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IMPACT ASSESSMENT OF SORPTION PROPERTIES OF COAL ON METHANE EMISSIONS INTO LONGWALL WORKING

A mathematical model for the purposes of methane hazard assessment in mines was developed in the Central Mining Institute as part of the statutory activities conducted in 2017 and 2018. The model describes the course of kinetics of methane sorption on coal samples while taking into account the diffusion coefficient. The paper presents the formulas describing the mathematical model of methane emission from coal sidewall to longwall working, taking into account the sorption properties of coal – sorption capacity of coal (related to methane) and the effective diffusion coefficient of methane in coal. In the light of the conducted research, such a methodology for describing this phenomenon enables a more precise determination of the amount of methane released to the longwall from the exploited coal seam, which in turn makes it possible to select appropriate methane prevention measures.

Keywords: mining, methane, physical chemistry, sorption

1. Introduction

Methane emission accompanying the development and operational works in coal mines and the resulting explosion hazard is still a very dangerous phenomenon. The amount of methane released in m^3/min, called methane content, has a direct impact on the safety of conducted operations. Combating methane hazard primarily means a limitation of the possibility of dangerous methane concentrations, as well as the use of measures to prevent its ignition. According to the stated methane hazard, various preventive measures are applied – from the requirements imposed on the equipment, methane-monitoring systems, to the requirements in the scope of appropriate ventilation conditions and possible methane removal (Krause, 2007, 2008; Krzystolik, 2000). Generally, preventive measures must be selected before the commencement of mining operation

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and it is therefore important to accurately estimate the forecasted methane emission, both for the driven roadway workings and excavations. Currently, methane emission forecasts in the course of longwall exploitation are prepared on the basis of the 'Dynamic forecast of absolute methane content (technical guide)', published as Instruction No. 14 by the Central Mining Institute in 2000. However, this methodology is based on the results of research conducted over 30 years ago. Currently, in most cases, longwalls are driven in other ways than those on the basis of which these forecasting methods have been developed. The use of currently 'old' methane forecasting methods during mining works results in a large discrepancy between the findings of the forecast and the actual state, which, as a result, prevents proper selection of methane prevention measures (Koptoń, 2010).

At the Central Mining Institute, since 2006, research has been carried out which confirms the decisive influence of coal sorption properties on methane emission while conducting mining works in mines (Koptoń 2010, 2011, 2012, 2015, 2017; Koptoń & Skiba, 2010; Skoczylas, 2012; Skotniczny, 2009; Wierzbicki, 2013; Wierzbiński & Krause, 2006). This analysis also uses the results of the research included in the author's Ph.D. dissertation: The method of forecasting absolute methane content in roadway workings drilled with heading machines in hard coal mines (Koptoń, 2009).

2. Research methodology and the course of research

The assessment of the influence of sorptive properties of coal on methane emission to the longwall will be carried out on the basis of verification of the mathematical model of methane release from coal sidewall of longwall heading constructed using a mathematical-physical method and taking into account the results of research and data on 17 longwalls contained in the documentation of the statutory work ent. 'Methane release model from active coal mining surfaces in selected mines of the Upper Silesian Coal Basin', developed in 2009 (computer work number in GIG: 110 1069 9-210), as well as the author's publications in the field in question (Koptoń, 2009). The subject of the analysis will be methane emission from coal seam exploited to its full thickness by the longwall system with caving. For the purpose of this paper, the analysis covered longwalls within the exploitation range of which, up to a 5-fold thickness of the exploited seam, there are no other layers, coal layers and sandstone layers (under conditions of strongly methane bearing deposit), and longwalls with 'Y' ventilation system with air discharge along the gobs and reblowing the outlet current from the longwall (Fig. 1).

Then, it can be assumed that the total amount of methane emitted to longwall heading is the sum of:

- the volume of methane emitted from the run-of-mine,
- the volume of methane emitted from the surface area of coal sidewall (from the longwall face).

Further, it is necessary to analyse and determine the dependencies showing the kinetics of methane emission from the excavated coal and coal deposited in the desorption zone around the longwall heading along with determining the extent of this zone.

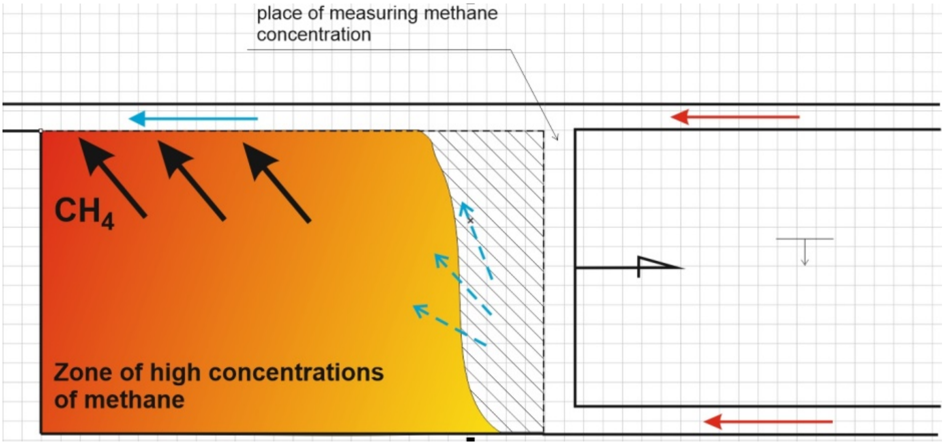


Fig. 1. Measurement of methane emission and distribution of methane concentrations in the longwalls with 'Y' ventilation system with air discharge along the gobs and reblowing of the outlet current

3. Research results

3.1. Determination of the extent of the desorption zone in the mined seam ahead of the longwall front

During the exploitation of the longwall, the primary balance of the rock mass is disturbed to a much greater degree and extent as a result of which stresses within the longwall heading reach other values compared to the stresses prevailing in the undisturbed rock mass. Assumptions regarding the shape and extent of the desorption zone behind the longwall front, included in the current methodology for forecasting absolute methane content of longwalls, are included, inter alia, in the abovementioned Instruction No. 14 GIG.

