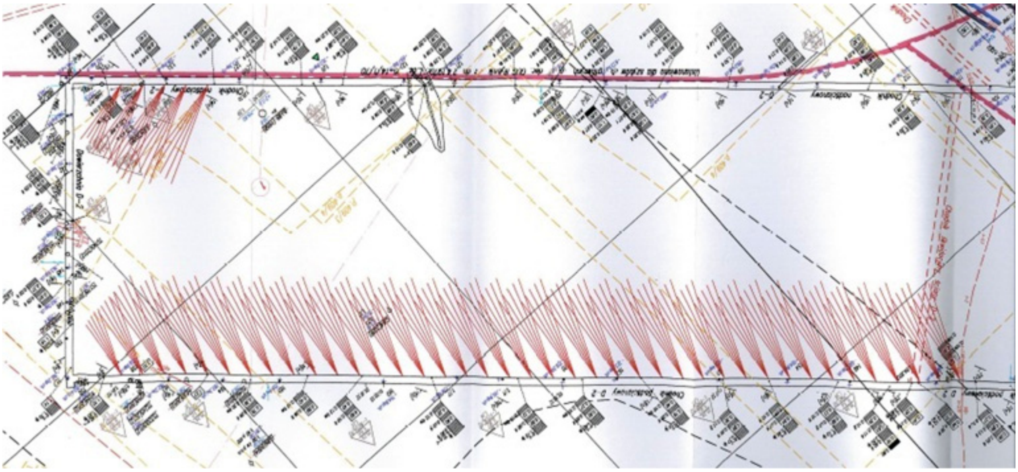

Fig. 5. The placement of drainage boreholes in the area of longwall D-2 in seam 410 after the ventilation system had been changed

4. The balance of methane release in the area of the mined longwall

At longwall D-2 in seam 410, a study was conducted in order to assess the methane release and the efficiency of the methane drainage system. The study consisted in measuring methane concentration, air velocity, absolute pressure and the amount of methane captured by the drainage system. The measurements were based on values recorded by sensors for measuring methane and air velocity placed at longwall D-2 in seam 410. The placement of the sensors is presented in Figure 6. Regardless of the efforts to gauge methane content and air velocity, the progression of mining works and daily output were documented. The sensors that served to assess methane concentration were checked at set time intervals by comparing their indications with reference mixtures, while the values indicated by the sensors of air velocity were checked periodically by comparing their indications with those obtained through instantaneous measurements carried out with manual anemometres at the places where air velocity sensors were installed.

The study was conducted in the period from April 2013 to the end of October 2013. The results made it possible to produce a balance of daily methane release in the mined area during the period under analysis. At the same time, average daily values of coal output, longwall advance and longwall life were calculated. In addition, the changes in methane concentration, air velocity and absolute air pressure at the outlet from the area were identified for the period under analysis. The numbers and placement of the sensors whose recorded values were used in the analysis are listed in Table 4.

