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Applying Model Studies to Support the Monitoring of Methane Hazard during the Process of Underground Coal Mining

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Abstract
The process of underground mining is one of the most complex and hazardous activities. In order to maintain the continuity and efficiency of this process, it is necessary to take measures to reduce this hazard. The paper addresses this issue by presenting a developed methodology for using model studies and numerical simulations to support the process of monitoring methane hazards. Its basis is the developed model of the region of underground mining exploitation along with the ventilation phenomena occurring in it. To develop it, the ANSYS Fluent program was used, based on the finite volume method classified as computational fluid mechanics. The model reflects both the geometries and physical and chemical phenomena occurring in the studied area, as well as the auxiliary ventilation equipment used during operation. The research was conducted for two variants of methane emissions from goaf zones, the first of which concerned the actual state of the mining area, and the second of which concerned increased methane emissions from these goaf zones. The purpose of the study was to determine the distribution of methane concentrations in the most dangerous part of the studied area, which is the intersection of the longwall and the tailgate, as well as the distribution of ventilation air flow velocities affecting them. The studies for both variants made it possible to determine places particularly exposed to the occurrence of dangerous concentrations of methane in this region. The methodology developed represent a new approach to studying the impact of methane emissions from goaf zones into mine workings.

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1. Introduction

Work in underground coal mines is widely regarded as both very difficult and dangerous (Midor, 2017; Palka et al., 2022; Škvareková et al., 2021). This opinion, supported by statements of accidents and dangerous events of a catastrophic nature, is mainly the result of the environment in which the mining process is carried out. Underground mining excavations are exposed to many different types of hazards, of which ventilation hazards are particularly dangerous, and among them methane hazards (Brodny and Tutak, 2015; Donnelly, 2018; Janjuhah et al., 2021; Rao et al., 2023). Thus, in addition to the traditional technical, organizational or personal hazards, there are also natural hazards in underground coal mining, the occurrence of which is associated with a violation of the original structure and balance in the rock mass. This disruption of the equilibrium state leads to the deterioration of the safety of implementing the mining process and disrupts its continuity and efficiency (Ma, 2020).

The methane hazard is mainly related to the possibility of ignition and/or explosion of methane gas in mine workings. Methane is a gas inextricably linked to the process of underground coal mining. Its emissions, from the coal being mined and additional significant outflows into mine workings from the rock mass surrounding the seam being mined, result in dangerous concentrations of methane in mine workings, which, with adequate access to oxygen, can lead to its ignition and/or explosion (Shi et al., 2017). Methane, as a lighter gas than air, tends to accumulate under the roof of mine workings and in areas where there is little air movement (so-called dead zones). If its volumetric concentration in oxygen-rich air (min. 12%) is in the range between 5-15%, an explosion of this gas can occur, resulting in a huge danger to the crew and the destruction of mine workings and their equipment (Juganda et al., 2022; Mishra et al., 2018).

The areas where methane most often accumulates are primarily the longwall regions, and more specifically, the intersection of the longwall and the tailgate. In these regions, methane flowing from goaf zones is also most often accumulated. This phenomenon occurs in the case of the most commonly used mining method in Polish mines for caving of the roof rock in the zone of a selected coal seam. In such cases, it can be assumed that in the area of the longwall, it is the goaf zone that is a potentially important additional source of methane emissions, which further worsens the overall balance of methane in the area of the longwall (Cheng et al., 2016; Lolon et al., 2020; Zhou et al., 2023). Thus, throughout the process of underground mining operations, efforts are made to maintain a state in which dangerous concentrations of methane will not be exceeded in mining excavations. This task is performed by mining services, whose main goal is to monitor the state of methane danger in mine excavations and manage the mining process in such a way that such concentrations do not occur. Mining regulations are helpful, as they clearly define the permissible values of methane concentrations in individual mine workings, at which the power supply to mining equipment is interrupted until the acceptable parameters of the mine atmosphere are reached. In this process, a huge role is played by the mine's automatic methanometry system (increasingly used in mines), the task of which is to monitor methane concentrations and other physical and chemical parameters in mine workings. Unfortunately, this system takes point measurements at strictly regulated locations in mine excavations.

This point measurement makes it difficult, to a wider extent, to determine the distribution of methane concentrations in these workings. This is important because methane, although lighter than air, very often accumulates in regions with slightly lower air flow intensity. Particularly important in this process is the methane migrating from the goaf, whose amount and timing of outflow are difficult to predict, while the result of such events can be very significant local increases in the concentration of this gas.

