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COMPARISON OF METHANE DRAINAGE METHODS USED IN POLISH COAL MINES

PORÓWNANIE METOD ODMETANOWANIA STOSOWANYCH W POLSKICH KOPALNIACH WĘGLA KAMIENNEGO

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

This article describes methods of methane drainage during mining used in Polish coal mines. The first method involves drilling boreholes from tailgate roadway to an unstressed zone in roof or floor layers of a mined seam. It is the main method used in Polish mining, where both the location of drilled boreholes as well as their parameters are dependent on mining and ventilation systems of longwalls. The second method is based on drilling overlying drainage galleries in seams situated under or over the mined seam.

This article compares these methods with regard to their effectiveness under mining conditions in Polish mines. High effectiveness of methane drainage of longwalls with different ventilation and methane drainage systems has been proven. The highest effectiveness of methane drainage has been observed for the system with overlying drainage gallery and with the parallel tailgate roadways. In case of classic U ventilation system of longwall panel, boreholes drilled from the tailgate roadway behind the longwall front are lost.

Keywords: methane hazard, 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. W związku z tym, że jest on gazem palnym i wybuchowym konieczne jest ograniczenie jego wypływu do przestrzeni wyrobisk górniczych. Proces ten wymaga stosowania środków profilaktycznych w postaci odmetanowania.

W artykule opisane zostały podstawowe metody odmetanowania górotworu stosowane w warunkach polskich kopalń. Warunki geologiczne występowania metanu w złożu węglowym oraz niska przepuszczalność polskich węgli powoduje, że uwolnienie gazu bez naruszenia struktury górotworu robotami górniczymi jest niewielkie. Ilość uwalnianego metanu jest ściśle związana z zakresem prowadzonych robót górniczych, zarówno robót udostępniających, jak i właściwej eksploatacji pokładów węgla (Krause i Łukowicz, 2004).

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W polskich kopalniach węgla kamiennego najczęściej stosowany jest ścianowy system eksploatacji. Pozwala on na uzyskanie stosunkowo dużej koncentracji wydobycia. Występująca często w rejonie eksploatacji wysoka metanonośność węgla wymaga zastosowania skutecznego odmetanowania. W dotychczas używanej technologii wyróżnia się dwa sposoby odmetanowania w trakcie eksploatacji. Pierwszy z nich związany jest z wierceniem otworów z chodników wentylacyjnych do strefy odprężonej w stropie lub spągu pokładu eksploatowanego. Jest to podstawowy rodzaj odmetanowania w polskim górnictwie. Miejsce wykonywania otworów, jak również ich parametry uzależnione są od systemu eksploatacji i sposobu przewietrzania ściany. Drugi sposób polega na wykonaniu chodników drenażowych w pokładach znajdujących się nad lub pod tym pokładem eksploatowanym.

Odmetanowanie górotworu jest najskuteczniejszym środkiem zwalczania zagrożenia metanowego, zapewniającym zmniejszenie wypływów metanu do przestrzeni roboczych. Najskuteczniejszą metodą okazało się drenowanie metanu z górotworu i otamowanych zrobów i odprowadzanie go osobnymi rurociągami na powierzchnię, wykorzystując depresję wytwarzaną w stacji odmetanowania. Metoda ta pomaga w utrzymaniu żądanych parametrów wentylacyjnych, stawia jednak określone wymagania co do sposobów rozcinania metanonośnych pokładów węgla. Odmetanowanie wyprzedzające w kopalniach polskich stosowane jest sporadycznie lub wcale ze względu na niską przepuszczalność węgli powodującą, że skuteczność tej metody jest zbyt niska.

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 rysunku 1.

Rozmieszczenie otworów drenażowych w rejonie ściany uzależnione jest od stosowanego systemu eksploatacji i przewietrzania. Jednym z najczęściej stosowanych jest system przewietrzania U (rys. 2), a w warunkach ścian o dużej prognozowanej metanowości system Y (rys. 3). W warunkach bardzo dużej prognozowanej metanowości system z równoległego chodnika wentylacyjnego (rys. 4). Rzadziej stosuje się system odmetanowania z nadległego chodnika drenażowego (rys. 5).

Celem artykułu jest porównanie systemów odmetanowania trzech ścian eksploatowanych w polskich kopalniach węgla kamiennego, różniących się systemem przewietrzania:
- Ściana D-2 w pokładzie 410 – system przewietrzania U,
- Ściana 2 w pokładzie 506 – system przewietrzania U z równoległym chodnikiem wentylacyjnym,
- Ściana B-11 w pokładzie 348 – system przewietrzania U z chodnikiem drenażowym.

Porównanie przeprowadzono na podstawie badań opartych o wyniki pomiarów: stężenia metanu, prędkości powietrza, ciśnienia barometrycznego i ilości ujmowanego przez systemem odmetanowania metanu. Wykorzystano wyniki z systemu rejestracji danych z czujników metanometrycznych i anemometrycznych rozmieszczonych w rejonie wyrobisk ścianowych. Na podstawie uzyskanych danych dokonano bilansu dziennego ilości wydzielającego się metanu w rejonie eksploatacji, a w dalszej kolejności określono przebieg zmienności metanowości wentylacyjnej, bezwzględnej, a także wyznaczono efektywność odmetanowania (rys. 7, 15, 23).

W celu przeprowadzenia oceny statystycznej wyników sporządzono wykresy ramkowe wyznaczonych na podstawie pomiarów wielkości na wybiegu eksploatowanych ścian (rys. 8-10, 16-18, 24-26). Dodatkowo dla ściany D-2 i B-11 wykreślono zależność wydobycia od wybiegu (rys. 11, 27).

Analiza statystyczna obejmowała również określenie przebiegu zmienności ilości metanu ujętego odmetanowaniem i efektywności odmetanowania od metanowości bezwzględnej i ciśnienia barometrycznego (rys. 12-14, 19-21, 30-32). Dodatkowo dla ściany 2 w pokładzie 506 wykreślono zależność stężenia metanu w rurociągu odmetanowania w funkcji ciśnienia barometrycznego (rys. 22), a dla ściany B-11 w pokładzie 348 zależności ilości metanu ujętego odmetanowaniem i jego efektywności w funkcji wydobycia (rys. 28, 29).

Przeprowadzona pozwala stwierdzić, że najwyższą efektywność odmetanowania uzyskuje się przy systemie z chodnikiem drenażowym (rys. 26) oraz z w systemie z równoległym chodnikiem wentylacyjnym (rys. 18). Przy klasycznym systemie przewietrzania U, otwory wiercone z chodnika wentylacyjnego za frontem ściany są tracone. W przypadku podwójnego chodnika wentylacyjnego filar pozostawiany pomiędzy chodnikami pozwala na uzyskanie trwałej szczelności otworów drenażowych, a co za tym idzie uzyskanie mieszaniny gazowej o wyższym stężeniu metanu.

W trakcie biegu ściany zmianie ulega ilość ujmowanego metanu oraz efektywność odmetanowania. Na etapie rozruchu ściany zarówno metanowość bezwzględna, jak również ilość ujmowanego przez

odmetanowanie metanu 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, natomiast zmiany wydobycia nie wpływały na zmiany ilości ujmowanego metanu.

Analiza zmian ilości ujmowanego metanu na tle zmian ciśnienia barometrycznego mierzonego w wyrobiskach wykazała, że zależność pomiędzy tymi parametrami nie zawsze istnieje. W przypadku systemu U analiza nie wykazała zmian ilości metanu ujmowanego przez system odmetanowania podczas zmian ciśnienia barometrycznego. Ilość metanu ujęta systemem odmetanowania przy przewietrzaniu U w całym badanym okresie utrzymywała się na stałym poziomie (rys. 14). Otwory drenażowe nie posiadają bezpośredniego połączenia ze strefą oddziaływania otworów. Przy systemie z równoległym chodnikiem wentylacyjnym oraz chodnikiem drenażowym wraz ze wzrostem ciśnienia barometrycznego w ścianie malała ilość ujmowanego przez system odmetanowania metanu (rys. 21, 32). W tym przypadku widoczne jest połączenie kanału ściany przez zroby z chodnikiem drenażowym lub otworami drenażowymi wykonywanymi za frontem ściany poprzez układ szczelin. Dlatego zmiana ciśnienia barometrycznego odgrywa dużą rolę w ujęciu metanu.

Zmiany ciśnienia barometrycznego w znaczący sposób wpływały na stężenie ujmowanej mieszaniny, co potwierdziły wyniki pomiarów stężenia metanu w obu nitkach rurociągów odmetanowania w ścianie 2 (rys. 22). Świadczy to o połączeniu zrobów z strefą oddziaływania otworów drenażowych.