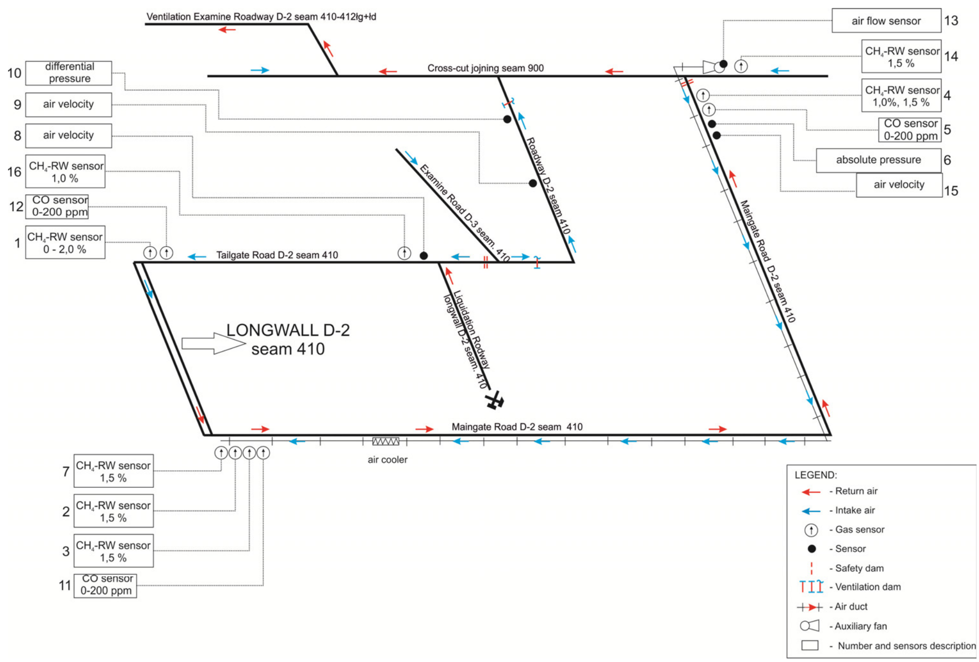

Fig. 6. The ventilation system of longwall D-2 in seam 410 with the location of the automated gas monitoring and the anemometric sensors

The values indicated by the measuring devices and the measured amount of captured methane were used to trace the changes in the methane-bearing capacity of ventilation air, absolute methane-bearing capacity and the efficiency of methane drainage.

During the period under analysis, the longwall face advanced by ca. 620 m. During this time, a maximum daily output of 3019 Mg/d was reached, while the average value was 1655 Mg/d. The greatest recorded longwall advance was 7.5 m/d, while on average its value was 2.94 m/d.

The results of the measurements made it possible to produce a balance of daily methane release in the mined area for the period between April and October 2013. The daily fluctuations in absolute methane-bearing capacity, in the ventilation air methane as well as in the amount of captured methane and methane drainage efficiency were determined and compared with coal output and longwall life. The results are presented in Figure 7.

TABLE 4

Numbers of automatic gas sensors and anemometric sensors used for calculations and their localization in longwall D-2

Sensor no.	Sensor position
AS-307	An anemometric sensor situated in the upper entry D-2/410 (inlet) about 40-60 m behind the crossing with the test heading D-3/410, in the clear cross-section of the excavation at the height of 2 m above the floor
AS-309	An anemometric sensor situated in the bottom road D-2/410 (outlet) about 10-25 m before the crosscut pos. 900, in the clear cross-section of the excavation at the height of 2 m above the floor
MM-80	A methanometric sensor situated (not more than 10 cm) below the roof of the support in the upper entry D-2/410, at a distance from the face end not greater than 10 m
MM-93	A methanometric sensor situated (not more than 10 cm) below the roof in the upper entry D-2/410, about 40-60 m behind the crossing with the test heading D-3/410 (in the direction of longwall D-2 seam 410)
MM-100	A methanometric sensor situated (not more than 10 cm) below the roof in the bottom road D-2/410, about 10-15 m before the crosscut pos. 900 (outlet from the area)
MM-125	A methanometric sensor situated (not more than 10 cm) below the roof in the bottom road D-2/410, at a distance of 6-10 m from sensor no. 2
MM-621	A methanometric sensor situated in the bottom road D-2/410 about 10-15 m before the crosing with the crosscut pos. 900

The obtained methane balance for the area of mined longwall D-2 in seam 410 shows that absolute methane-bearing capacity ranged from 2.09 to 36.62 m^3/min, whereas the average value was 24.07 m^3/min. The methane-bearing capacity of ventilation air ranged from 2.09 to 26.55 m^3/min, whereas the average value was 15.8 m^3/min.