Thus, despite its great importance, the system of point measurements of methane concentrations in mine excavations is not perfect and does not reflect the actual distributions of concentrations of this gas. Especially since these distributions are also strongly influenced by the flow parameters of the ventilation air stream. This process becomes more complex with the use of additional auxiliary ventilation equipment in the tailgate (Tutak and Brodny, 2018). It is also obvious that in real conditions, the determination of such distributions is very difficult, and in many cases impossible. On the one hand, this is due to the enormous cost of installing many sensors and the entire system for recording and analysing their indications, and on the other hand, due to the fact that very intensive mining operations are taking place in these excavations. Therefore, the determination of the distribution of methane concentrations in real conditions, in the entire mining area, taking into account the goaf zone, is practically impossible to carry out. However, in order to improve mining safety, the designation of such zones is very reasonable.

This problem can be solved through the use of model studies and numerical simulations, which provide opportunities to study the entire mining exploitation region with the ventilation conditions in it. These studies allow geometric mapping of the studied region along with the ventilation phenomena in it. This includes both physical and chemical phenomena.

Such possibilities are provided by computational fluid dynamics (CFD), and mainly by the finite volume method, dedicated to the study of thermal and flow phenomena.

In recent years, model-based studies, and CFD in particular, have been increasingly used for analyses related to the prediction of ventilation states, including in mining. To date, the issue of applying model studies and CFD to the study of methane hazard conditions has been addressed by several researchers (Oberholzer and Meyer, 1995; Hasheminasab et al., 2019;Kumar et al., 2017; et al., 2014; Mishra et al., 2016; Tutak and Brodny, 2017; Wang et al., 2018; Zhou et al., 2015). In their studies, they mainly focused on the analysis of this hazard in headings, and much less frequently – in the area of the longwall.

Among others, Oberholzer and Meyer (1995) used CFD to evaluate the effectiveness of various ventilation systems used to dilute methane in mine excavations and remove dust from them. In turn, Wang et al. (2021) used CFD to analyse the distribution of methane concentration in goaf zones and its interaction with fire hazard. Mishra et al. (2018), on the other hand, studied the influence of selected geological and mining factors on the distribution of methane concentration in a tailgate. Kurnia et al. (2014) examined what factors affect the dispersion of methane in a driven heading. In turn, Hasheminasab et al. (2019) and Zhou et al. (2015) used CFD to analyse the distribution of methane concentrations in driven headings. Mishra et al. (2016) and Kumar et al. (2017) analysed how methane can be diluted to safe levels in underground coal mines using ventilation parameters. Tutak and Brodny (2017), on the other hand, studied what effect the type of goaf sealing used has on the migration of methane from goaf zones to the longwall region.

The presented studies indicate a great potential for the use of model studies and numerical simulations to support the process of managing ventilation (methane) safety in underground mine workings.

The analysis of these works shows a conspicuous lack of studies with regard to comprehensive analysis of the ventilation condition in the region of intensive mining operations, especially with the use of auxiliary ventilation equipment. This is because the region of the longwall is a very complex physical object in which a number of ventilation phenomena occur, and the mapping of which requires a great deal of knowledge of the mining process, as well as experience and skills in conducting model tests. In particular, this applies to the aforementioned goaf zones, which, as a porous and permeable medium, have a particular impact on the distribution of methane concentrations in the area of mining operations. Of great importance, especially in the process of preparing the model and determining the boundary conditions, are also the actual geometric parameters of the studied region and the physical and chemical flow phenomena occurring there.

Addressing the research gaps in the area of methane hazard studies in the region of mining operations, the paper presents the developed research methodology based on model studies and numerical simulations. Also, the results of the analysis of methane concentration distributions obtained are presented, as a result of its application for a real region of underground mining operations in one of the coal mines in Poland in the GZW region.

The Ansys Fluent numerical code based on the finite volume method was used for the study. The developed numerical model of the mining longwall made it possible to analyse the influence of the volume of methane emitted from the goaf zone on the spatial distribution of its concentration in the area of the intersection of this longwall and the tailgate.

The results should be an important source of information for services responsible for ensuring work safety, in terms of methane hazards. Identification of zones with possible occurrences of dangerous concentrations of this gas should facilitate the selection of effective methods to reduce the possibility of such concentrations. This is important insofar as methane outflows from goaf zones can occur suddenly, which means that the time for the reaction of these services cannot be too long. Thus, the results provide the opportunity to prepare for potentially dangerous events resulting from methane outflows from goaf zones. Effective prediction of methane concentration in the area of the intersection of a longwall and a tailgate is therefore extremely important from the point of view of ensuring occupational safety and the continuity and efficiency of the process of underground coal mining.

2. Materials and methods

The section presents the studied, real mining longwall region with a description of the conditions and the ventilation system used. Based on this, geometric, physical and mathematical models of the studied region were developed, which are also discussed in the section.