The subject of this analysis is to investigate the extent of the desorption zone in the exploited seam ahead of the longwall front. In the exploitation of deposits with a longwall system, in the immediate vicinity of the longwall face there is a concentration of stresses resulting from the exposed roof in the working space and its subsidence, conditioned by the stiffness of both the roof and the seam, housing resistance and compressiveness of the gobs (Kłeczek, 1994). Theoretically, the maximum operating pressure occurs in the longwall face and its value decreases as it moves away from the face into the depths of the longwall. At the operating depths exceeding 500 m (the vast majority of the currently exploited longwalls), the maximum value of operating pressure exceeds the compressive strength of coal. Therefore, in the longwall face, as a result of critical strain of unmined coal, an unstressed cracking zone will form and, consequently, the place of occurrence of maximum operating pressures will be shifted into the depth of the seam (Kłeczek, 1994). The range of the stress relieved zone in exploited coal seam depends on geological, mining and technical factors.

The range depends on the depth of exploitation, the method of roof management, strength parameters of the seam and neighboring layers, the mutual relationship as well as the extent of exploitation advance. It can be stated that the seam in the longwall face destresses to a certain depth, for given geological, mining and technical conditions, maximum depth and it is from this zone that methane desorbs into the excavation. The zone of maximum operating stresses, located further away, has the effect of reducing the permeability of coal for methane, forming the so-called barrier for degassing the seam. Bearing this in mind, it can be assumed that a longwall heading exploited in the methane coal seam is behind the degassing zone, called the desorption zone, which moves with the advance, and whose range and shape corresponds to the fracturing zone – the area of destruction of the rock mass around the excavation. It is primarily methane from the coal lying in this zone that is desorbed directly to the longwall heading. Calculation of the size and shape of the fracturing zone is possible in an analytical manner, for example based on known theories by Protodiakonow, Cymbariewicz, Sałustowicz and Borecki (Kidybiński, 1982; Kłeczek, 1994) or using numerical modelling.

Research related to the determination of the size of the zone of rock mass destruction around the longwall heading, in the aspect of the stability analysis of the roof in the longwall-face zone with caving, depending on the mechanical properties of the rocks and the housing resistance, was conducted by St. Prusek and A. Walentek (Prusek et al., 2009). The size of the zones in which the rocks surrounding the excavation were destroyed (due to the vicinity of the gobs), was obtained as a result of numerical calculations using the finite element method – assuming the Hoek-Brown strength criterion for the elastic-plastic medium (Hoek, 1998; Phase^2, 1998). The rock mass model adopted for calculations is shown in Figure 2.

The numerical calculations were carried out in three stages and in each of them the influence of various factors on the range and shape of this destruction zone in the vicinity of the longwall heading was considered:

- stage I – analysis of the impact of compressive strength of coal of the exploited seam on the destruction zone,
- stage II – analysis of the impact of exploitation depth on the destruction zone,
- stage III – analysis of the influence of the thickness of the exploited seam (longwall height) on the destruction zone.

The calculations were made in stages for different values of the seam thickness (longwall height) – 1.6 m, 2.0 m, 2.5 m and 3.5 m and different values of the compressive strength of coal – 5, 10, 15, 20, 25, and 30 MPa. Compressive strength of floor and floor rocks was assumed at 25 MPa (40 and 55 MPa were also analyzed for the roof). In addition, different exploitation depths – 600 m, 800 m, 1000 m and 1200 m were assumed in the calculations in stages.

For each of the calculation stages, the following assumptions were also adopted:

- displacement on all edges of the model in the vertical and horizontal direction are equal zero,
- primary stresses result from the set depth and the average weight of the overburden,
- the analysis of changes in the state of effort is determined according to the Hoek-Brown criterion for the elastic-plastic medium.

The distribution of reactions in the powered housing chock was established in accordance with the statutory work of Ph.D. Eng. Marek Płonka ent. ‘Measurements and analysis of the load dynamics of the housing based on the registration of rapid pressure changes in the stands of the powered roof support’ (Płonka, 2009). The results of numerical calculations, depicting the zone of destruction of the rock mass around the longwall heading, are presented below in the form of stress maps and graphs, allowing the comparison of the impact of particular factors on the size