Figures 8 to 10 show the variations in absolute methane-bearing capacity, the ventilation air methane and in the amount of captured methane, compared with coal output at particular 100-metre sections of the longwall life. The analysis of the results presented in the diagrams allows for the following conclusions:

1. 0 to 100 m (Fig. 8). During the start-up phase of mining it was observed that the level of absolute methane-bearing capacity showed a high degree of fluctuation within the range from 2.09 to 27.10 m^3/min. Drops in the value of absolute methane-bearing capacity were recorded during non-mining periods and when daily coal output declined, its

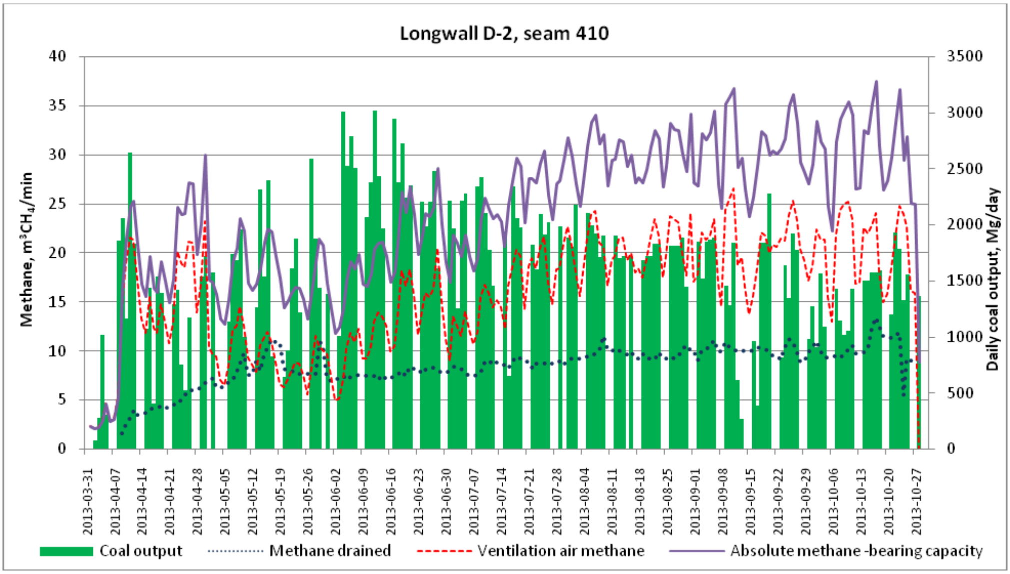

Fig. 7. Changes of absolute methane-bearing capacity, the ventilation air methane and the amount of drained methane compared with the coal output in the area of longwall D-2

average value during the period under analysis being 1278 Mg/d. Initially, the amount of captured methane was not recorded; then, its values increased gradually, their range being between 1.6 and 9.7 m^3/min.

2. 100 to 200 m (Fig. 9). Absolute methane-bearing capacity was at a level from 11.84 to 22.44 m^3/min and dropped during non-mining periods. The amount of captured methane ranged from 6.9 to 11.2 m^3/min. The coal output was around 1922 Mg/d.
3. 200 to 300 m (Fig. 10). Absolute methane-bearing capacity was at a fairly steady level from ca. 17 to 25.58 m^3/min, but also dropped during non-mining periods. The amount of captured methane ranged from 7.5 to 8.8 m^3/min and remained more or less constant. The average coal output was 2192 Mg/d.

During the entire analysed period, the greatest fluctuations of absolute methane-bearing capacity and coal output were detected during the start-up phase of mining until the longwall advanced to approx. 200 m. It was observed that despite an increase in the methane-bearing capacity of ventilation air, the amount of methane captured by the drainage system remained at a steady level, except for the start-up phase of mining the longwall (0 to 100 m). Therefore, it can be concluded that the adopted methane drainage system is an efficient preventive measure that reduces methane hazard during exploitation.

During non-mining periods the release of methane into the working drops. Nevertheless, the amount of captured methane remains at the same level as when mining is in progress.

