Influence of the Permeability of the Longwall Goaf Zones on the Location of an Area With Explosive Methane Concentration Levels

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INTRODUCTION

In Polish hard coal mines, the mining process is most often carried out using the longwall system with the breaking down of roof rocks. In the area of the exploited seam, as a result of the movement of roof rocks into the space after the mined coal, an area is created, known as a goaf zone.

Goaf zones form a special kind of a porous medium, which is made of the broken blocks of roof rocks previously lying above the exploited seam (Adhikary and Guo, 2004; Brodny and Tutak, 2018; Brodny et al., 2018; Karacan, 2008; Moore, 2012; Noack, 1998; Pan and Connell, 2012; Szlązak, 2001; Szurgacz et al., 2019; Zheng et al., 2018; Tutak and Brodny, 2017b; Tutak and Brodny, 2018; Tutak and Brodny, 2019). There are voids between the broken blocks of roof rocks through which gas can flow. The presence of these voids in goaves affects their permeability, which is the basic property characterizing a porous medium. At the same time, it is fundamental to the gas flow process. If the exploited hard coal seam is a methane seam, then methane can flow through goaves and accumulate there (Brodny et al., 2018; Jürgen and Saki, 2017).

The reason for the occurrence of methane in goaves is coal (e.g. from non-collected parts or off-balance resources) and the release of methane from the underworked and overworked hard coal seams, followed by its migration through cracks and fissures in the rock mass (Fig. 1). The methane accumulated in goaves may also be released into active mining excavations (Brodny and Tutak, 2019; Felkaand Brodny, 2018; Kurnia et al., 2014; Kurnia et al., 2016; Tutak and Brodny, 2017a).

From the point of view of the methane hazard, in the area of exploitation, goaves are considered an important center, in which the phenomenon of methane accumulation and its mixing with air may occur. As a result of these processes, areas with varying concentrations of this dangerous gas are formed. These areas can be marked with non-explosive methane concentration due to oxygen

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deficiency, with non-explosive methane concentration due to its excess, and with methane concentration within the explosive limits when mixed with air.

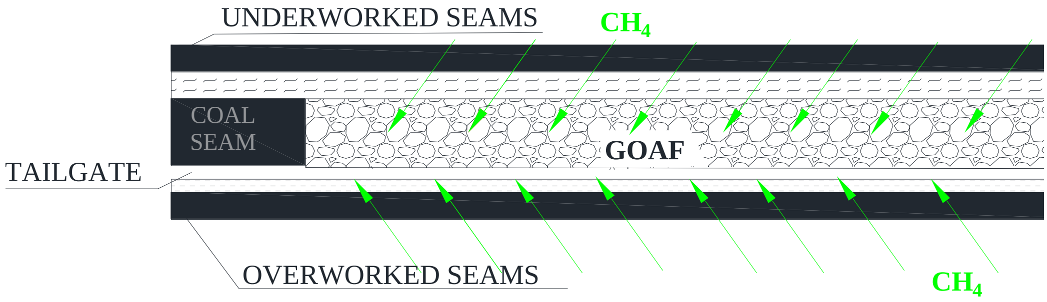

Fig. 1 Migration of methane to goaves from seams

Source: Own elaboration based on (Brodny et al., 2018a)

In the case of the spontaneous combustion of coal, an additional thermal source of methane ignition may appear, leading to its explosion. In practice, certain cases of methane ignition in the area of goaf zones have been reported, and they were caused by endogenous fires (Fernández-Alaiz et al., 2019; Szurgacz et al., 2019).

The occurrence of areas with explosive methane concentration levels in goaves is not recommended. Combined with air, it is considered a serious gas hazard.

Since goaves are a permeable medium through which gas can easily flow, it is necessary to determine how this permeability affects the distribution of gas concentration, including methane. The determination of such distributions makes it possible to designate areas with dangerous methane concentration levels in goaves. At the same time, it can show the impact of their permeability on both the size and location of such an area.

Under real conditions, it is practically impossible to carry out such tests or to determine the distribution of methane concentration in goaves.

For this reason, model studies were performed to determine the impact of the permeability of goaves on the location of areas with explosive methane concentration levels in the mixture with air. This type of research is currently successfully used for the variant analyses of processes related to the ventilation of underground mining excavations. They also enable the inclusion of goaves as a porous medium, as well as the analysis of emergency conditions in exploited areas.