2.1. Area of research

Model studies using the Ansys Fluent numerical code to determine the spatial distribution of methane concentration were carried out for the region of a longwall exploited in one of the mines located in southern Poland, in the Upper Silesian Coal Basin area.

This longwall was mined with a longitudinal system with the caving of rock roof. Its length was about 116 m, its height was 2.6 m, and its runout was 1,050 m. The longwall was characterized by a slight transverse slope (1.9°) and longitudinal slope (4.9°).

In the studied longwall, a ”U” ventilation system was used from the borders. In addition, its refreshment was also applied. The process of refreshing was carried out through the tailgate by means of an air-duck line (auxiliary ventilation device) built into it. A ventilation brattice was also built into the tailgate. The ventilation scheme of the studied longwall with marked directions of airflow is shown in Figure 1.

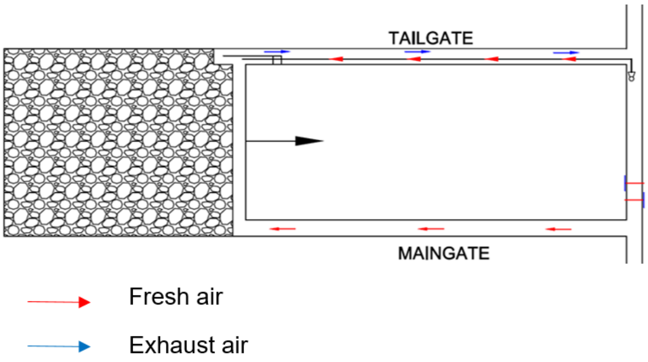

Fig. 1. Ventilation scheme of the studied longwall

An average of about 1,100 m^3/min of air was supplied to the longwall through the tailgate, and an additional about 140 m^3/min of air was supplied to the area of the intersection of the longwall with this tailgate, where an auxiliary air-duct line was installed. The air was discharged from the longwall through the tailgate.

Methane discharge from the goaf zone was about 12.5 m^3/min. The measured, average value of methane concentration in the tailgate, at the measurement point located at a distance of 10 m from the longwall exit during operation, was 1% CH_4.

2.2. Development of Computational Model

For the correctness of the numerical analyses, it was crucial to develop a model that would represent the actual longwall region.

Thus, the geometric model developed included the longwall, the longwall excavations (maingate and tailgate), as well as the goaf zone and auxiliary ventilation equipment (air-duct line and brattice) built in the tailgate. Figure 2 shows the geometric model of the analysed region, while the basic parameters of the developed computational model are summarized in Table 1.

The presented data were used to conduct model studies, the purpose of which was to determine the spatial distribution of methane concentration in the area of the intersection of the longwall and the tailgate, depending on the amount of outflow of this gas from the goaf zone. In order to achieve this goal, calculations were carried out for the actual amount of methane emitted from the goaf during mining, which was about 12.5 m^3/min, and additionally for the variant in which this outflow is increased to a value of 18 m^3/min. Thus, the analysis was aimed at comparing the determined distributions for the actual state and for the variant with increased outflow of methane from the goaf zone.

Table 1. Computational model geometry, basic setups for the numerical simulations and ventilation parameters of longwalls

Airflow volume rate - maingate, m^3/min	1100.00
Airflow volume rate – air duct in tailgate, m^3/min	140.0
Methane emission rate from goaf, m^3/min	12.5
The height of longwall, m	3.5
The length of longwall, m	116.0
The width of longwall, m	3.5
The Width of longwall gate roads, m	4,0
The Height of longwall gate roads, m	3.5
The area of longwall gate roads, m^2	12.28
The length of goaf, m	100.0
The Height of goaf, m	10,0
The length of maingate, m	25
The length of tailgate m	75
Temperature of fresh air, K	293.15
Temperature of wall, K	300
Oxygen concentration in inlet air flow (maingate), %	20.9
Atmospheric pressure, MPa	0,1
Air density, kg/m^3	1.225
Pressure difference between inlet and outlet of longwall, Pa	26
Viscosity of air, Pa·s	$1.8 \cdot 10^{-5}$
Permeability of goaf, m^2	from $1.33 \cdot 10^{-5}$ to $6.67 \cdot 10^{-7}$
Ventilation type	"U"-type from the borders
Solver type	Pressure-based
Models	k-ε standard model turbulence, species transport (methane–air mixture), energy
Time	Steady
Scheme	Coupled

2.3. Physics and governing equations

The flow of the gas mixture stream (air and methane) through the longwall region, the subwall gallery, tailgate, maingate, and the goaf zone, is described by the equations of conservation of mass, energy conservation of momentum, transport and gas state (Li et al., 2020; Liu et al., 2020; Mishra et al., 2011; Song et al., 2014; Wang et al., 2018):