Najniższą efektywność odmetanowania w granicach 30-40% uzyskiwano w ścianie przewietrzanej systemem U. Natomiast najwyższą, średnią efektywność odmetanowania, dochodzącą do 80% osiągano w ścianach z chodnikiem drenażowym. W ścianach z podwójnym chodnikiem wentylacyjnym uzyskiwano efektywność odmetanowania w granicach 50-60%.

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

1. Introduction

Methane occurring in coal seams negatively affects the safety of underground mines due to its release during mining activity. It is a flammable and explosive gas, which means it is – and always has been – a serious threat to safety in coal mines. Reducing the outflow of methane gas into the area of excavation sites, in an effort to avoid exceeding the limit of its concentration in the air around an excavation site as outlined by mining regulations, requires the application of safety precautions in the form of methane drainage from rock mass (Roszkowski & Szlązak, 1999; Szlązak & Korzec, 2010; Skotniczy, 2013). Efficient methane drainage from coal in underground excavation sites does not only improve safety, but also yields a higher concentration of production (Szlązak & Korzec, 2010; Szlazak & Kubaczka, 2012). Effective drainage systems enable the capture of methane as a natural energy source, and also limit the adverse effect on the natural environment resulting from its emission into the atmosphere.

In Poland in 2012, exploitation was conducted in 31 mines, 21 of which were home to work in methane coal beds and registered the emission of methane gas (Central Mining Institute, 2013).

In 2012 the annual coal extraction from methane deposits totaled 59.4×10^6 Mg (tonnes), which is 75% of total extraction, and from non-methane deposits 19.8×10^6 Mg (25% extraction). The exploited rock mass produced 828.24×10^6 m^3 of methane, which constitutes an average production of 1571.49 m^3 CH_4/min (Central Mining Institute, 2013).

In the next few years of exploitation in Polish mines, the threat of methane gas is expected to occur on a similar level. This means that it will continue to be a dominating factor. Therefore, safe operation of mines can be assured only with the use of appropriate methane precautions.

2. Methods of methane drainage from rock mass used in Polish mines

Geological conditions for the occurrence of methane in coal seams, as well as the low permeability of Polish coal, cause the natural release of gas – without mining interference – to be low. Hence the quantity of methane released is strictly related to the scope of mining works in a given place, i.e. both excavation site construction, and the actual exploitation of coal seams (Krause & Łukowicz, 2004; Berger et al., 2010).

In Polish coal mines, longwall system exploitation is most frequently used. This allows for relatively large output and considerable progress in mining activity (Szlązak et al., 2008). Occurring frequently in areas of exploitation is a high level of methane concentration, which requires effective methane drainage. Due to the variety of factors influencing the selection of a methane drainage system, many methods of longwall drainage have been used in Poland.

Among the drainage methods used today, there are two that stand out. The first involves drilling boreholes from the airways to the stress relief zone in the roof or floor of the exploited coal bed area. This is the basic method of methane drainage in Polish mining, with which both the placement of boreholes drilled, and their parameters depend on the system of exploitation in use as well as on the method of longwall ventilation. The second method is based on building drainage galleries in the coal seams found either over or under the seam being exploited.

Methane drainage from rock mass is the most effective means of combating the threat of methane, ensuring the reduction of gas outflow into the work area, and also preventing or reducing symptoms such as exhaust, sudden discharges of methane and coal, etc. The most efficient way of doing this has turned out to be draining methane from rock mass and diked caving zones, and then transferring it out with separate pipelines to the surface, using negative pressure produced in the methane drainage station. This method helps upkeep the desired parameters of ventilation, but it entails certain requirements with regard to the ways in which methane-containing coal seams are cut. Preemptive methane drainage in Polish mines is little or never used due to the low permeability of coal, making its effectiveness low.

When draining methane from adjacent seams it is essential to specify the zone of desorption brought on by longwall exploitation. Drainage boreholes should be located such that they are in the stress relief zone, but that they don't intersect the direct infarct zone. Under Polish geological conditions, good results are yielded by setting the angles of drainage boreholes according to the work being done (Flügge, 1971), as in figure 1.

Shown in figure 1, the angles of the scope of desorption correspond to the angles of boreholes drilled parellelly to the face of the longwall. When drilling boreholes diagonally to the longwall front it is necessary to appropriately incline the angles of the holes. If the boreholes are drilled from a parallel roadway, the angles must be set with respect to the width of the pillar between individual roadways; taking care that, insofar as possible, the largest part of the borehole is located in the stress relief zone.

The length of the borehole results from geological conditions, especially the location of the coal seams, which are a source of methane. If technically possible, the boreholes should intersect all seams located in the stress relief zone (the zone of desorption). The height of the desorption zone depends on the length of the longwall face L.

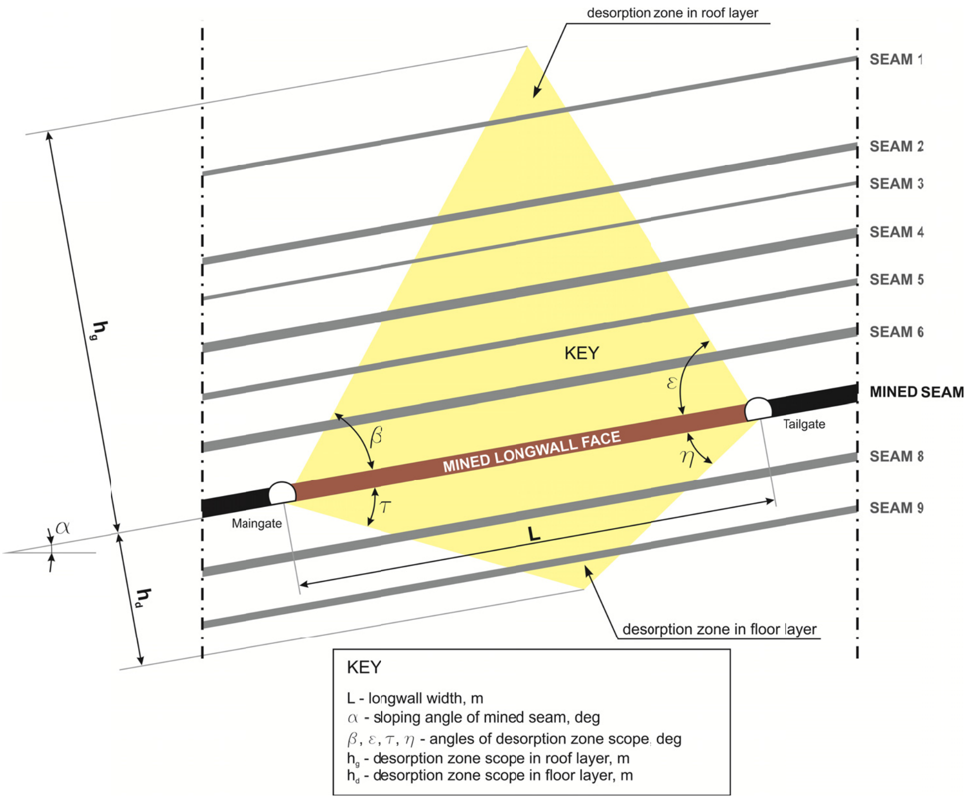

Fig. 1. Determining methane desorption zone during mining a longwall (Flügge, 1971)

Given fig. 1, the height of the zone in the roof seam can be calculated from the 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 are the angles of the desorption zone.

For the area of gas drainage on the vertical plane, and according to the scheme in figure 1, the angles of incline for the zone of desorption for the seam will amount to:

- For the lower airway
  $\beta = \delta_d - \alpha$
- For the upper airway
  $\varepsilon = \delta_d + \alpha$

where α – incline angle of the exploited seam (degree).

For layers of the floor we can assume the appropriate opposite angles. Because the actual outflow of gasses from layers of the floor is less than what is calculated for the zone of desorption, we can assume only half the value of the desorption angles in the roof of the seam: $\tau = \frac{\beta}{2}$, $\eta = \frac{\varepsilon}{2}$.

Thus for layers of the floor, the range of desorption can be calculated from the formula

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

The placement of drainage boreholes in the longwall area is dependent on the applied system of exploitation and ventilation (Szlązak and Szlązak, 2004).

2.1. Methane drainage system in longwall panel ventilated by U system

The air in this system is supplied by the airway, and after passing through the wall is then piped-away before the wall front along the body of coal. The drainage holes in this system are drilled from the tailgate road (return airway) and are eliminated after passing the exploitation front. An example of the placement of drainage boreholes in a longwall ventilated by U system is presented in figure 2.