The study was performed using the geometry of the real longwall and the ventilation parameters recorded during its operation. Based on tests in real conditions, the strength parameters of roof rocks forming the break down were determined. This showed the permeability of goaves. The tests were carried out for the longwall ventilated with the Y system. In order to determine the impact of the permeability in question on the location and size of the area with an explosive concentration of methane in the mixture with air, additional analyses were also performed for two different permeabilities of the studied goaves. The basis of these analyses were the geometrical and ventilation parameters of the studied longwall.

METHODOLOGY OF RESEARCH

The aim of the study was to determine the impact of the permeability of goaves on the location of an area with explosive methane concentration levels, i.e. from 5 to 15%, and an oxygen concentration level of min. 12%. The explosion limits of methane are shown in Figure 2. In order for ignition and subsequent explosion of methane to occur in a goaf, a trigger is necessary, for example, an endogenous fire, blasting works and sparks from the friction of moving roof blocks.

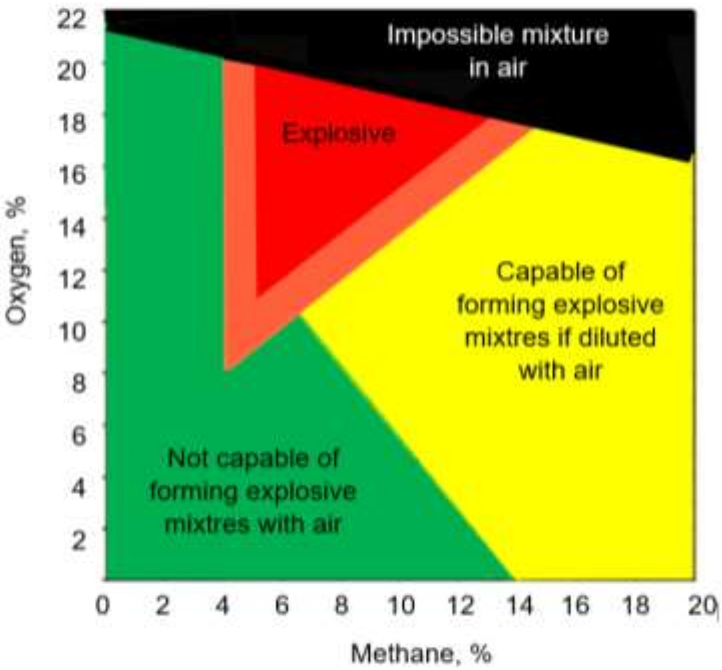

Fig. 2 Coward explosive triangle for methane

Source: own elaboration based on (Jürgenand and Saki, 2017)

The tests were carried out for a spatial model reflecting a real longwall ventilated with the Y system. The developed model included a longwall with longwall galleries and goaves. The studies were performed using the computational fluid mechanics (CFD).

In the first stage of the research, a geometric model of the goaves as well as the long wall and longwall galleries was developed (Fig. 3).

The vertical range of airflow in the goaves was 3.5 times the height of the exploited seam, which is in line with current theories.

The boundary conditions necessary to perform numerical calculations were adopted based on the real measurements of the physical and chemical parameters of the air stream supplied to the longwall and absolute methane content of the longwall (Table 1).