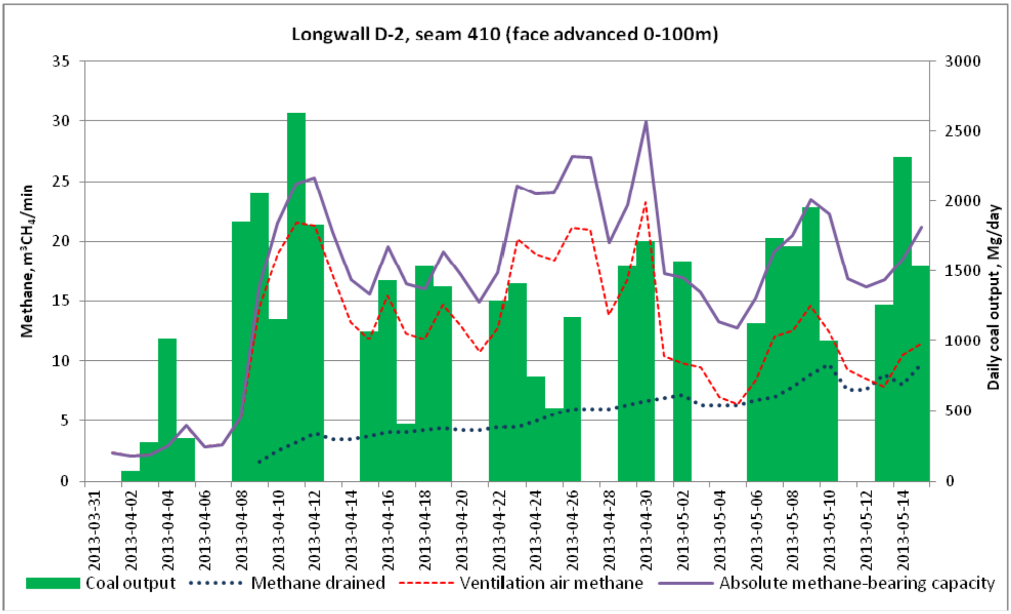

Fig. 8. Changes of absolute methane-bearing capacity, the ventilation air methane and the amount of drained methane compared with the coal output in the area of longwall D-2

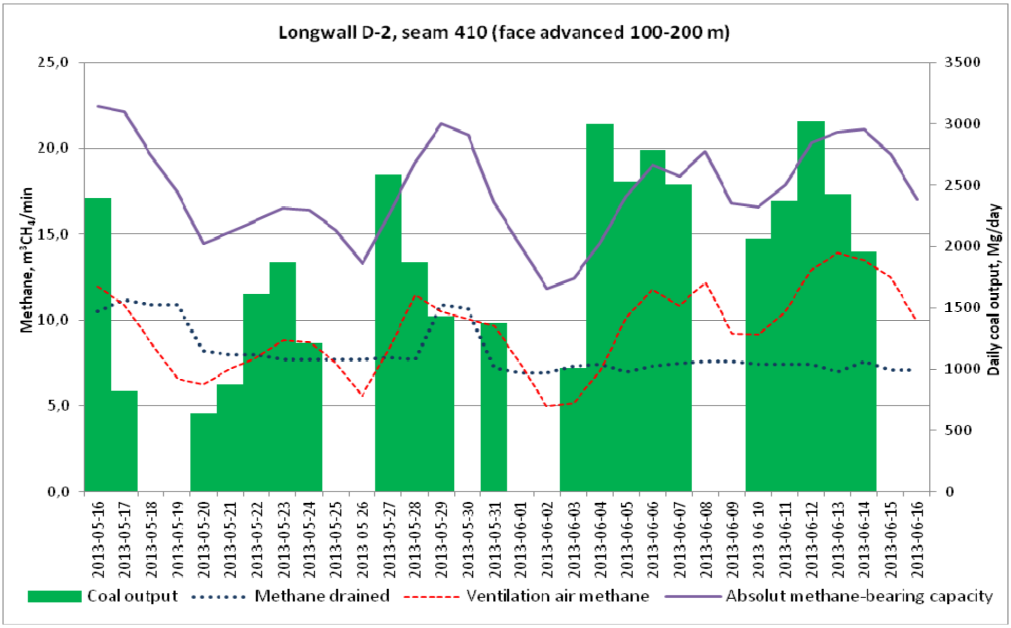

Fig. 9. Changes of absolute methane-bearing capacity, the ventilation air methane and the amount of drained methane compared with the coal output in the area of longwall D-2