– The mass conservation equation is shown in Eq. (1):

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{1}$$

– The momentum equation is shown in Eq. (2):

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = \frac{\partial}{\partial x}\left(\mu \frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu \frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu \frac{\partial u}{\partial z}\right) - \frac{\partial p}{\partial x} + S_i \tag{2}$$

– The energy equation is shown in Eq. (3):

$$\frac{\partial}{\partial t}(pc_pT) + \nabla \cdot (\rho c_p vT) = \nabla \cdot J \cdot \left(k_{eff} + \frac{c_p \mu_t}{Pr_t}\right) \nabla T \tag{3}$$

– The equation of state for ideal gas is shown in Eq. (4):

$$\rho = \frac{PM}{RT} \tag{4}$$

– The species transport equation is shown in Eq. (5):

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla \cdot (\rho v Y_i) = \nabla \cdot J_i + R_i + S_i \tag{5}$$

In addition, the set of these equations is supplemented by equations describing the turbulent nature of this flow in the form of equations (6 and 7):

– The turbulent kinetic energy transport equation can be written as:

$$\rho \frac{\partial k}{\partial t} + \frac{\partial}{\partial x_i}(\rho k v_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\epsilon - Y_M + S_k \tag{6}$$

$$\rho \frac{\partial \varepsilon}{\partial t} + \frac{\partial}{\partial x_i}(\rho \varepsilon v_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon\rho}\frac{\varepsilon^2}{k} + S_\varepsilon \tag{7}$$

Due to the inclusion of goaf zones in the model, which is a porous medium, the analysed flow model is described by an additional equation – the momentum loss source term of three-dimensional porous media:

$$S_i = -\left(\sum_{j=1}^{3} D_{ij}\mu v_j + \sum_{j=1}^{3} C_{ij}\frac{1}{2}\rho|v_j|v_j\right) \tag{8}$$

where: *u*, *v* and *w* are the average gas (air and methane) velocities spatially per unit time, m/s; ρ is the gas density, kg/m^3; c_p is the specific heat of the gas; G_b is turbulence depending on buoyancy; G_k is the generation term of the turbulent kinetic energy *k* due to the average velocity gradient; J_i is the diffusion flux of species *i*, kg/(m^2s); *k* is turbulence kinetic energy, m^2/s^2; k_{eff} is the effective gas thermal conductivity, *p* is pressure, Pa; P_{rt} is the turbulent Prandtl number; R_i is the net rate of production of species *i* by chemical reaction; S_i is the rate of creation by addition from the dispersed phase plus any user-defined sources, *T* is the temperature, K; Y_i is the local mass fraction of each species; Y_M is the turbulence effect of compressibility; ε is the dissipation of turbulence kinetic energy, m^2/s^3; τ is the viscous stress tensor, Pa; μ_t is turbulent viscosity, Pa·s; $C_{1\varepsilon}$, $C_{2\varepsilon}$, and $C_{3\varepsilon}$ are the constants for *k-ε* turbulence model; S_k and S_ε are the user-defined source items, *Dij* and *Cij* are the viscous resistance coefficient and inertial resistance coefficient.

2.4. Development of numerical domain

In order to represent the flow processes occurring during the flow of the air stream through the mine workings, a geometric model of the studied region was developed, taking into account the geometric parameters of the longwall and longwall goaves (maingate and tailgate) and goaf zones. All these excavations constituted the calculation domain and at the same time the flow area of the air and methane mixture. The model also took into account auxiliary ventilation equipment (brattice and auxiliary air-duct) built in the tailgate.

The geometric model of the study region with the direction of air flow and its main elements marked is shown in Figure 2.

A very important element included in the study was auxiliary ventilation equipment, installed in the tailgate. The view of these devices in the developed model is shown in Figure 3.

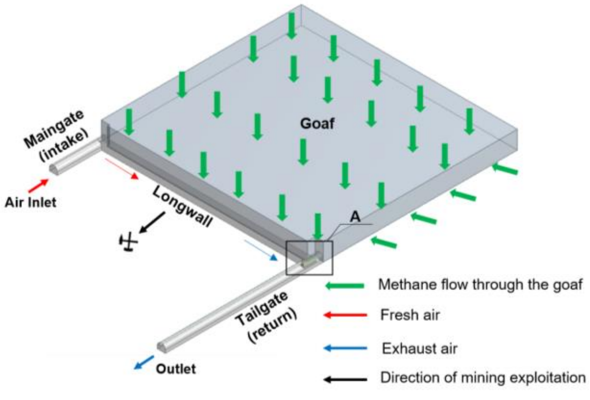

Fig. 2. Geometric model of the studied region with its main elements and the direction of air flow marked