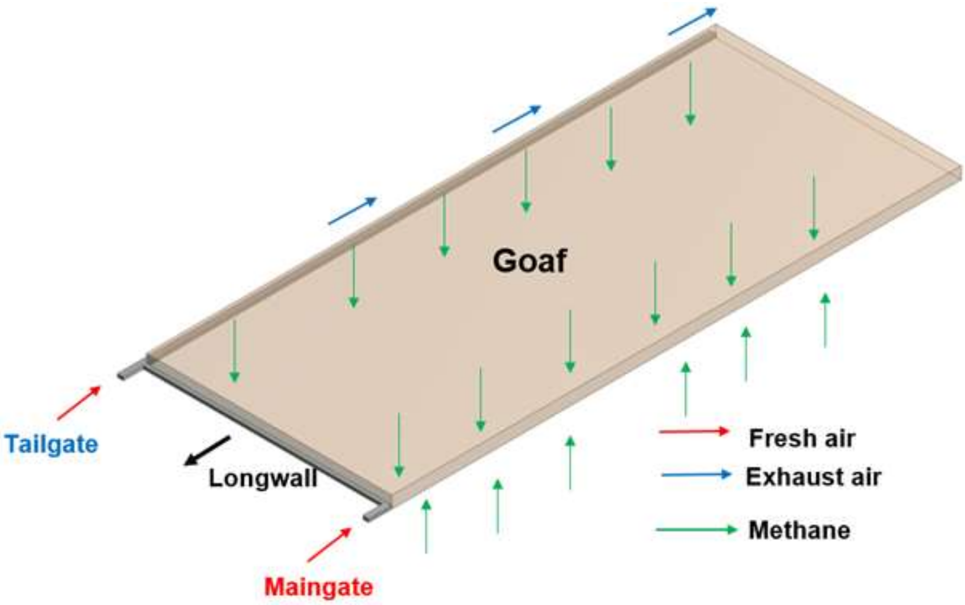

Fig. 3 Geometric model of the studied research area

Source: (Own elaboration)

Table 1 Geometry, Ventilation Parameters and Geological Parameters

Parameters	**Values**
Volumetric flow rate of the air supplied to the longwall, m^3/min	1000
Air supplied through the tailgate, m^3/min	410
Methane emission rate (absolute methane content), m^3/min	15
Length of the longwall, m	220
Height of the longwall, m	3
Length of the section of goaves with caving, m	500
Length of the section of the longwall gallery, m	20.0
Cross-sectional area of the longwall gallery, m^2	15.0
Length of the tailgate maintained along the goaves with caving, m	525
Width of the excavation, m	4.0

Source: (Own elaboration)

For the area shown, fresh air flows through the main gate to the junction with the longwall, then it changes the flow direction by 90 degrees and flows through the longwall, after which it again changes the flow angle by 90 degrees and flows out into the tailgate kept along the goaves. In addition, an air stream is supplied along the body of coal through the tailgate that refreshes the area where the longwall intersects with this excavation.

Figure 4, on the other hand, presents the distribution of goaf permeability that was adopted for the studied model.