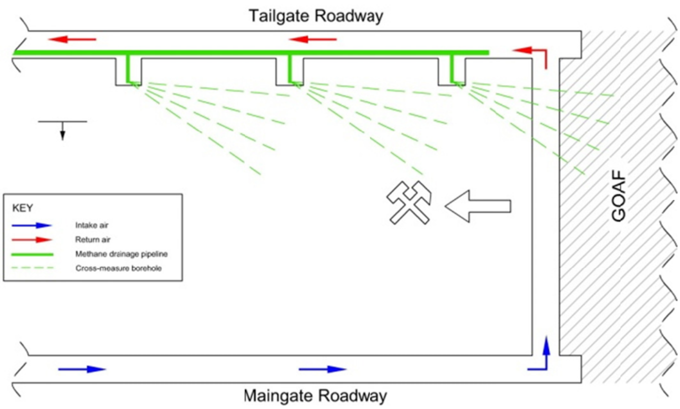

Fig. 2. Methane drainage system in longwall panel ventilated by U system

2.2. Methane drainage system in longwall panel ventilated by Y system

This type of system is used for longwalls with a high predicted level of methane content. In this system the air is supplied to the longwall face by the maingate roadway, and the discharge from the wall is facilitated by an airway. The drainage boreholes in this system are drilled from the tailgate roadway. The task of the boreholes in this system is to discharge the methane from the places of highest emission. The caving zone of the longwall is subjected to methane drainage. The largest quantities of methane are captured by drainage boreholes located 50-200 m behind the longwall front. An example of the placement of these boreholes in a longwall ventilated by Y system is shown in figure 3.

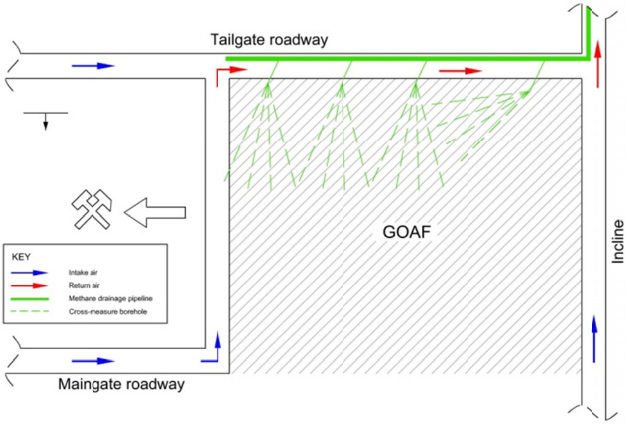

Fig. 3. Methane drainage system in longwall panel ventilated by Y system

2.3. Methane drainage system in longwall panel with a parallel tailgate roadway

This method of conducting methane drainage is used under conditions of high methane concentration in the excavation longwall. However, it requires additional mining work. There must be two airways. The air is supplied to the longwall via the upper roadway, and its exit from the longwall face is facilitated by a slightly lower roadway which runs parallel. The air in the first phase is discharged from the longwall face in the direction of the caving zone. Then, via the intersection between the two airways, it is the led upwards to the higher roadway. The drainage boreholes in this system are drilled from the higher parallel roadway towards the lower roadway which separates the system from the body of coal. An example of such placement of drainage boreholes from a parallel tailgate roadway is shown in figure 4.

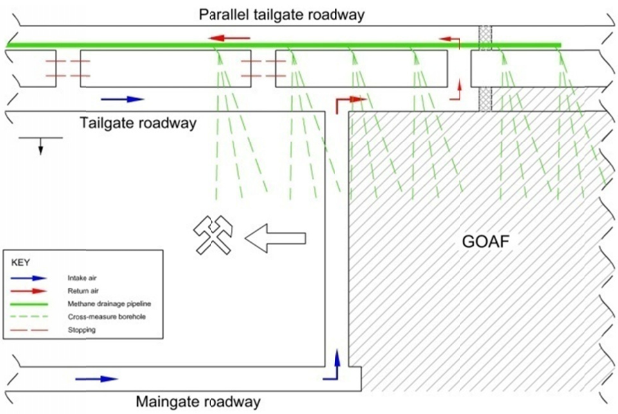

Fig. 4. Methane drainage system in longwall panel with a parallel tailgate roadway

2.4. Methane drainage system with an overlying drainage gallery

This system of methane drainage is less commonly used. At a certain distance above the exploited longwall area, airways are built from which boreholes are drilled towards the caving zone of the longwall. In this system, it is possible to drill boreholes to neighboring coal seams. An example of the placement of drainage boreholes drilled from an overlaying drainage gallery is presented in figures 5 and 6. One principle of this system is the construction above the exploited seam – in an accompanying seam not intended for exploitation – of a special airway called a methane drainage gallery. The airway should be located in the rock mass zone, within

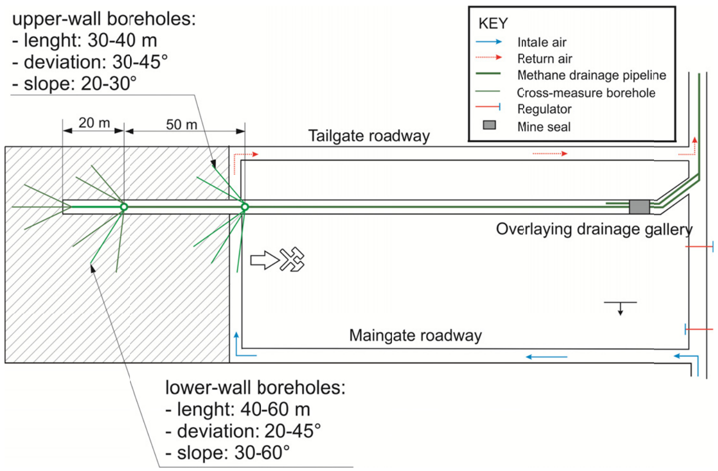

Fig. 5. Scheme of methane drainage with overlaying drainage gallery (Filipecki et al., 2006)

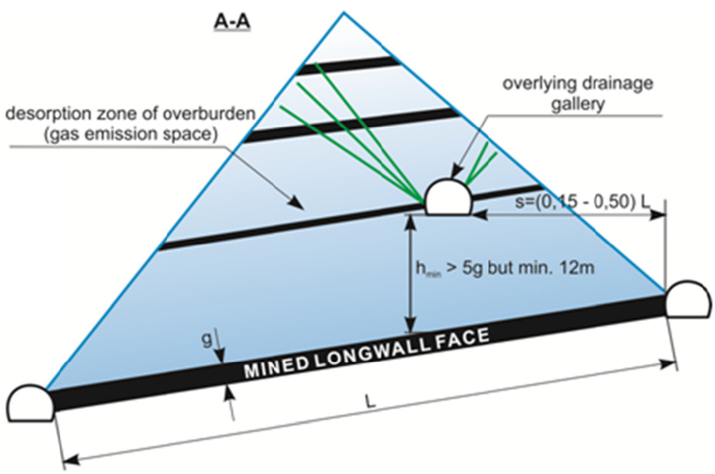

Fig. 6. Location of overlaying drainage gallery (Filipecki et al., 2006)

the desorption area. The method of designating this zone is shown in figures 1 and 6, and is described by relationships (1) and (2).

The distance between the exploited coal seam and the drainage gallery should not be smaller than the 5-fold thickness of the exploited area, and at the same time not smaller than 12 m. Offsetting the level of the drainage way from the edge of the desorption zone (from the side of the airway) should amount to $l_d = 0{,}3 \cdot L$. In the direction of the upper and lower sidewalls, at distances of about 50 m, drainage hole beams of typical diameters are installed from the drainage gallery. The angles of the beams are as follows:

– Upper sidewall boreholes:
  • length – 30-40 m
  • deviation – 30-45°
  • inclination – 20-30°
– Lower sidewall boreholes:
  • length – 40-60 m
  • deviation – 20-45°
  • inclination – 30-60°.

These boreholes are drilled into adjacent seams, improving drainage from the rock mass. However, they are not indended to be drilled in the seam with the drainage gallery. These boreholes are drilled without holding tubes.