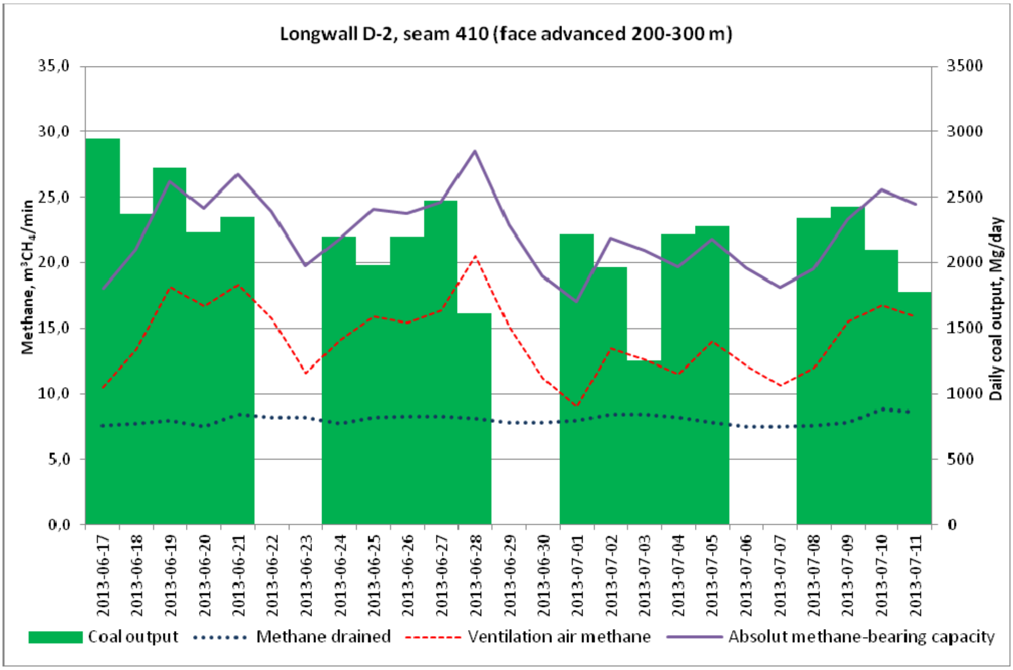

Fig. 10. Changes of absolute methane-bearing capacity, the ventilation air methane and the amount of drained methane compared with the coal output in the area of longwall D-2 air and the amount of captured methane compared with the coal output in the area of longwall D-2 in seam 410

5. The evaluation of the influence of various factors on the methane-bearing capacity and the amount of captured methane during the life of longwall D-2

In an attempt to evaluate the obtained results in statistical terms, box plots were created of the properties measured during the advance of longwall D-2. The results were organized according to 50-metre sections of the longwall life. In the plots, points denote arithmetic means, boxes refer to 95 percent confidence intervals, while whiskers mark the smallest and the highest of the recorded values. The results are presented in Figures 11 to 14. Average methane-bearing capacity varied from 14.37 to 30.96 m^3/min (Fig. 11), but its increase was continuous throughout the longwall life (except for the stretch between 100 to 150 m). At the same time, the average amount of methane captured by the methane drainage system rose from 3.92 to 10.47 m^3/min (Fig. 12).

During this time, the average efficiency of drainage initially increased from 20.45 to 51.36 percent and then dropped to remain at a level of 40 percent between the 150th and 620th metre of the longwall life (Fig. 13). During the period under analysis, the daily coal output fluctuated considerably between 1212 and 2457 Mg/d, while the average value was 1665 Mg/d (Fig. 14).