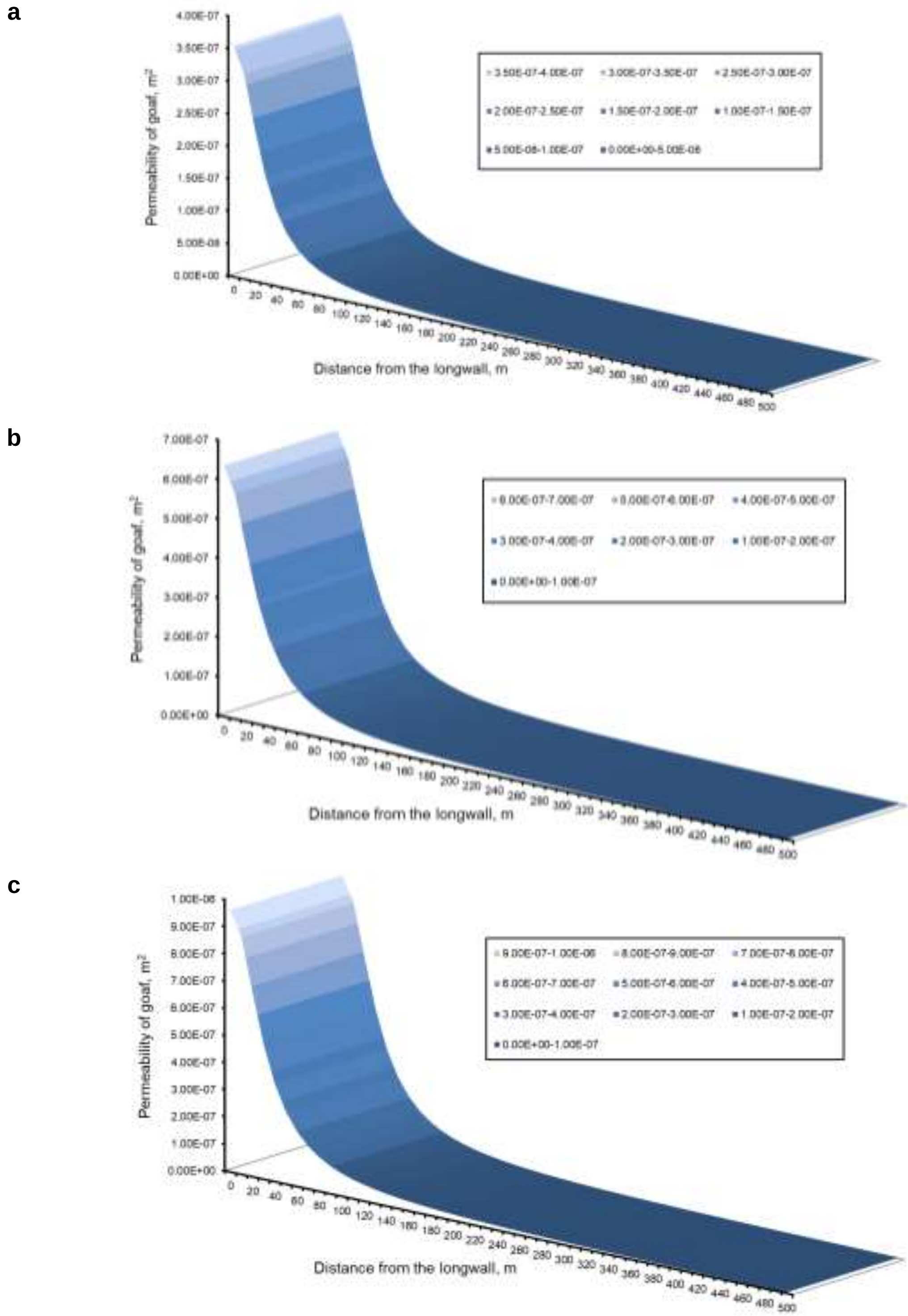

Fig. 4 Permeability distribution of the goaves for studied variants (a - variant 1, b - variant 2, c - variant 3)

Source: (Own elaboration)

Such models, along with the adopted conditions of uniqueness, were subjected to numerical analysis.

RESULTS AND DISCUSSION

The study allowed the determination of physical and chemical parameters of the air and methane mixture, which flows through the goaves, for various permeabilities of these goaves. Figure 5 shows the distribution of methane at an explosive concentration level, i.e. within 5 to 15%, and Figure 6 shows the distribution of oxygen concentration in the goaves, needed for methane explosion (minimum 12%).