After completing the scope of necessary drilling activities, the longwall support system is eliminated. The drift inlet is then isolated with an airtight insulating plug (made from the dust of burnt coal), through which the methane and control (measurement) pipes are run. The caputre of methane is carried out almost exclusively from outside the insulating plug, except for in the first phase of longwall work in which, due to the lack of caving zone, methane cannot be captured using overlaying drainage. During this period methane drainage is done using drainage boreholes drilled from the tailgate roadway of the longwall panel. On the basis of experience, it can be stated that the method of overlaying drainage is especially useful in cases where the majority of methane production is from the coal seam being exploited or from roof seams affected by previous exploitation. Extremely important is the quantity and total thickness of the latter, which are subject to gas drainage – the thicker they are, the better the drainage results.

3. Comparison of the efficiency of methane drainage using different systems

The efficiency of a methane drainage system can be verified through a detailed analysis of methane emissions in longwall excavation sites. Under the conditions of Polish mines, measurements were taken in three such sites: a longwall ventilated by U system; a longwall with a parallel tailgate roadways; and a longwall with a drainage gallery. Measurements were limited to determining the concentration of methane, the speed of airflow, barometric pressure, and the amount of methane captured by the drainage system. This study was performed on the basis of methane and anemometric sensors placed in the longwall excavation site. On the basis of data obtained, the authors of this article have determined a balance of the daily quantity of methane produced in an exploitation area, specified the variation in absolute ventilation methane-bearing capacity, and determined the effectiveness of methane drainage.

In order to statistically evaluate results, graphs of set measurements have been drawn up on the basis of exploitation longwall size. The measurements have been grouped at distances of 50 m. With 95% confidence interval, the arithmetic average on the graphs is indicated by a point, and the measured minimum and maximum value with box plots.

Subjected to analysis was the variation in the amount of methane captured by drainage, and the efficiency of this process in relation to absolute methane-bearing capacity and barometric pressure measured in excavation sites. Additionally plotted on the graph for longwall 2 in seam 506 is the relationship of methane concentration in the drainage pipeline as a function of barometric pressure; and for longwall B-11 in seam 348 the relationship of the amount of methane captured by drainage and its efficiency as a function of mining.

In longwall D-2 seam 410, U ventilation system is used. This study was conducted from 01.04.2013 to 28.10.2013.

During this time, the length of the exploited part of the longwall reached approximately 620 m and a maximum extraction of 3019 Mg/d, with an average of 1655 Mg/d. Maximum work progress came to 7.5 m/d, with an average of 2.94 m/d. The results are shown in figure 7. The balance of methane reached in longwall D-2 seam 410 showed absolute methane-bearing capacity in the range of 2.09 – 36.62 m^3/min, with an average value of 24.07 m^3/min. Ventilation air methane ranged from 2.09 to 26.55 m^3/min, with an average of 15.8 m^3/min. Analysis of results presented in the graphs shows that:

1. In the beginning phase of excavation (0-100 m into the longwall), the absolute methane-bearing capacity was highly variable, and its values ranged from 2.09 to 27.10 m^3/min. Decreases in absolute methane-bearing capacity were noted during periods of no or lesser mining activity, which for these periods averaged 1278 Mg/d. The amount of methane captured by drainage in the beginning phase of excavation was not determined, although

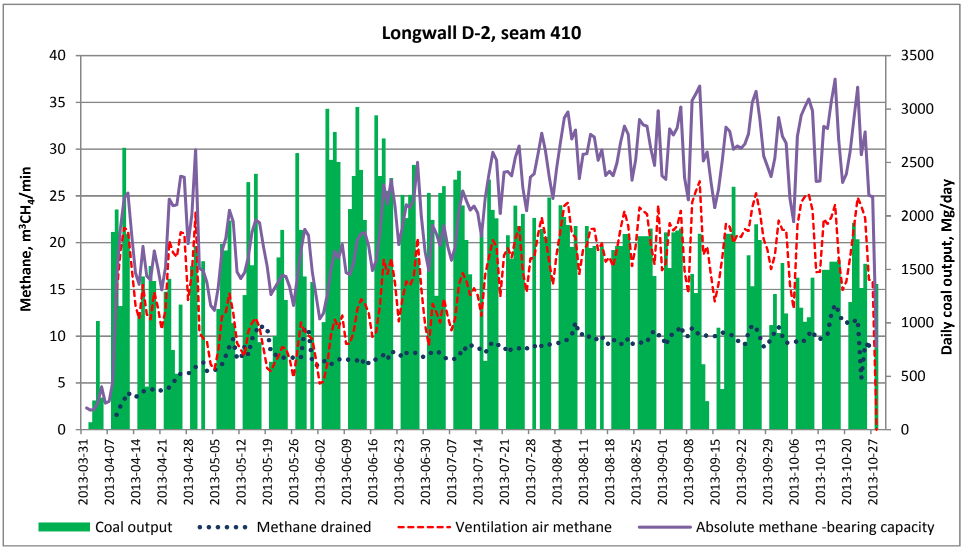

Fig. 7. Changes of absolute methane-bearing capacity, the ventilation air methane and the amount of drained methane compared with the coal output in the area of longwall D-2

in the following days its value gradually increased. During the whole period of research, it changed from 1.6 to 9.7 m^3/min.

2. 100 to 200 m into the longwall, the absolute methane-bearing capacity ranged from 11.84 to 22.44 m^3/min and showed decreases in value when mining activity was stopped. The amount of methane captured by drainage ranged from 6.9 to 11.2 m^3/min, and extraction amounted to about 1922 Mg/d.
3. 200 to 300 m into the longwall, the absolute methane-bearing capacity remained on a relatively stable level during the whole period (from approximately 17 to 28.58 m^3/min), but also showed a decrease in value when mining activities ceased. The amount of methane captured by drainage totaled from 7.5 to 8.8 m^3/min and remained on a relatively stable level. Average extraction totaled 2192 Mg/d.

During the period in question, the largest changes in absolute methane-bearing capacity and extraction were visible at the beginning of longwall exploitation (in the first 200 m). We can see that, as ventilation methane-bearing capacity rose, the amount of methane captured by the drainage system – with the exception of the first 200 m of exploitation – remained on a relatively stable level, which confirms that the system effectively limited the threat of methane during mining activity.

During periods of no extraction, methane emissions into the excavation area were lower. However, the level of captured methane remained similar to that observed during exploitation activity.

The results of statistical analysis are shown in figures 8 through 11. In the exploited area of the longwall, the average absolute methane-bearing capacity varied from 14.37 to 30.96 m^3/min (Fig. 8). At the same time, the average amount of methane captured by the drainage system grew from 3.92 to 10.47 m^3/min (Fig. 9).

In this time, the average efficiency of methane drainage grew from 20.45 to 51.36%, and then dropped; and for the longwall area from 150 to 620 m remained on the 40% level (Fig. 10). During the period covered by the analysis, the average extraction showed a high degree of variability, ranging from 1212 to 2457 Mg/d, with an average of 1665 Mg/d (Fig. 11).

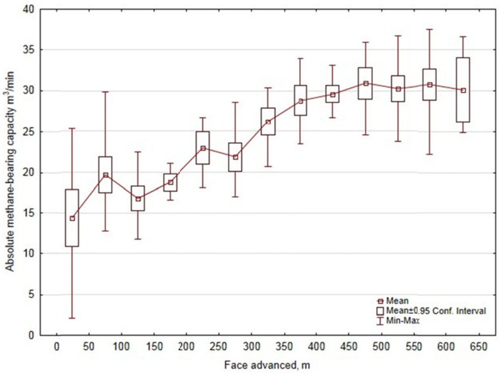

Fig. 8. Changes in absolute methane-bearing capacity compared with the face advance of longwall D-2

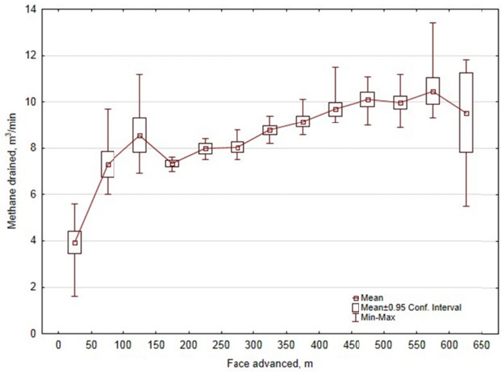

Fig. 9. Changes in the amount of drained methane compared with the face advance of longwall D-2

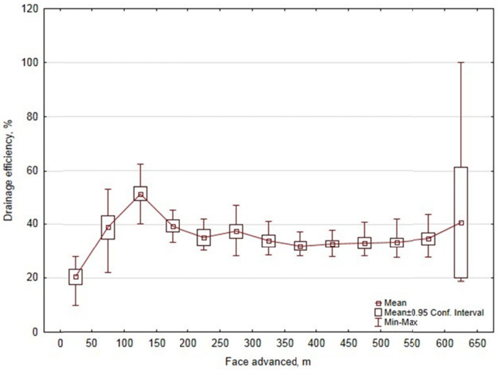

Fig. 10. Changes in the efficiency of methane drainage compared with the face advance of longwall D-2