In addition, the impact of coal output on methane-bearing capacity of the longwall was also assessed. The results obtained from longwall D-2 are presented in Figures 15 and 16. Figure 15 presents the changes in the amount of captured methane compared with coal output. It can be

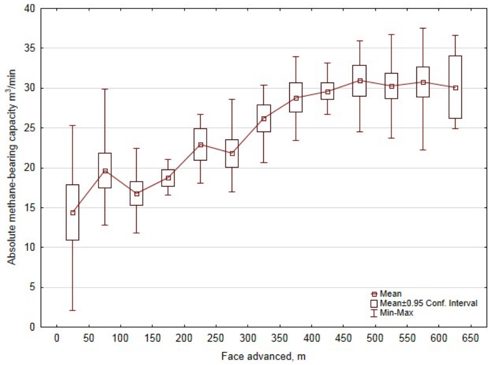

Fig. 11. Changes in absolute methane-bearing capacity compared with the face advance of longwall D-2 in seam 410

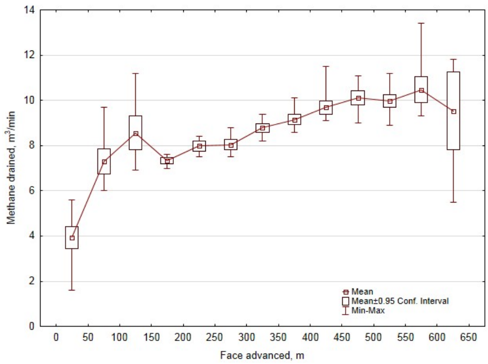

Fig. 12. Changes in the amount of captured methane compared with the face advance of longwall D-2 in seam 410

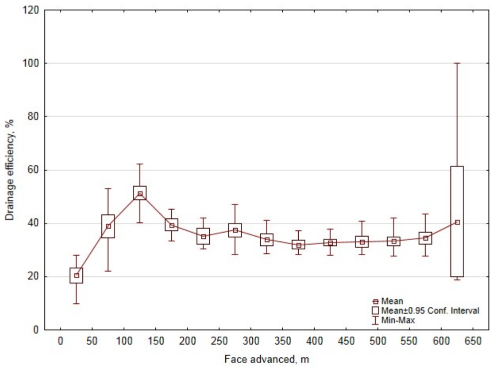

Fig. 13. Changes in the efficiency of methane drainage compared with the face advance of longwall D-2 in seam 410

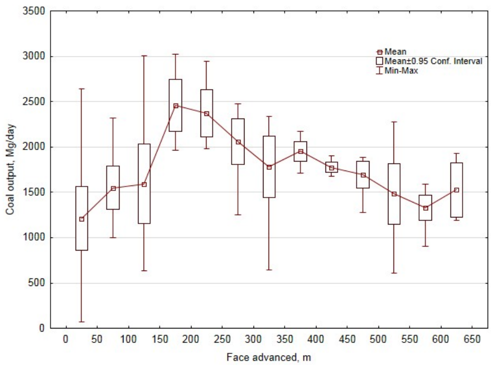

Fig. 14. Changes in coal output compared with the face advance of longwall D-2 in seam 410

observed that as coal output increases, the amount of captured methane remains at a fairly steady level ranging from the average value of 7 m^3/min to 9.2 m^3/min when the output was smaller (ca. 1700 Mg/d). The analysis of data presented in Figure 16 leads to the conclusion that the average methane drainage efficiency remains at a steady level of 40 percent regardless of the value of daily coal output.