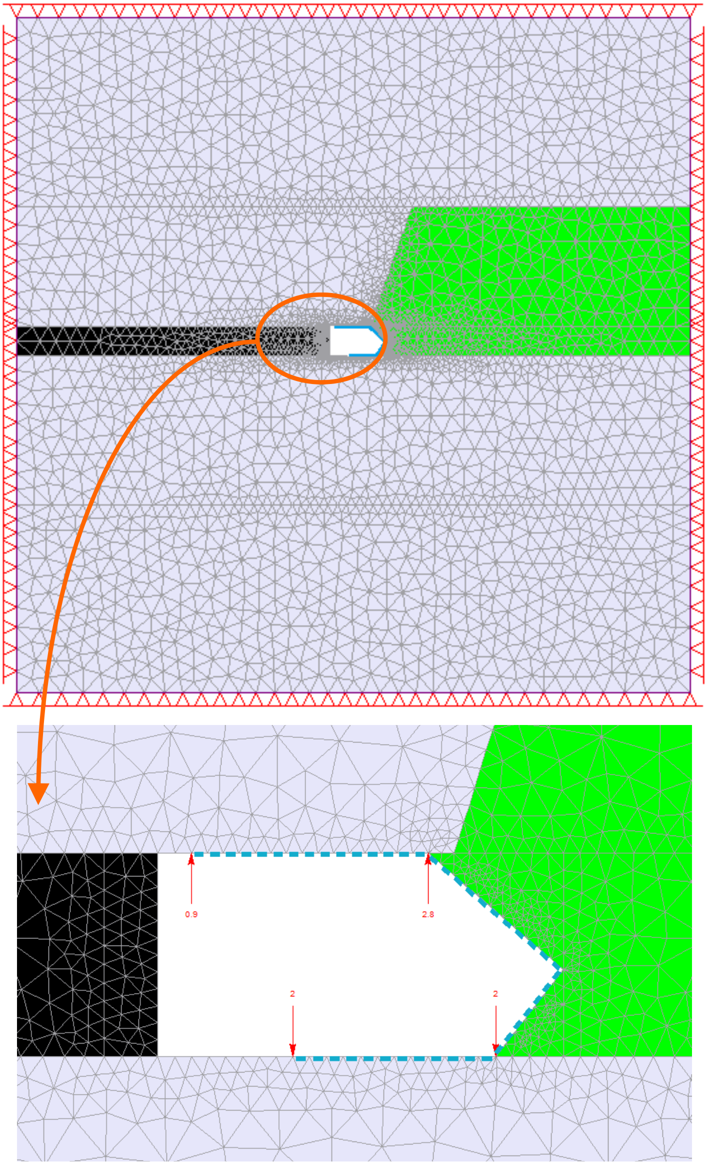
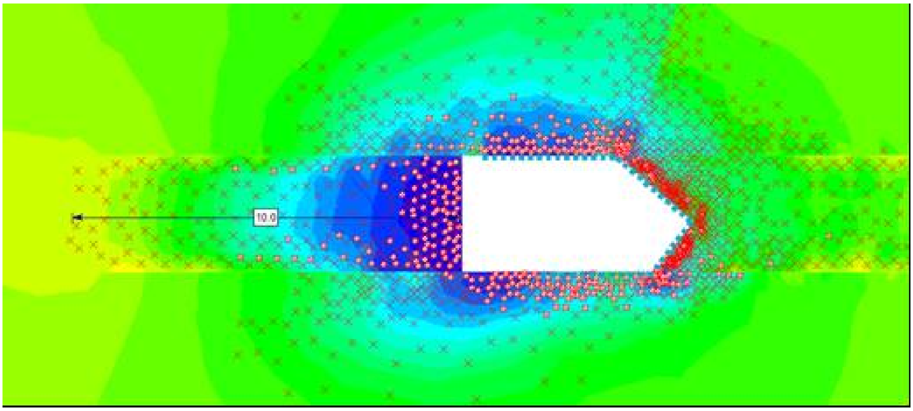


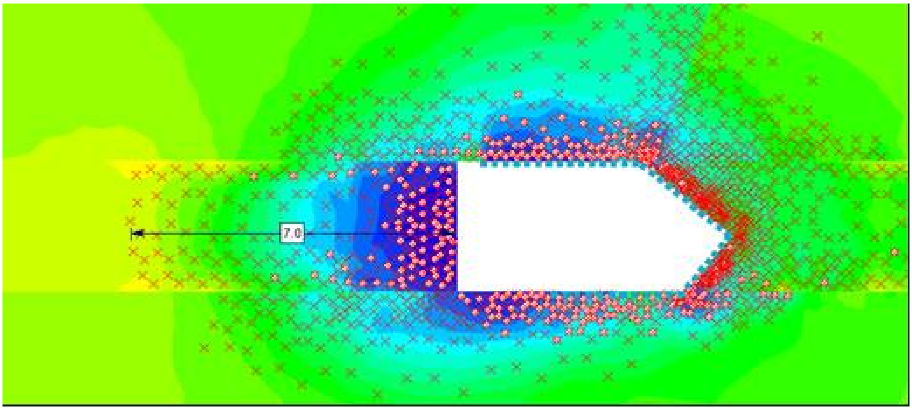
Fig. 2. A rock mass model adopted for the calculation of the extent of the rock mass destruction zone in the vicinity of a longwall heading

of this zone. In order to facilitate the interpretation of the obtained results, all stress maps are presented on the same scale. The results of the numerical calculations made for individual stages are shown in the Figures: 3-5 – stage I, 6-8 – stage II, and 9-11 – stage III.