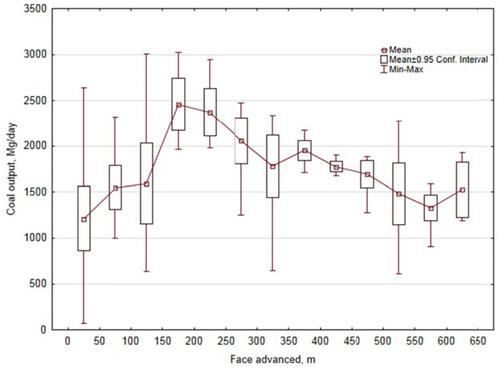

Fig. 11. Changes in the coal output compared with face advanced of longwall D-2

Figure 12 shows the change in the amount of captured methane juxtaposed against absolute methane-bearing capacity. Notable is the linear rise in absolute methane-bearing capacity along with the amount of captured methane. Figure 13 shows the change in efficiency of methane drainage from absolute methane-bearing capacity. On average, it decreased from 51 to 31% together with the rise in absolute methane-bearing capacity.

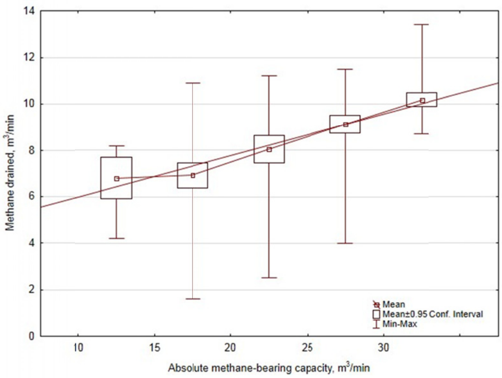

Fig. 12. Changes in the amount of drained methane compared with absolute methane-bearing capacity in longwall D-2

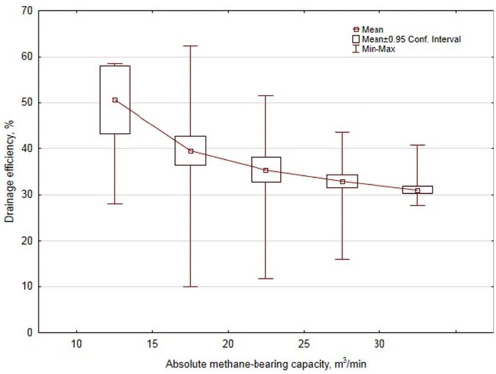

Fig. 13. Changes in the efficiency of methane drainage compared with absolute methane-bearing capacity in longwall D-2

Figure 14 shows changes in the amount of captured methane juxtaposed against the barometric pressure measured in the area of the studied excavation longwall. The relationship shows that the growth in barometric pressure did not influence the amount of methane captured by the drainage system. The amount remained constant during the whole research period. This means that the methane drainage system is not sensitive to changes in barometric pressure in an excavation site. Drainage boreholes are not directly connected to the area they affect.

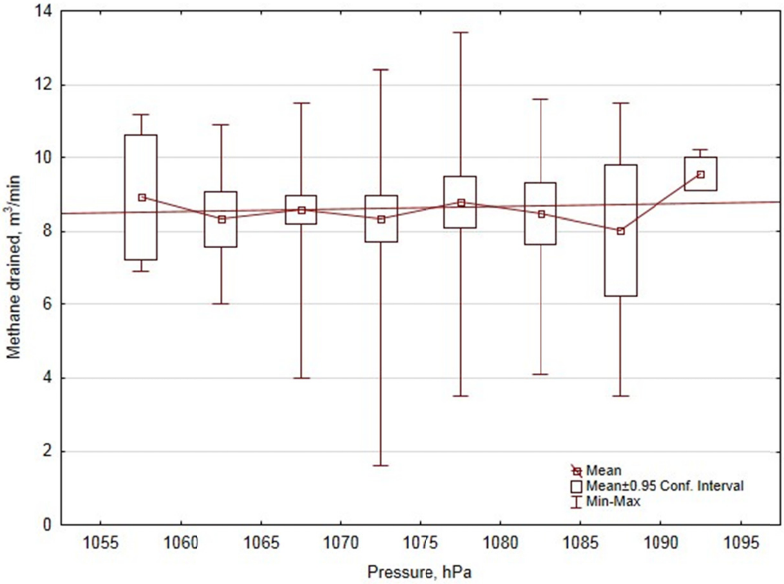

Fig. 14. Changes in the amount of drained methane from longwall D-2 in relation to air pressure in the longwall area

For longwall 2 seam 506, the U ventilation system was used with a parallel tailgate roadway. Measurements for the longwall were taken from 20.08.2012 to 02.09.2013. During this time, the exploited part of the longwall reached a distance of 400 m and a maximum extraction level of 3200 Mg/d, with an average of 1500 Mg/d. Maximum work progress came to 3,5 m/d, with an average of 1,1 m/d.

The results for specific time periods are shown in figure 15. The balance of methane in longwall 2 seam 505 revealed that the absolute methane-bearing capacity ranged from 8.7 to 48.4 m^3/min, with an average of 32.9 m^3/min. Ventilation air methane varied from 3.7 to 30.2 m^3/min, with an average equal to 15.8 m^3/min.

It was observed that, within the first 100 m section of longwall exploitation, absolute methane-bearing capacity rose and leveled out around 30 m^3/min. The amount of captured methane ranged from 10 to 15 m^3/min. Simultaneously, extraction stood at about 1500 Mg/d. Towards the end of this period, an increase in methane emissions was observed. In the section of the longwall from 100 m to 200 m, absolute methane-bearing capacity reached 40 m^3/min, with the quantity of captured methane ranging from 15 to 20 m^3/min. Extraction stayed on a level of about 1500 Mg/db. When mining activities were stopped, methane emissions dropped to 10 m^3/min. Nevertheless, the level of captured methane remained similar to that observed during mining activities.

Results of the statistical analysis are shown in figures 16 through 18. In the exploited area of the longwall, the average absolute methane-bearing capacity varied from 24 to 39 m^3/min (Fig. 16). At the same time the average quantity of methane captured by the drainage system rose from 8 to 22 m^3/min (Fig. 17). However, the average efficiency of methane drainage rose from 35 to 62% (Fig. 18).

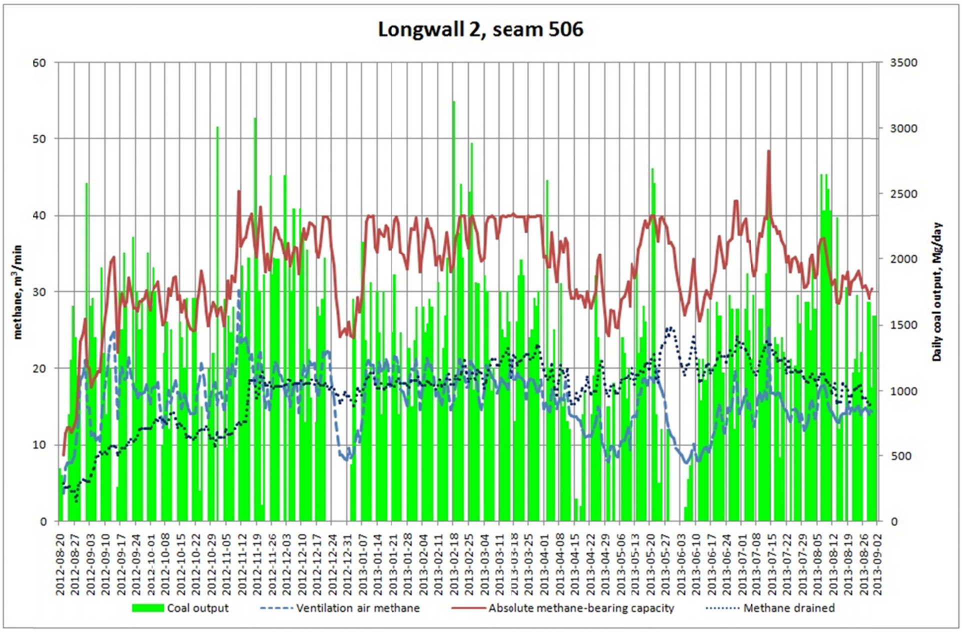

Fig. 15. Changes of absolute methane-bearing capacity, the ventilation air methane and the amount of drained methane compared with the coal output in the area of longwall 2 in seam 506