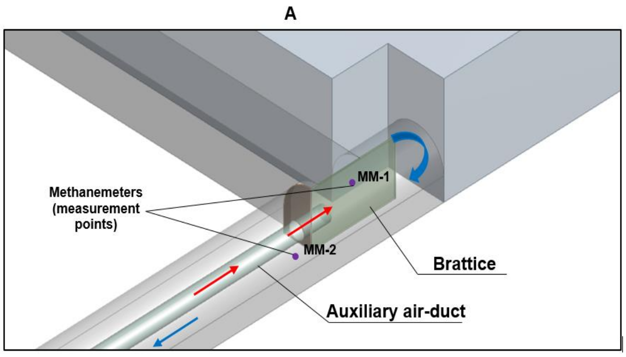

Fig. 3. View of auxiliary ventilation equipment in the tailgate

The developed geometric model was subjected to a discretization process to divide the computational domain into finite volumes. For all analysed variants, the computational domain of the goaf zone consisted of a structured mesh (cubic mesh). And for the longwall and headings – from an unstructured three-dimensional tetrahedral mesh. In the longwall and the maingate and tailgate, longwall layers near the edges of the workings were included to accurately represent the flow of the gas mixture in these areas (Figure 4).

Such developed model, consisting of 9,896,553 finite volumes, was subjected to simulation. This process was still preceded by the adoption of boundary conditions, the values of which were determined based on studies of ventilation parameters under real conditions.

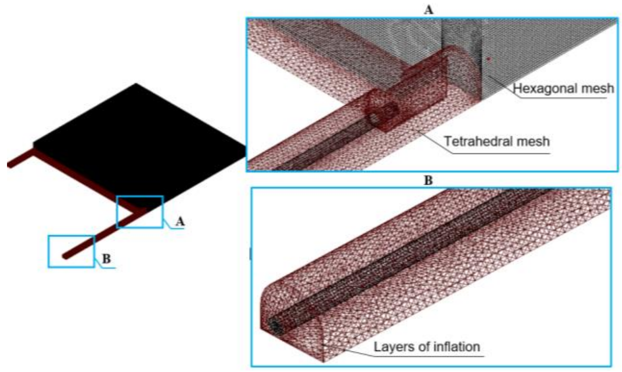

Fig. 4. Mesh of the computational domain

3. Results and discussion

Based on the developed methodology and model, a number of analyses were carried out, which resulted in the determined distributions of methane concentration and dispersion in the area of the intersection of the longwall with the tailgate (ventilation), as well as the distributions of physical parameters of the ventilation airflow. These analyses took into account different emissions (two variants) of methane from the goaf into the working space of the excavations.

In the first stage of the study, the distributions of air velocities flowing through the analysed region of the intersection of the longwall and the tailgate were determined. Measurements performed during the operation of the longwall showed that the average velocity of the air stream supplied to the longwall through the maingate was about 1.5 m/s, and the velocity of the air stream supplied through the auxiliary air duct line built in the tailgate was about 3 m/s. Air velocity distributions are crucial to the process of forming zones with elevated methane concentrations. Therefore, it is so important to analyse them, especially in areas of potential concentrations of this gas.

The determined distributions of air velocity in the excavations under study, along with the kinetic energy of turbulence (Fig. 5). In turn, the distributions of air velocity in a plane located 1.5 m from the bottom (base) in the excavations under study are shown in Fig. 6.

When analysing the results in the form of streamlines (Fig. 5) and the contours of the velocity distributions shown on the horizontal plane (Fig. 6), it can be seen that the stream of air flowing out of the longwall towards the tailgate strikes the ventilation brattice located in it. After bouncing off it, it heads toward the section of unclosed tailgate, which is located behind the so-called goaf line, and toward the goaf zone itself. These phenomena contribute to the formation of air recirculation zones and the formation of vortices in the area of the intersection of the longwall and the tailgate. At the same time, it is worth noting that the air stream does not evenly fill the entire cross-section of the workings in this area. The air stream in the initial section of the tailgate (from the side of the goaf) sticks to the pit longwall located on the opposite side to the air-duct line located in this excavation, which is associated with the occurrence of the Coanda effect. Moving away from the area of the intersection of the longwall and the maingate, the airflow fills the entire cross-section of the workings.