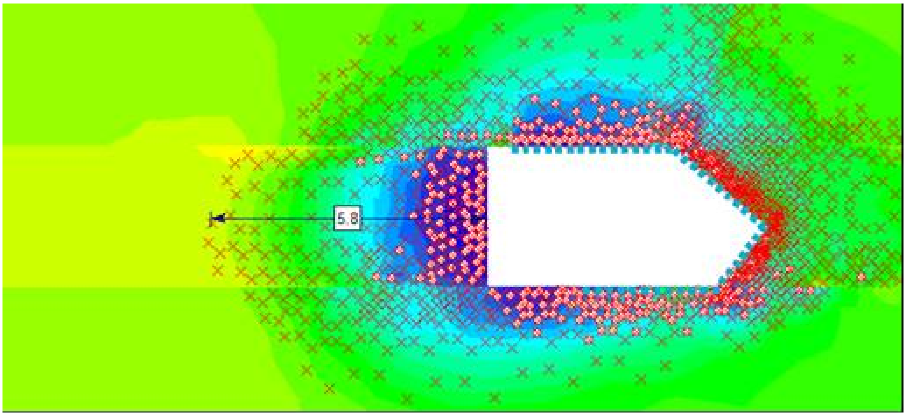
Fig. 12 shows the course of the extent of the longwall face destruction as a function of the compressive strength of the roof rocks.



R_{cw} = 5 MPa

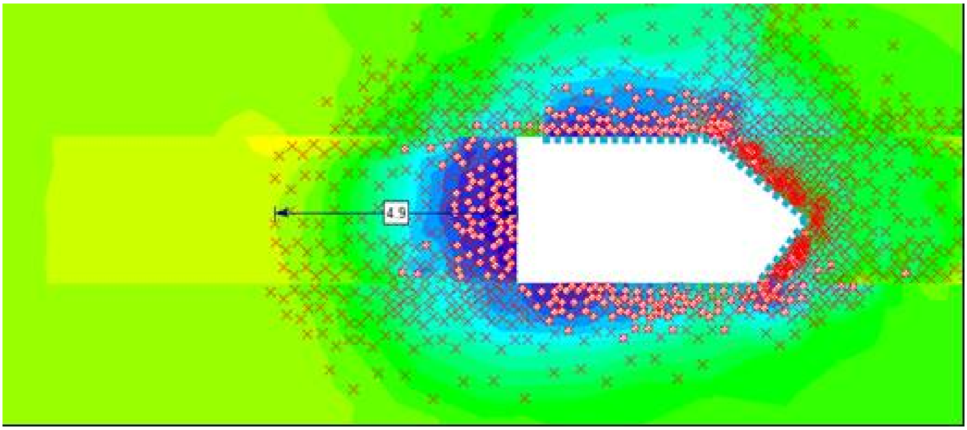


R_{cw} = 10 MPa

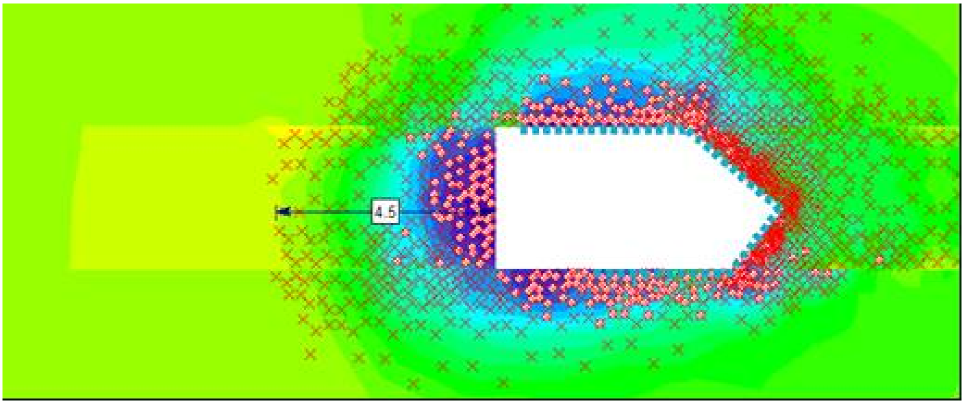


R_{cw} = 15 MPa

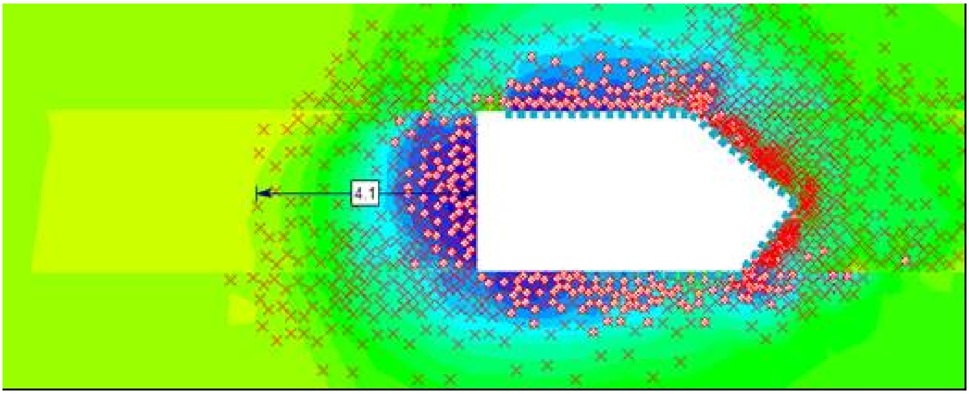
Fig. 3. Calculation results for compressive strength of 10 and 15 MPa. Depth 800 m, compressive strength of the roof 25 MPa, floor 25 MPa, longwall height h = 3.0 m