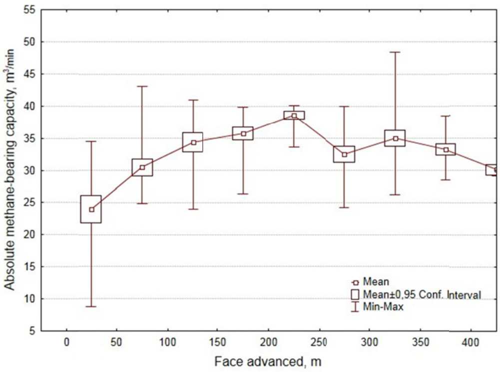

Fig. 16. Changes in absolute methane-bearing capacity compared with the face advance of longwall 2 in seam 506

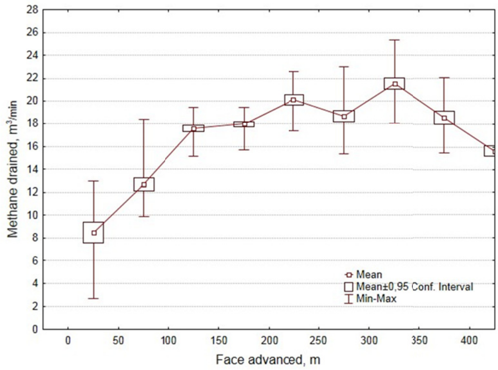

Fig. 17. Changes in the amount of drained methane compared with the face advance of longwall 2 in seam 506

Figure 19 shows the change in the amount of captured methane juxtaposed against absolute methane-bearing capacity. There is a positive linear correlation between the growth of absolute methane-bearing capacity and the amount of captured methane. However, figure 20 presents the change in efficiency of methane drainage from absolute methane-bearing capacity. We can also

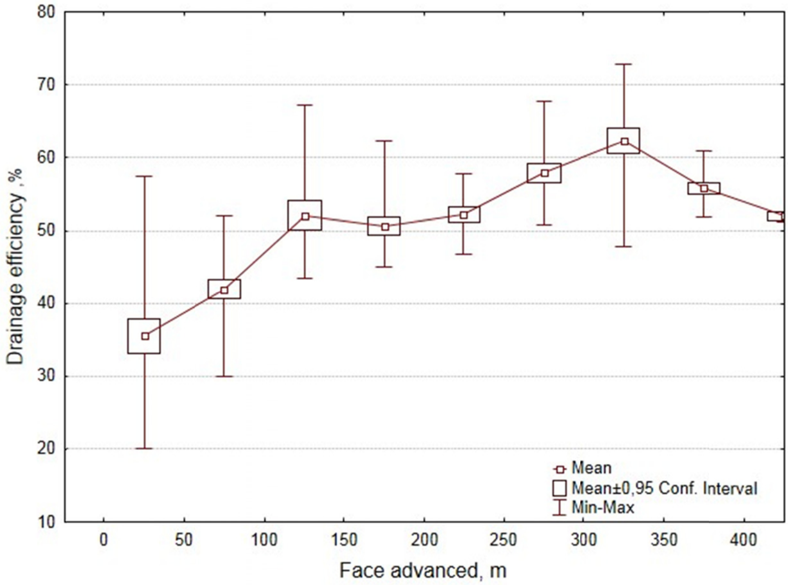

Fig. 18. Changes in the efficiency of methane drainage compared with the face advance of longwall 2 in seam 506

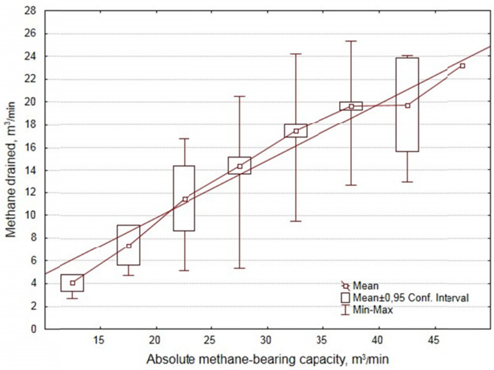

Fig. 19. Changes in the amount of drained methane compared with absolute methane-bearing capacity in longwall 2 in seam 506

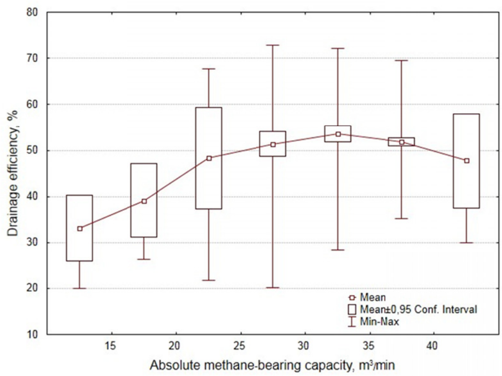

Fig. 20. Changes in the efficiency of methane drainage compared with absolute methane-bearing capacity in longwall 2 in seam 506

notice that the efficiency of methane drainage grew until absolute methane-bearing capacity reached about 30-35 m^3/min, after which it decreased.

Figure 21 shows changes in the amount of captured methane from changes in barometric pressure measured in the gateroad excavation site. The linear relationship shows that the growth in barometric pressure correlated to a decrease in the amount of methane captured by the drainage system. This observation unambiguously indicates that the researched system of methane drainage has a connection with the caving zone of the exploited longwall face. The methane drainage holes remained behind the front of the longwall panel. Figure 22 shows the change in methane-bearing capacity in the gaseous mixture captured by the drainage pipeline. When looking at the graph, we can see a clear influence of the changes in barometric pressure on the concentration of the captured mixture. In both drainage pipeline threads, we can observe a similar phenomenon. This reflects the connection of caving zones with the zone of drainage hole influence.

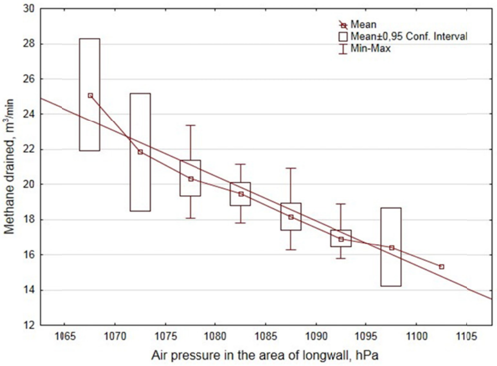

Fig. 21. Changes in the amount of drained methane from longwall 2 in seam 506 in relation to air pressure in the longwall area

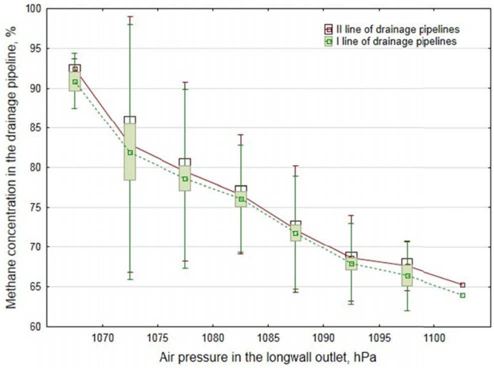

Fig. 22. Changes in methane concentration in the drainage pipelines (pipelines I and II)

In longwall B-11 seam 348, research was conducted on the emission of methane and its capture by the drainage system using a drainage gallery. This was done from 12.12.2012 to 29.09.2013. In this time period, the working section of the longwall reached a distance of almost 700 m, with an extraction maximum of 4420 Mg/d, and an average of 2320 Mg/d. Maximum work progress came to 5.8 m/d, with an average of 2.32 m/d.

On the basis of measurements taken, a balance of methane emissions was established in the period from December 2012 to September 2013. Recorded were the daily changes of ventilated absolute methane-bearing capacity, as well as the efficiency of captured methane juxtaposed against extraction and the exploited part of the longwall. The results for the period of research are shown in figure 23.

The balance of methane in longwall area B-11 seam 348 showed that the absolute methane-bearing capacity ranged from 14.4 to 94.76 m^3/min, with an average of 63.67 m^3/min. Ventilation air methane reached values of 8.57 to 27.73 m^3/min (average 18.86 m^3/min).