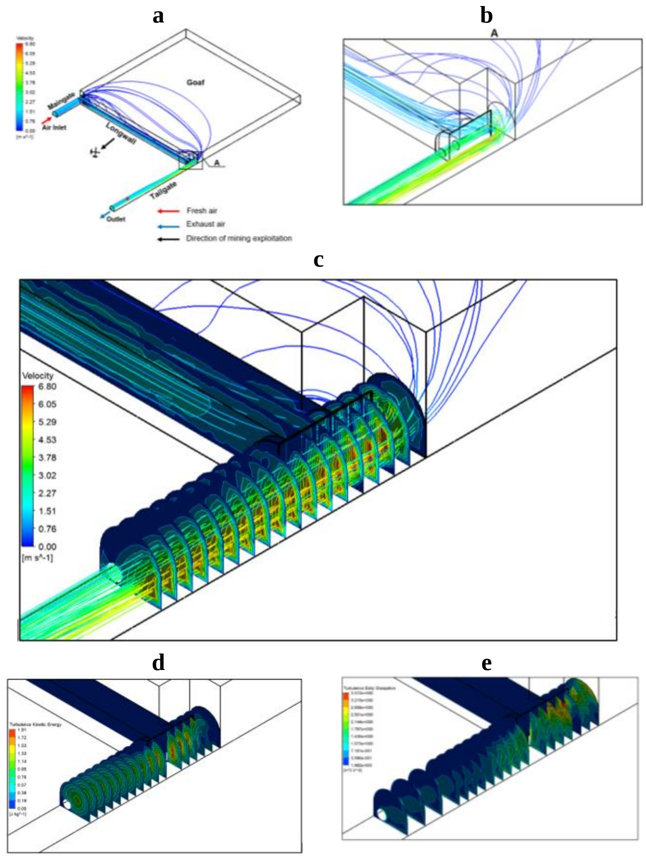

Fig. 5. Airflow streamlines (a, b), velocity (c), turbulent kinetic energy (d) and turbulence eddy dissipation (e) contour profiles in the tailgate at inlet air velocity of 1.5 m/s

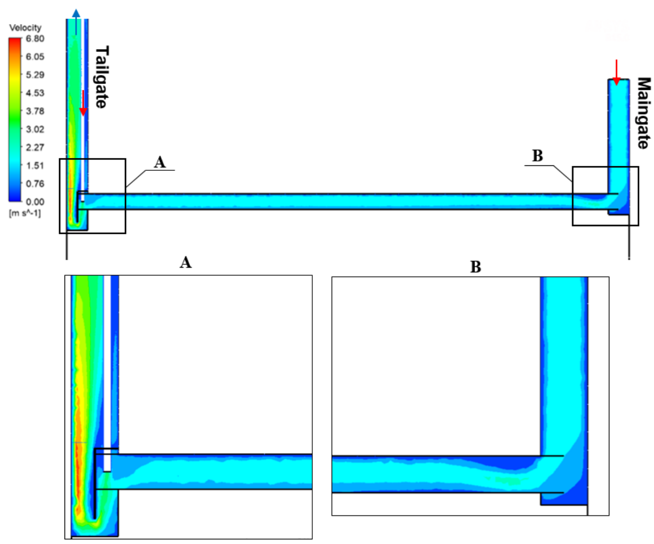

Fig. 6. Distribution of air velocity in the region of the longwall excavation on a horizontal plane located at a height of 1.5 m from the bottom of these excavations

In the area of the upper corner of the longwall (Fig. 5b), there is a combination of two air streams: the main one, which flows out of the longwall, and the refreshing stream, which is brought into the analysed region by means of the air-duct line. These phenomena significantly affect the distribution of methane concentration in the tailgate and contribute to changing the place in the excavation where the highest concentrations of methane occur (Fig. 7). This is because, in general, methane accumulates under the roof of the workings. However, this happens when the air flow fills the entire cross-section of the excavation evenly (Tutak and Brodny, 2018). However, the use of the air duct line in the tailgate, i.e. an additional air stream, changes this distribution of methane in the tailgate. The maximum methane concentrations then occur in the vicinity of the sidewall, opposite the air duct line, rather than below the roof. This phenomenon is related to the displacement of methane by the stream of air flowing through the workings. At the same time, the fragment of the unclosed section of the tailgate, located behind the goaf line, is relatively very well ventilated due to the auxiliary ventilation devices used (brattice and air duct line) (Figure 5c). Changes in the velocity of the air stream in the region where auxiliary ventilation devices were used can also be seen in the turbulence kinetic energy distributions (Figures 5c and 5d).

However, the main purpose of the study was to determine the distribution of methane concentrations in the excavations studied. The results obtained based on the analyses carried out for the first variant of the study are presented in Figure 7. This figure shows the distributions of methane concentrations in vertical planes located every 1 meter in the tailgate (Figure 7a), behind the longwall exit. In addition, air velocity trajectories in this area are also shown for these distributions (Fig. 7b).