R_{cw} = 20 MPa



R_{cw} = 25 MPa



R_{cw} = 30 MPa

Fig. 4. Calculation results for compressive strength of 20, 25 and 30 Mpa. Depth 800 m, compressive strength of the roof 25 MPa, floor 25 MPa, longwall height h = 3.0 m

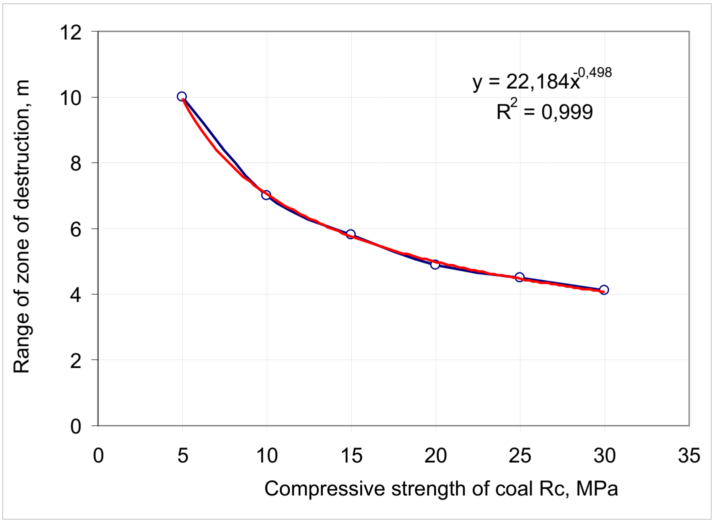
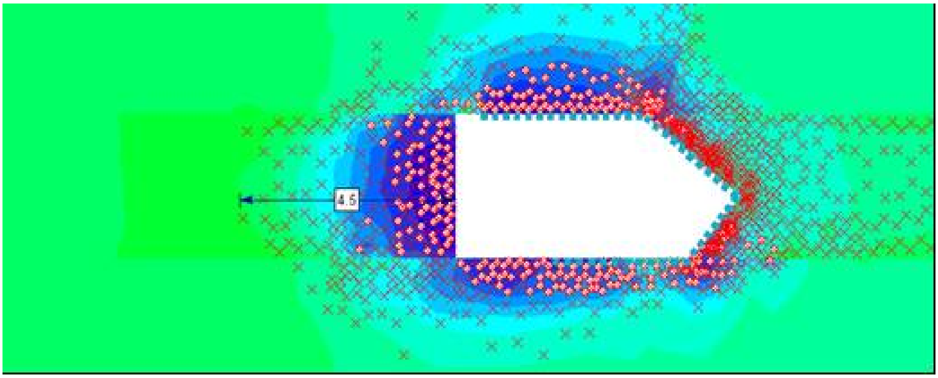


Fig. 5. The course of the extent of longwall face destruction as a function of coal strength

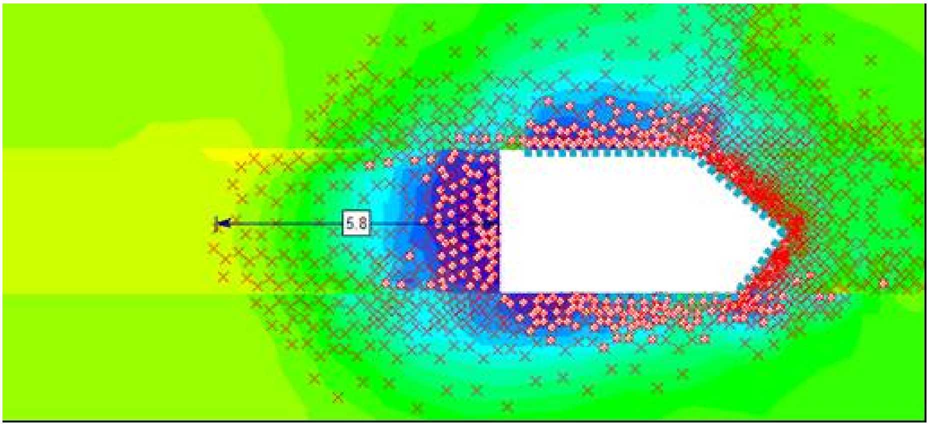


G = 600 m

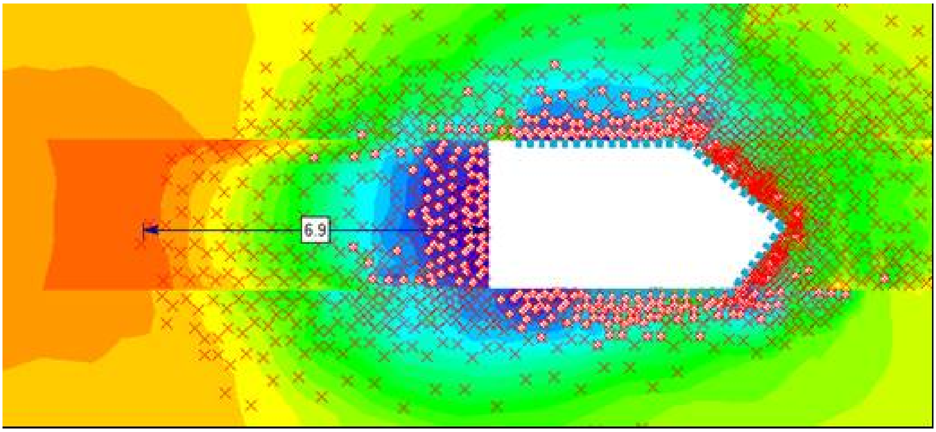
Fig. 6. Calculation results for a depth of 600 m. Compressive strength of coal 15 MPa, roof 25 MPa, floor 25 MPa, longwall height *h* = 3.0 m