Analysis of the results presented in figure 23 demonstrates that:

1. In the beginning period of longwall exploitation (in the first 100 m exploited section of the longwall), it was observed that the absolute methane-bearing capacity increased to values of approximately 70 m^3/min, and then decreased to values of approximately 52.5 m^3/min. The quantity of captured methane varied from 3.2 to 43 m^3/min. Average extraction amounted to around 2049 Mg/d. At the end of this period, methane emissions began to rise.
2. In the 100-200 m exploited section of the longwall, absolute methane-bearing capacity remained more or less stable, ranging from 50 to 64 m^3/min, with a decrease in value

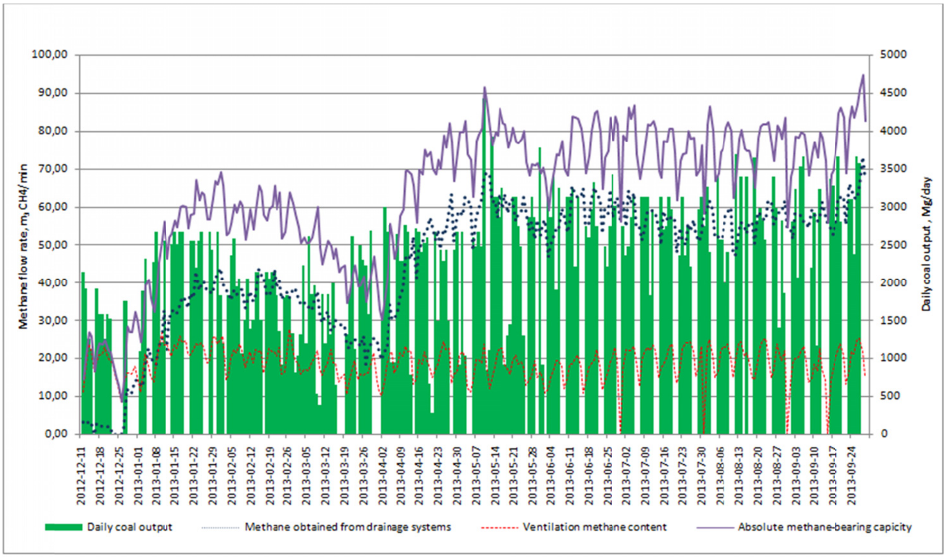

Fig. 23. Changes of absolute methane-bearing capacity, the amount of ventilation and captured methane compared with the coal output in the area of longwall B-11 in seam 348

to approximately 34 m^3/min from about 180 m on. The quantity of captured methane ranged from 10.65 to 27.73 m^3/min. Extraction stayed at around 1648 Mg/d.

3. In the 200-300 m exploited section of the longwall, the value absolute methane-bearing capacity decreased until it reached about 30 m^3/min at 221 m. From this point on, the absolute methane-bearing capacity began to increase, reaching 82, 5 m^3/min at 298 m. The quantity of methane captured by drainage varied from 18.5 to 62.3 m^3/min, with an average extraction of 2015 Mg/d.
4. In the 300-400 m section of the exploited longwall, the absolute methane-bearing capacity remained more or less the same throughout the range, i.e. it varied only slightly from 62.6 do 91.56 m^3/min. The quantity of methane captured via drainage ranged from 46.9 to 68.9 m^3/min with an average extraction of 2577 Mg/d.

During the whole analyzed period, the biggest changes in absolute methane-bearing capacity and extraction were visible in the first 300 m exploited section of the longwall. In the later part of the period, both the absolute methane-bearing capacity and extraction remained on a stable level. It can be noted that the efficiency of methane drainage rose along with the ventilation methane-bearing capacity. During periods of no mining activity, methane emission into the longwall excavation site decreased. The level of captured methane also decreased, but to a much lesser extent.

The results of the statistical analysis are shown in figures 24-29. In the exploited section of the longwall, the average absolute methane-bearing capacity fluctuated from 26.37 to 84.07 m^3/min (Fig. 24). Simultaneously, the average amount of methane captured by the drainage system grew from 8.76 to 63.34 m^3/min (Fig. 25), and the average efficiency of methane drainage from 32.5 to 75.4 % (Fig. 26). In the time of analysis, the average extraction wavered from 1741 to 3131 Mg/d, with a mean of 2320 Mg/d (Fig. 27).

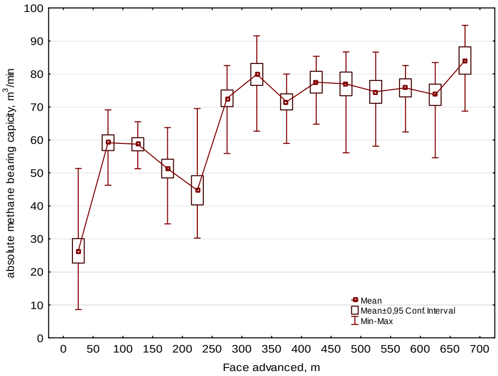

Fig. 24. Changes in absolute methane-bearing capacity compared with the face advance of longwall B-11

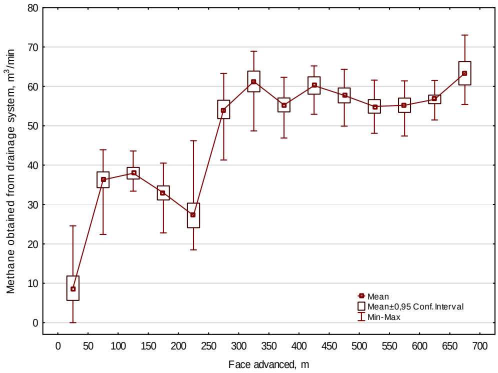

Fig. 25. Changes in the amount of captured methane compared with the face advance of longwall B-11

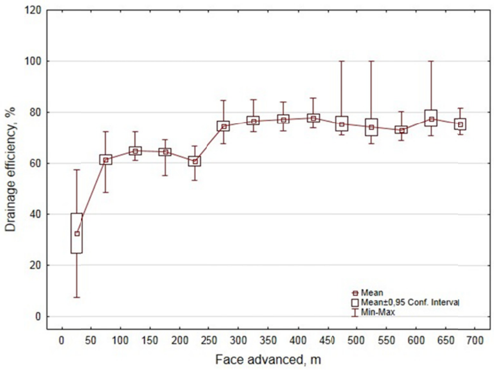

Fig. 26. Changes in the efficiency of methane drainage compared with the face advance of longwall B-11

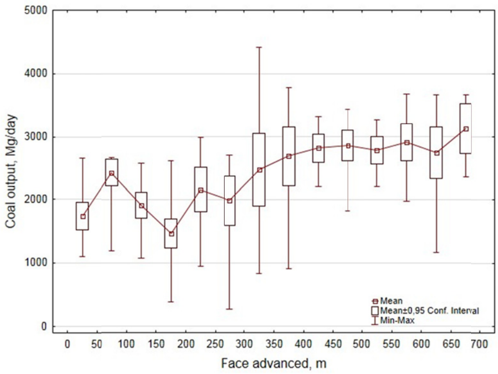

Fig. 27. Changes in coal output compared with the face advance of longwall B-11

An evaluation of the measurement results in relation to extraction was carried out and shown in figures 28 and 29. In figure 28 is the amount of captured methane with respect to extraction. It can also be seen that, together with the rise in extraction, the amount of methane captured initially fell from an average of 46 m^3/min to 28 m^3/min, and then increased to 58 m^3/min. Similar was the efficiency of methane drainage (Fig. 29). Only greater progress resulted in a larger amount of methane and higher efficiency ranging from 60 to 80%.

Figure 30 shows change in the amount of captured methane juxtaposed against absolute methane-bearing capacity. We can also notice that the increase in amount of captured methane rises linearly with absolute methane-bearing capacity. Figure 31 shows the change in efficiency of methane drainage from absolute methane-bearing capacity. It can also be seen that the average effectiveness of methane drainage rose from around 24.9 to 71.5%, and then remained on a stable level of 74-75%.