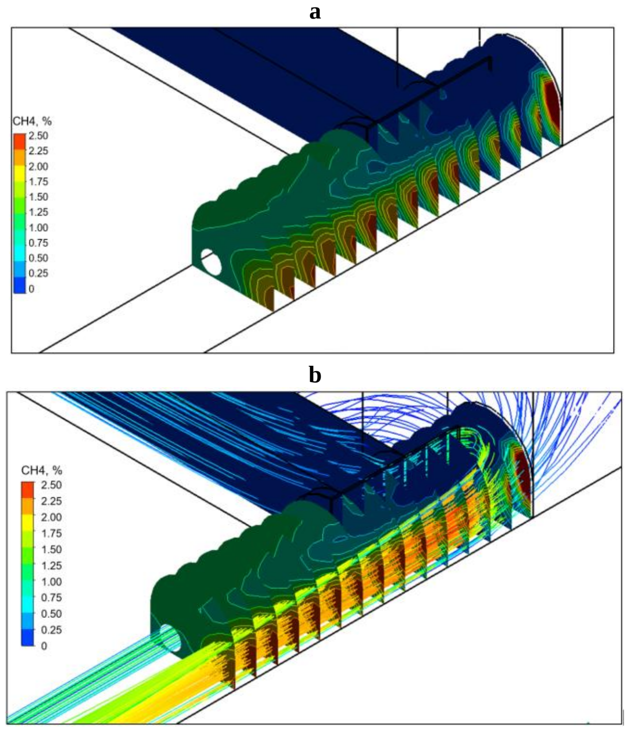

Fig. 7. Distribution of methane concentrations in the tailgate on vertical planes located every 1.0 m, behind the longwall air outlet for methane inflow from the goaf of 12.5 m^3/min (a) and trajectories of air velocity (b)

The determined distributions of methane concentrations in the tailgate, behind the longwall outlet, show that as the distance from the goaf line increases, the methane concentration decreases and stabilizes across the entire cross-section of the excavations. It is also noticeable that in the unclosed section of the tailgate, located behind the goaf line, there is no free flow of methane into the tailgate with the entire surface of this excavation bordering the goaf zone. The highest concentration of methane occurs behind the goaf line, in the unclosed section of the tailgate at the point of its outflow into the excavation, and is as high as 2.5% (Figure 7a).

In order to determine the impact of a sudden outflow of methane from the goaf into the region of the intersection of the longwall and the tailgate, additional analyses were carried out (second variant of the study). It was assumed that 18 m^3/min of methane enters the working space during the sudden outflow. For such assumptions, a numerical simulation was made, as a result of which the distributions of methane concentrations in the study area were determined. The resulting distributions are shown in Figure 8.

The results unambiguously indicate that with increased outflow of methane from the goaf, the maximum methane concentrations in the pit cross-section increase and reach their maximum (3%) at the right edge of the excavation (Fig. 8a).

In order to validate the results obtained from the model tests, a comparison was made between the values of methane concentrations obtained from mine measurements conducted under real conditions and those determined from the model tests. Measurements under real conditions were carried out by the methanometry system automatically at two measurement points (MM-1 and M-2). The results of this analysis are shown in Table 2.

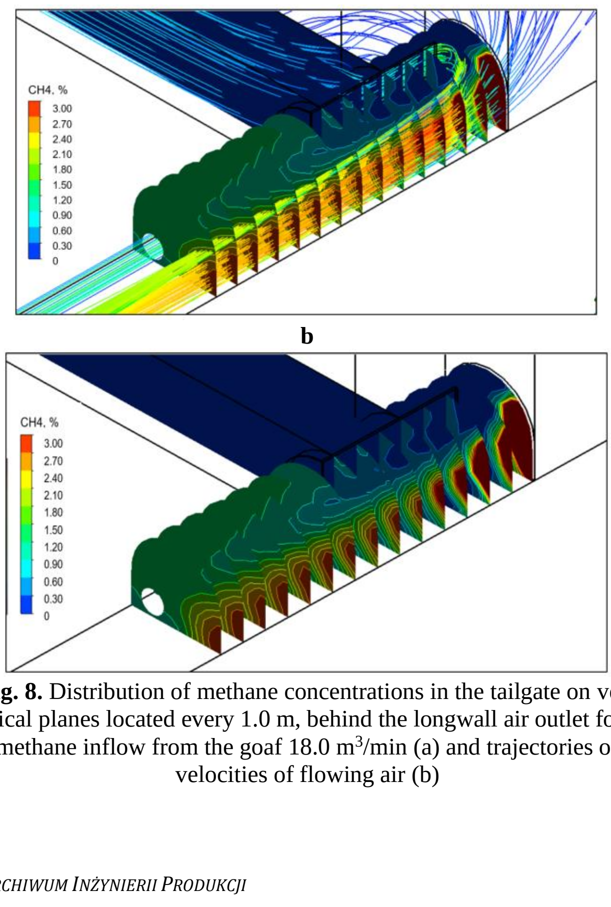

Fig. 8. Distribution of methane concentrations in the tailgate on vertical planes located every 1.0 m, behind the longwall air outlet for methane inflow from the goaf 18.0 m^3/min (a) and trajectories of velocities of flowing air (b)