Analysing the obtained results of calculations, the following conclusions can be drawn:

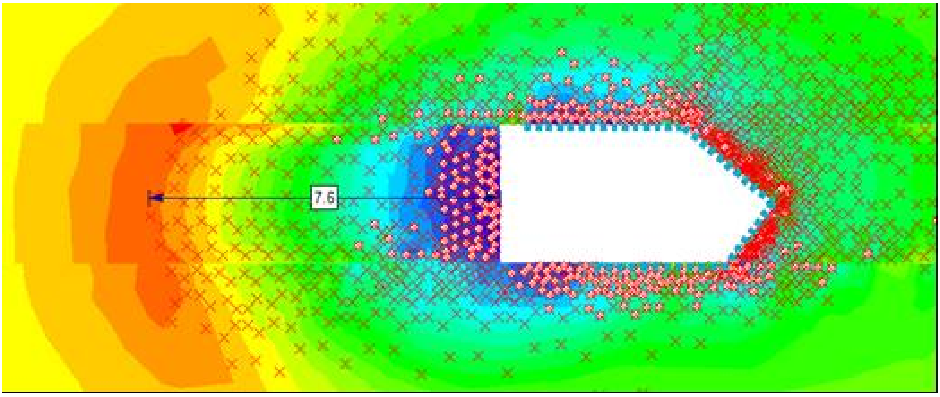
- Each of the factors considered, i.e.: thickness of the seam (longwall height), depth of the excavation depth, compressive strength of both coal and roof rocks in the exploited seam – affects the extent of the destruction zone ahead of the longwall front. This impact is diverse.
- Increase in exploitation depth from 600 to 1200 m increases the extent of the destruction zone from 4.5 m to 7.6 m. It results from the fact that along with the increase in depth, the values of rock mass pressure increase, having a significant impact on changes occurring around the excavation, including the formation of the fracturing zone.



G = 800 m



G = 1000 m



G = 1200 m

Fig. 7. Calculation results for a depth of 800 m, 1000 m and 1200 m. Compressive strength of coal 15 MPa, roof 25 MPa, floor 25 MPa, longwall height *h* = 3.0 m

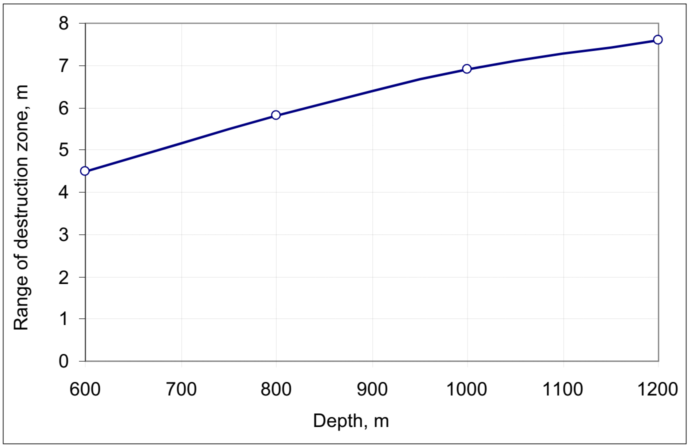
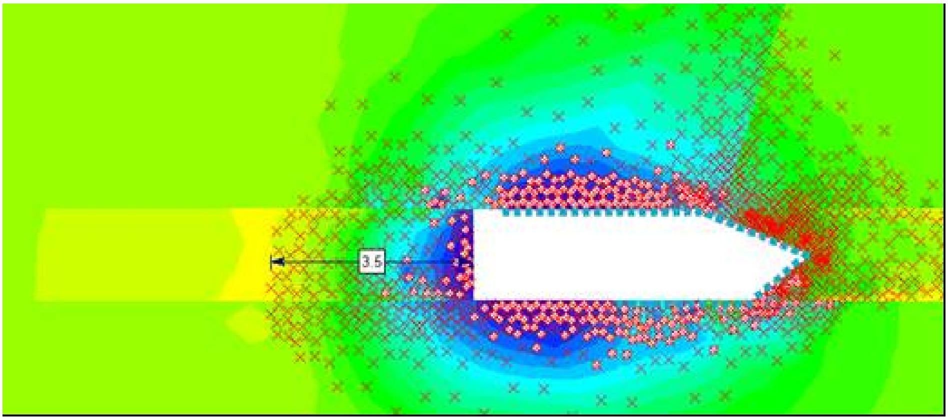
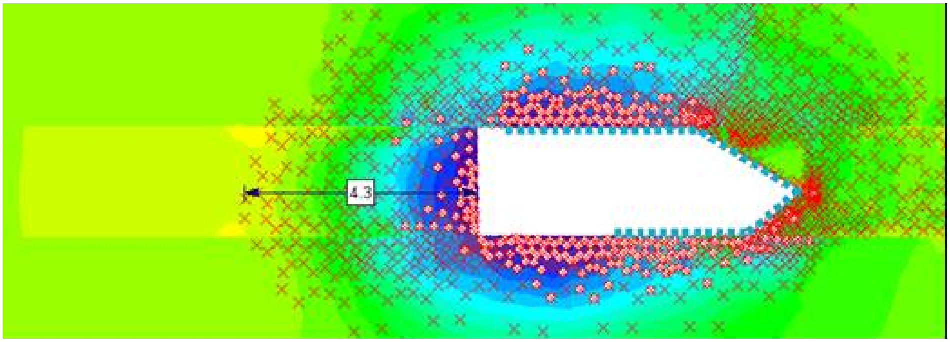