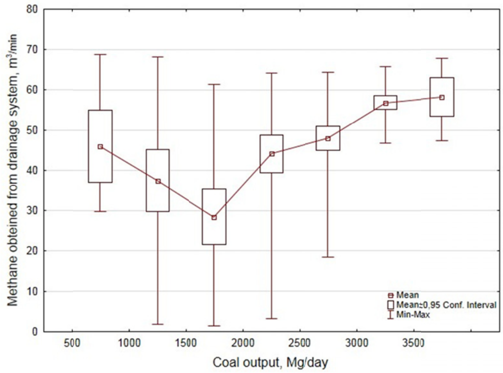

Fig. 28. Changes in the amount of captured methane compared with coal output from longwall B-11

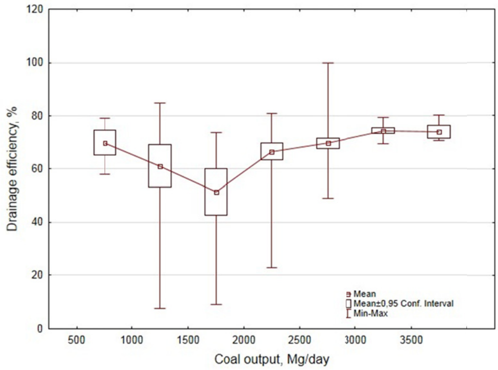

Fig. 29. Changes in the efficiency of methane drainage compared with coal output from longwall B-11

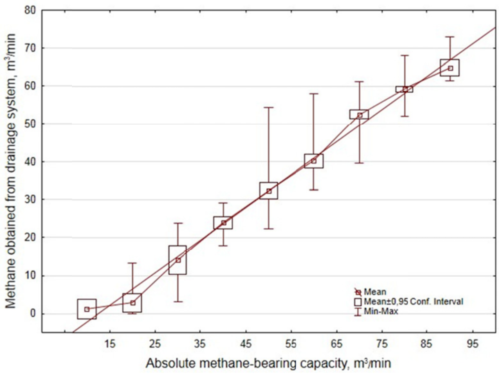

Fig. 30. Changes in the amount of captured methane compared with absolute methane-bearing capacity in longwall B-11

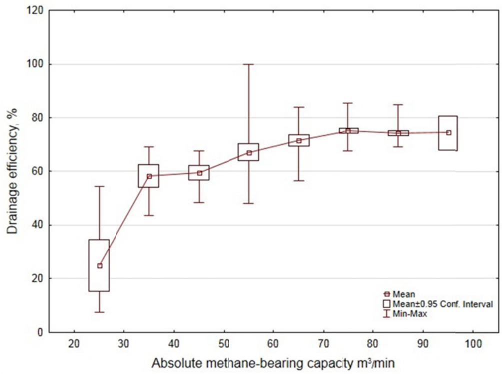

Fig. 31. Changes in the efficiency of methane drainage compared with absolute methane-bearing capacity in longwall B-11

Figure 32 shows changes in the quantity of methane captured juxtaposed against barometric pressure measured in excavation sites. The linear relationship shows that as barometric pressure increased, the amount of methane captured by the drainage system decreased. In this case, the connection of the caving zone with the drainage gallery through porting is also visible. In such situations the change in barometric pressure plays a large role in the capture of methane.

4. Conclusions

It can be concluded from the above research that the highest efficiency of methane drainage can be achieved with a drainage gallery, as well as with a parallel tailgate roadways. With classic U ventilation system, the boreholes drilled from the return airway behind the front of the

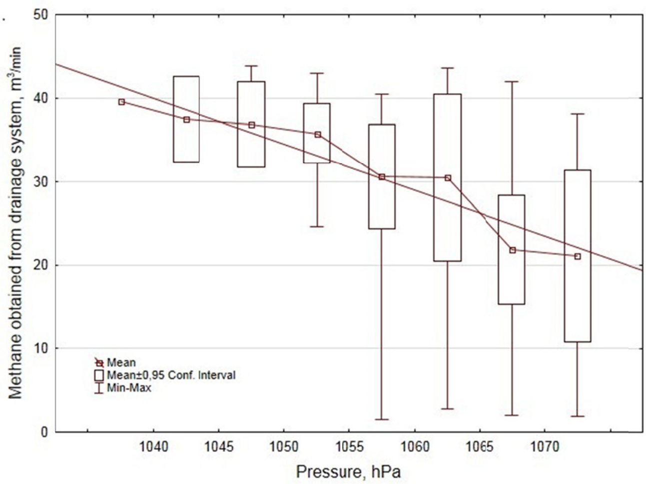

Fig. 32. Changes in the amount of methane captured from longwall B-11 in relation to air pressure in the longwall area

longwall panel are lost. With a parallel tailgate roadways, the pillar positioned between individual airways makes the drainage holes permanently airtight, thus yielding a gaseous mixture of higher methane concentration.

Throughout the exploited part of the longwall, both the amount of methane captured and the efficiency of methane drainage are subject to change. In the beginning part of the longwall exploitation, the values of the absolute methane-bearing capacity and the quantity of methane captured by drainage were low. As exploitation continued, these parameters grew and remained on a relatively stable level. The efficiency of methane drainage rose as well.

During the whole period of exploitation, the rise in the amount of methane captured by the drainage system corresponded to the rise in absolute methane-bearing capacity in the exploited area; however, the changes in extraction had no effect on the changes in methane captured.

Analysis of changes in the amount of methane captured juxtaposed against changes in barometric pressure measured in excavation sites depends on the ventilation system of longwall panel. In the case of a longwall panel with U ventilation system, barometric pressure had no effect on the amount of methane captured by the methane drainage system. With this ventilation system, drainage boreholes are not directly connected to the zone of drainage hole influence.

Nevertheless, using a system with a parallel tailgate roadways and a drainage gallery, the growth in barometric pressure corresponded to a drop in the amount of methane captured by the drainage system. In this case, the canal of longwall face is connected with the drainage gallery by the caving zone, or with the drainage holes through porting. Changes in barometric pressure significantly influenced the concentration of the captured mixture, which confirmed the results of methane concentration measurements in both threads of methane drainage pipelines in longwall 2 in seam 506. This reflects the connection of the caving zone with the zone of drainage borehole influence. In such systems of methane drainage, change in barometric pressure in longwall excavation sites plays a large role in the capture of methane.

The lowest efficiency of methane drainage, in the range of 30-40%, was achieved in the longwall with U ventilation system. The highest average efficiency of methane drainage, reaching up to 80%, was achieved in longwall with a drainage gallery. In longwall panels with parallel tailgate roadways, efficiency of methane drainage was achieved in the range of 50-60%.

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References

Berger J., Markiewicz J., Dołęga T., 2010. *Influence of Distance of Exploitational Front from Drainage Boreholes on their Effi ciency with Use the U Ventilation System*. Archives of Mining Sciences, Vol. 55, No 3, p. 561-571.

Filipecki J., Janowicz E., Malina Z., 2006: *Efektywne metody odmetanowania górotworu w warunkach KWK „Brzeszcze--Silesia" Ruch I „Brzeszcze"*. 4 Szkoła Aerologii Górniczej, 10-13.10.2006.

Flügge G., 1971. *Die Anwendung der Trogtheorie auf den Raum der Zusatzausgasung*. Glückauf Forchungshefte, nr 32.

Central Mining Institute, 2013. *Raporty roczny o stanie podstawowych zagrożeń naturalnych i technicznych w górnictwie węgla kamiennego*. Główny Instytut Górnictwa. Katowice.

Krause E., Łukowicz K., 2004. *Odmetanowanie w polskich kopalniach węgla kamiennego osiągnięcia i perspektywy*. XI Międzynarodowa Konferencja Naukowo-Techniczna Tąpania 2004 nt. Nowe rozwiązania w zakresie profilaktyki tąpaniowej i metanowej", 8-10.11.2004, Ustroń.

Roszkowski J., Szlązak N., 1999. *Wybrane problemy odmetanowania kopalń węgla kamiennego*. Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków.

Skotniczy P., 2013. *Three-dimensional numerical simulation of the mass exchange between longwall headings and goafs, in the presence of methane drainage in a U-type ventilated longwall.* Archives of Mining Sciences, Vol. 58, No. 3, p. 705-718.

Szlązak J., Szlązak N., 2004. *Dobór systemu przewietrzania ściany w aspekcie występujących zagrożeń naturalnych*. Wydawnictwa WUG, Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie, miesięcznik Wyższego Urzędu Górniczego, nr 9, Katowice

Szlązak N., Borowski M., Obracaj D., 2008. *Kierunki zmian w systemach przewietrzania ścian eksploatacyjnych z uwagi na zwalczanie zagrożeń wentylacyjnych*. Gospodarka Surowcami Mineralnymi, t. 24, z. 1/2.

Szlązak N., Korzec M., 2010. *Zagrożenie metanowe oraz jego profilaktyka w aspekcie wykorzystania metanu w polskich kopalniach węgla kamiennego*. Górnictwo i Geoinżynieria, 34 z. 3/1.

Szlązak N., Kubaczka C., 2012. *Impact of coal output concentration on methane emission to longwall faces.* Archives of Mining Sciences, Vol. 57, No 1, p. 3-21, Kraków

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