Table 2. Comparison of the values of methane concentrations obtained from measurements under real conditions and those determined from model tests, for the studied region (real conditions)

Methane concentration, %	Field Investigations	Numerical model	Error, %
Point MM-1	1.15	1.25	8.70
Point M-2	1.05	1.12	6.67

The results show that the relative error between the methane concentration values derived from mine measurements (from automatic manometry equipment) and those obtained by model tests using the Ansys Fluent code does not exceed 11.4%. Such an error value allows us to conclude that the obtained calculation results are at an acceptable level, and the developed model satisfactorily reproduces the real conditions with the flow processes occurring there.

4. Conclusions

Methane hazard is among the most dangerous hazards occurring in underground coal mines. Activation of this hazard in the form of an explosion or ignition of methane in the underground excavation environment poses a huge threat to the safety of the entire workforce and the processes carried out. These events also very negatively affect the continuity and efficiency of the mining process and can cause huge material losses for the mining company.

For these reasons, it becomes very important to take measures to improve the state of methane safety in the area of underground mining. One of the measures included in these activities is the developed research methodology with a model of the studied region, which is aimed at determining potential zones where methane flowing out of goaf zones can accumulate. Identification of such zones provides opportunities for preventive measures and preparation of mine services for the possibility of such a condition. Taking into account the outflow of methane from goaf zones in the study is of great practical importance, since such events oftentimes occur during mining, disturbing the state of equilibrium and causing local, immensely dangerous increases in methane concentrations. This is particularly true at the intersection of the longwall and the tailgate, and for this reason the study focused mainly on this area.

The developed methodology makes it possible to study the entire mining region, both in terms of distribution of methane concentrations and determination of other physical and chemical parameters of the mine atmosphere.

It is also obvious that the determination of such distributions by other methods than on the basis of model studies based on the structural model of the region is practically impossible.

The distributions of methane concentrations and ventilation flux velocities determined and presented in the paper provide the possibility of determining zones with elevated values of concentrations of this gas. This, in turn, provides an opportunity for mine services to prepare for the occurrence of such events, in order to minimize the state of danger.

The example presented in the paper confirms the possibility of using model studies to support the process of ventilation safety management in mines. It also indicates the wide possibilities of this research in forecasting potential operating or critical conditions during such operations. Monitoring of the state of methane hazard, by the system of automatic methanometry, supported by the results of model studies should expand the knowledge of this hazard and support the processes of reducing its effects. It is also reasonable to expand the research to include transient states, which can even more accurately represent the actual ventilation states in this process.

Therefore, it can be concluded that the developed methodology and model provide great opportunities for monitoring, forecasting and analysing methane hazard states in the process of underground mining production.

The only limitations, in the application of this methodology, may be the lack of access to reliable measurement data and the possibility of validating the obtained results, which is necessary to make the developed model credible.

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应用模型研究支持地下煤矿开采过程中的甲烷危害监测

關鍵詞
地下采矿作业
甲烷危害
数值模拟
模型研究
CFD 和 Ansys Fluent

摘要
地下采矿过程是最复杂、最危险的活动之一。 为了保持这一过程的连续性和效率，有必要采取措施减少这种危害。 本文通过提出一种使用模型研究和数值模拟来支持甲烷危害监测过程的成熟方法来解决这个问题。 其基础是地下采矿开采区域及其中发生的通风现象的开发模型。 为了开发它，使用了 ANSYS Fluent 程序，该程序基于计算流体力学的有限体积方法。 该模型反映了研究区域发生的几何形状和物理化学现象，以及运行期间使用的辅助通风设备。 该研究针对采空区甲烷排放的两种变体进行，第一个涉及矿区的实际状况，第二个涉及这些采空区甲烷排放量的增加。 该研究的目的是确定研究区域最危险部分（即长壁和后挡板的交汇处）的甲烷浓度分布，以及影响它们的通风气流速度的分布。 对这两种变体的研究使得确定该地区特别容易出现危险浓度甲烷的地点成为可能。 所开发的方法代表了一种研究采空区甲烷排放对矿山作业影响的新方法。