Figure 17 illustrates the changes in the amount of captured methane in relation to absolute methane-bearing capacity. It emerges that the increase in absolute methane-bearing capacity is correlated with a linear increase in the amount of methane obtained through drainage. Figure 18 shows the changes in the efficiency of drainage compared with absolute methane-bearing capacity. It can be observed that the efficiency of drainage dropped from 50.63 to 31 percent as absolute methane-bearing capacity increased. Figure 20 shows how drainage efficiency dropped as the methane-bearing capacity of the ventilation air increased. This relationship can be explained by the fact that the more methane is released at the longwall face, the less gas is captured by the drainage system.

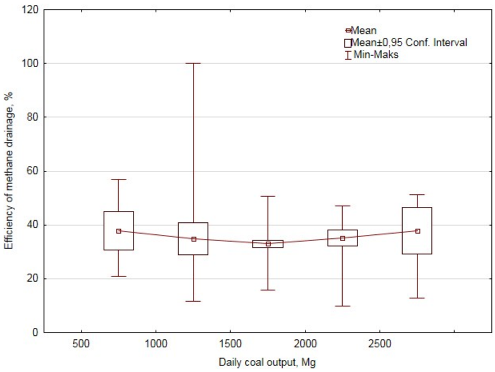

Fig. 15. Changes in the amount of captured methane compared with coal output from longwall D-2 in seam 410

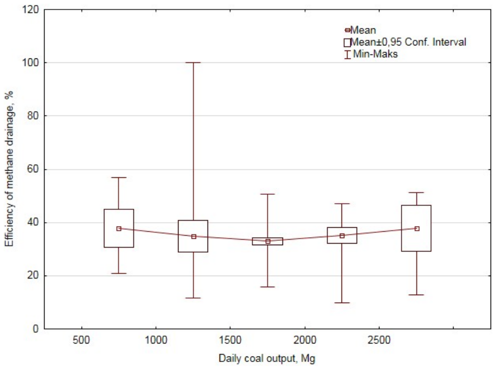

Fig. 16. Changes in the efficiency of methane drainage compared with coal output from longwall D-2 in seam 410

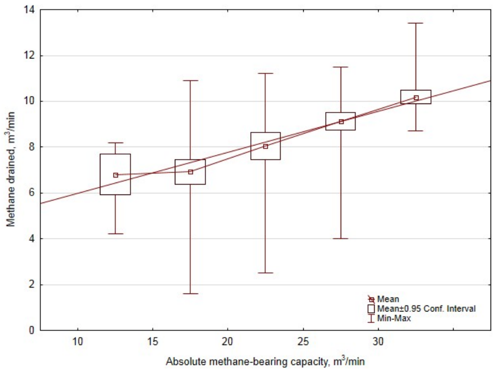

Fig. 17. Changes in the amount of captured methane compared with absolute methane-bearing capacity in longwall D-2 in seam 410

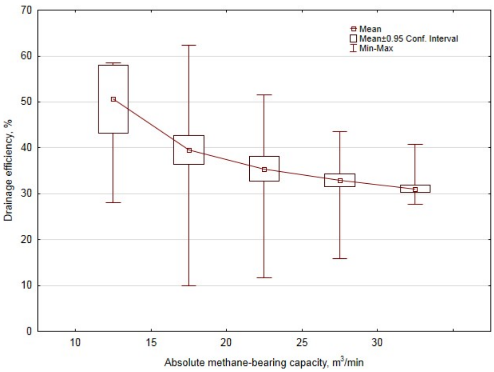

Fig. 18. Changes in the efficiency of methane drainage compared with absolute methane-bearing capacity in longwall D-2 in seam 410

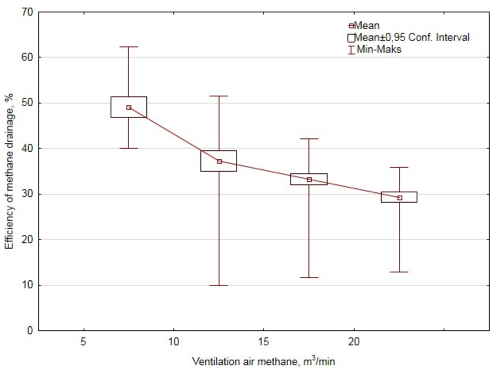

Fig. 19. Changes in the efficiency of methane drainage compared with the ventilation air methane in longwall D-2 in seam 410