a b c

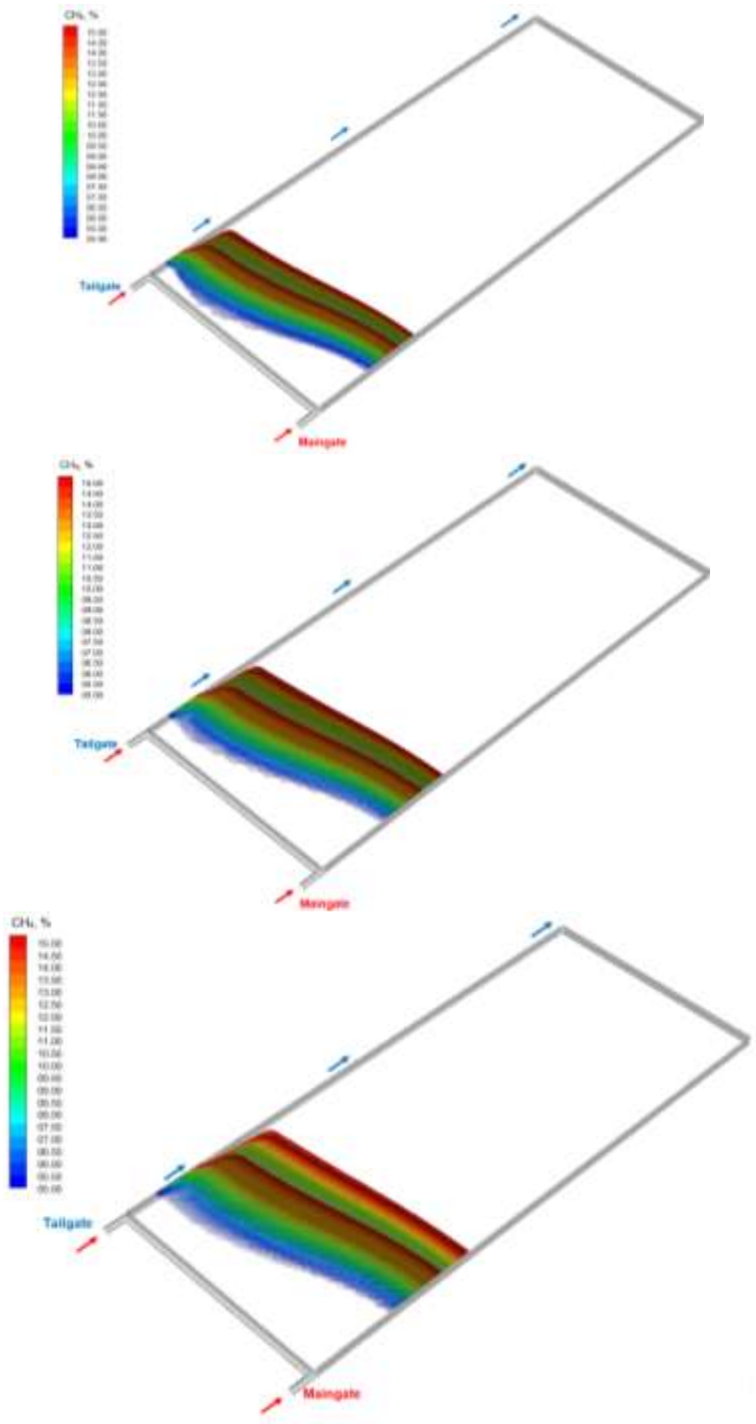

Fig. 5 Distribution of methane concentration in the goaves within explosion limits, i.e. from 5 to 15% (a - variant 1, b - variant 2, c - variant 3)

Source: (Own elaboration)