Fig. 8. The course of the extent of longwall face destruction as a function of depth

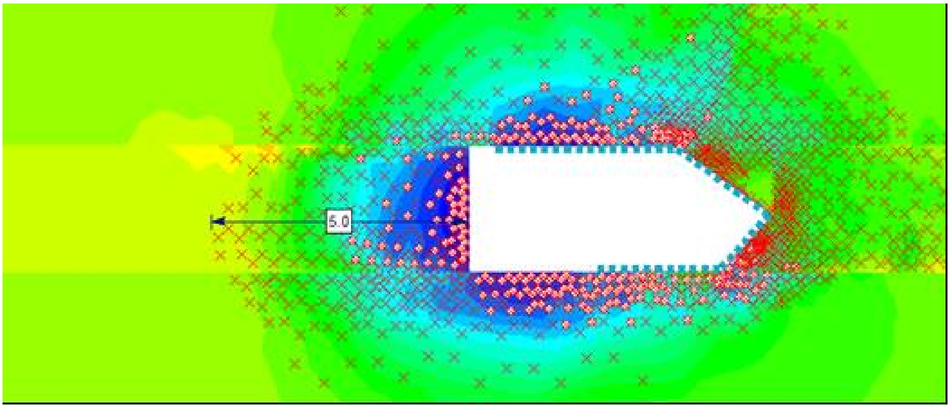


h = 1.6 m

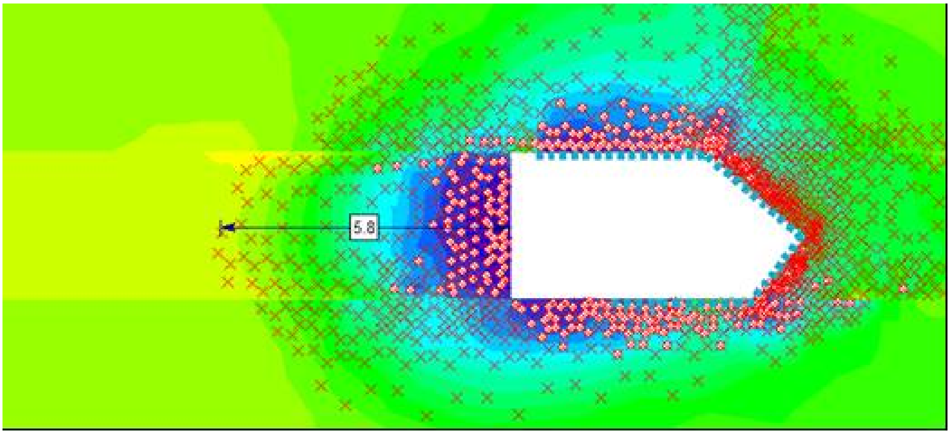


h = 2.0 m

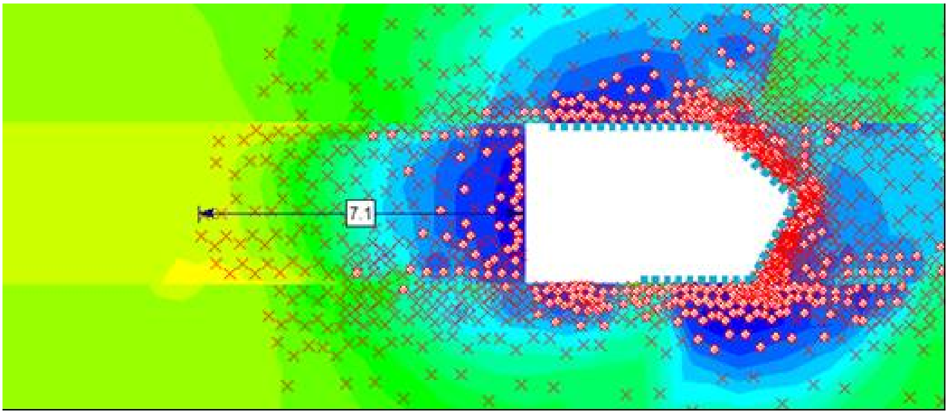
Fig. 9. Calculation results for longwall height of 1.6 m and 2.0 m. Depth 800 m, compressive strength of coal 15 MPa, roof 25 MPa, floor 25 MPa



h = 2.5 m



h = 3.0 m



h = 3.5 m

Fig. 10. Calculation results for longwall height of 2.5 m, 3 m and 3.5 m. Depth 800 m, compressive strength of coal 15 MPa, roof 25 MPa, floor 25 MPa