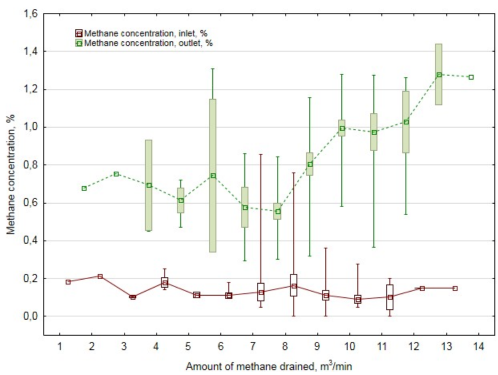

Fig. 20. Changes in methane concentration in longwall D-2 compared with the amount of captured methane

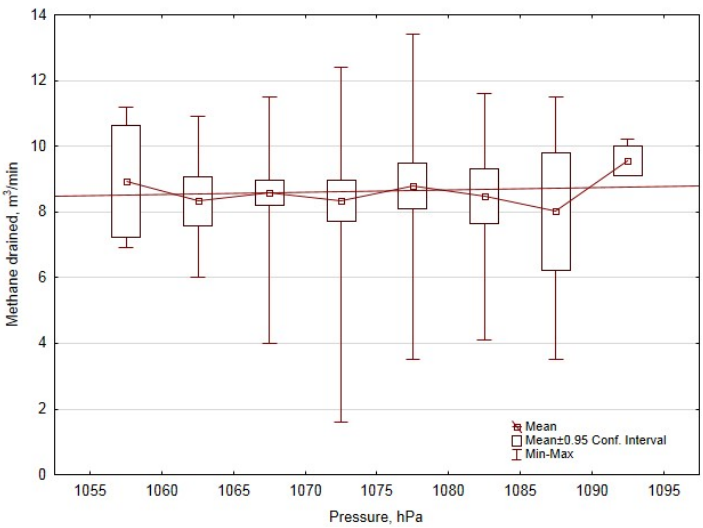

Fig. 21. Changes in the amount of methane captured from longwall D-2 in seam 410 in relation to air pressure in the longwall area

Figure 20 presents the changes in methane concentration compared with the amount of methane captured by the drainage system. As the amount of captured methane increased, the average methane concentration at the face end fluctuated between 0.55 and 1.27 percent and had a tendency to rise.

Figure 21 shows changes in the amount of captured methane in relation to the fluctuations of air pressure measured in the excavations. It emerges that an increase in air pressure bears no influence on the amount of methane captured by the drainage system, which remained at a steady level throughout the period under analysis. The implemented methane drainage system is not vulnerable to changes in air pressure. The drainage boreholes are not connected directly with the area from which they collect mine air.

6. Conclusions

The observations made in the area of longwall D-2, in which a U ventilation system from the boundaries of the field is implemented, justify the following conclusions:

- As the face of the longwall advanced, the amount of captured methane and the efficiency of methane capture fluctuated. At the beginning of the progression, values were lower for both parametres. When the start-up phase was over, the values for both parametres increased and remained at a relatively stable level during mining. Also, an increase in the efficiency of methane drainage was observed.
- As the mining works at the longwall continued, it was noticed that the amount of captured methane increases along with the rise of absolute methane-bearing capacity in the area.
- Changes in coal output did not affect the amount of methane captured by the methane drainage system.

- The analysis of the changes in the amount of captured methane in relation to the fluctuations of air pressure measured in the excavations revealed that an increase in air pressure bears no influence on the amount of methane captured by the drainage system, which remained at a steady level throughout the period under analysis. The implemented methane drainage system is not vulnerable to changes in air pressure. The drainage boreholes are not connected directly with the area from which they collect mine air.

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