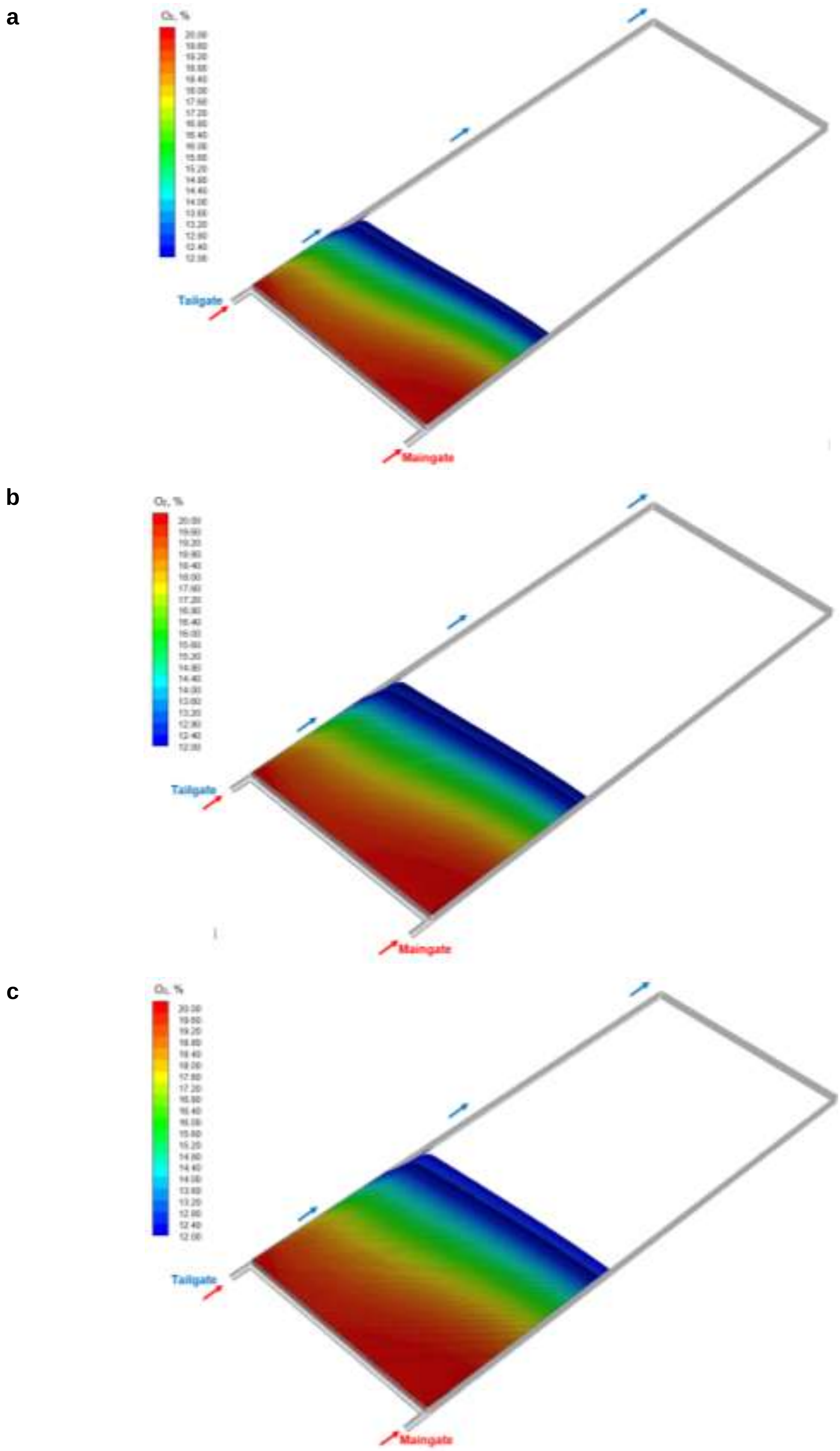

Fig. 6. Distribution of oxygen concentration in the goaves at the concentration level necessary for methane explosion, i.e. from 12%
(a - variant 1, b - variant 2, c - variant 3

Source: (Own elaboration).

The conducted studies and determined distributions of air velocity flowing through the goaves and oxygen concentration in this air enabled the designation of an area in the entire goaf volume, in which methane concentration levels reach values in the range of its explosion, i.e. from 5 to 15%. Table 2 presents the ranges and sizes of these zones in the goaves.

Table 2 Range of the area in which methane explosion may occur in goaves due to the explosive concentration of methane for various permeabilities of the goaves

Goaf permeability, m^2	Area with an explosive concentration level of methane in the goaves m	Area with an oxygen concentration level needed for methane explosion, m	Range of the area where methane explosion may occur in the goaves, m
Variant 1	34.0~94.0	0~138.2	34.0~94.0
Variant 2	48.0~124.0	0~168.2	48.0~124.0
Variant 3	62.0~154.0	0~198.2	62.0~154.0

Source: (Own elaboration)

The results clearly indicate that the permeability of the goaves has a significant impact on the location and size of areas in which hazardous methane concentrations may occur. The necessary condition for the occurrence of a fire or explosion is also the presence of oxygen and an energy impulse. It is clear that the lower the permeability of the goaf, the further away the area with the explosive methane concentration is from the working space of the longwall.

CONCLUSION

The methane hazard is one of the most dangerous natural ventilation hazards in underground mining excavations and goaf zones. The activation of this threat, which results in methane explosion or ignition, in the underground work environment is a serious danger to the safety of work of the entire crew and can cause large material losses on the part of mines. Therefore, it is crucial to take measures that will increase the safety and efficiency of the production process in hard coal mines.

One such action is to identify potential areas where methane may explode. These areas are characterized by the presence of explosive methane concentration levels ranging from 5 to 15% with a simultaneous oxygen concentration level of at least 12%.

This article presents the method of determining an area in the longwall goaves ventilated with the Y system, in which a methane explosion may occur. Under real conditions, it is practically impossible to designate such an area. The tests were conducted for various permeabilities of the goaves. The aim of the study was to determine how the change in the permeability of goaves affects the location of areas where a methane explosion may occur.

The results clearly indicate that the permeability of goaves has a significant impact on the location of this area in goaves. The results also broaden the knowledge of the process of ventilation of the longwall with the Y system, which is used when there is a high methane hazard in the longwall. These results also demonstrate that goaves have a significant impact on the ventilation process of mining excavations, which, due to their porosity and permeability, must be taken into account in this type of analysis.

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Abstract: One of the basic ventilation hazards and, at the same time most dangerous, in hard coal mines is the methane hazard. During the exploitation process using the longwall system with the breaking down of roof rocks, methane is released into mining excavations from both mined coal and the one left in goaves. Significant amounts of methane also flow from the underworked and overworked seams, through cracks and fissures formed in the rock mass. When accumulated at an explosive concentration level in goves and at an appropriate oxygen concentration level and the occurrence of a trigger (e.g. a spark or endogenous fire), methane may either explode or ignite. These are immensely dangerous phenomena. Therefore, the possibility of their occurrence should be limited. The article presents the results of the research aimed at determining the impact of the permeability of goaf zones on the distribution of methane and oxygen concentration levels in these goaves. The study was carried out for the longwall ventilated with the Y system. The model analysis was conducted, the results of which allowed the authors to determine these distributions. On their basis, both the location and size of the areas in which hazardous methane concentrations could occur were designated. The results are of great practical importance as they indicate areas in goaves where preventive measures should be implemented.

Keywords: methane hazards, longwall, mining operation, “Y” longwall ventilation system, goaf, CFD