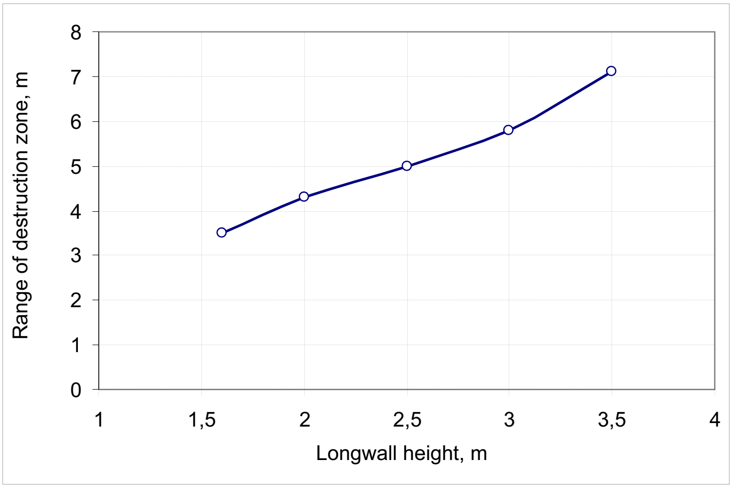


Fig. 11. The course of the extent of the longwall face destruction as a function of longwall height

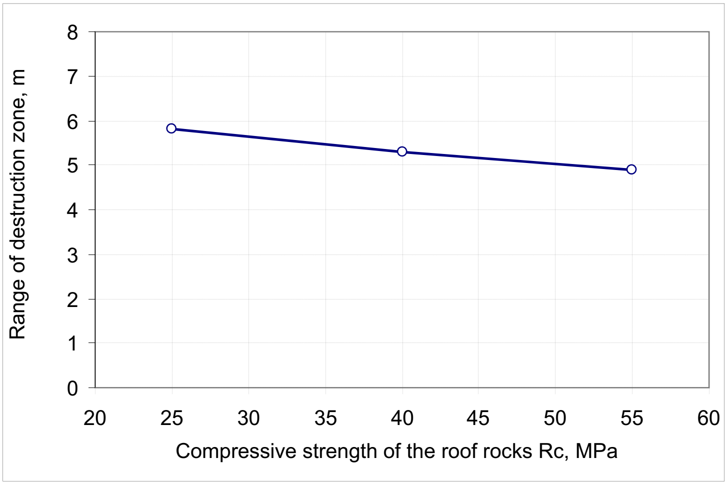


Fig. 12. The course of the extent of longwall face destruction as a function of compressive strength of roof rocks

- The increase in the compressive strength of both, the exploited seam and the roof rocks reduces the extent of the fracturing zone. For example, the increase in compressive strength of the exploited seam from 5 to 30 MPa reduces the range of the fracturing zone from 10 to 4 m.
- The increase in the thickness of the seam (longwall height) from 1.6 to 3.5 m, at constant depth values and compressive strength of coal, increases the extent of the destruction zone of the seam ahead of the longwall front from 3,5 to 7.1 m.

Assuming that the extent of the fracturing zone (destruction of the rock mass) ahead of the longwall's front corresponds to the range of the methane desorption zone, it remains to determine the surface area of its part containing coal in the cross-section. Analysing the range of the fractures in the exploited coal seam ahead of the longwall front shown in the above figures, a cross section of the coal part of the F_d desorption zone will be assumed (the longwalls exploited to the full thickness of the seam are being analysed):

$$F_d = d \cdot a_s,\ \mathrm{m}^2 \tag{1}$$

where

d — thickness of the seam – total thickness of coal layers in the $\sum d_w$ zone (longwall height), m,

a_s — the extent of fracturing zone in the seam ahead of the longwall front, m.

The volume of the coal part of the desorption zone ahead of the longwall Q_s can be calculated from the formula:

$$Q_s = L_s \cdot d \cdot a_s,\ \mathrm{m}^3 \tag{2}$$

where

L_s — longwall length, m,

(other designations as above).

All the above assumptions regarding the extent of the desorption zone in the coal seam ahead of the longwall front will be used in the construction of a mathematical model for methane emission from coal sidewall of a longwall heading in hard coal mines.

3.2. Mathematical model of methane emission from coal sidewall of longwall heading in mines

The following assumptions will be made for the construction of a mathematical model for the release of methane from coal sidewall of a longwall heading in hard coal mines:

- the release of methane into the area of the longwall heading from the exploited seam will be taken into account,
- the exploited seam is homogeneous over its entire length in terms of physicochemical properties,
- the range and shape of the desorption zone will correspond to the extent of the destruction zone of the exploited seam in front of the longwall defined on the basis of the Hoek-Brown criterion (Hoek, 1998),
- release of methane from coal will be determined using the formulas resulting from the J.P. Seidle's method (Metcalfe et al., 1992; Olajossy, 1993), based on Fick's second law equation for isotropic radial diffusion, and assuming a substitute radius for coal grains in the volume of the desorption zone $R_{zz} = 0.1340$ cm (Koptoń, 2009),
- the model will not take into account the sudden inflows of methane to the excavation space due to rock mass tremor, ejection or the occurrence of the so-called methane squealer,
- the model will not take into account the methane inflow from the gobs behind the longwall.

The value of the substitute radius for the residual coal grains in the desorption zone $R_{zz} = 0.1340$ was determined based on the results of the author's separate research carried out for the conditions of the Upper Silesian Coal Basin and presented in the doctoral dissertation (Koptoń, 2009).

During longwall mining the sorption equilibrium is disturbed as a result of changes in stress distribution – from the primary pressure to decomposition in the destruction zone around the excavation, where the pressure in coal sidewall is in the order of 1at (10^5 Pa) and as a result methane desorbs into the excavation space.

Therefore, the equation describing the course of the sorption kinetic curve (obtained as a result of laboratory tests of sorption on coal), would allow us to describe the mechanism of methane emission during mining works underground, in the analysed case – during mining the longwall.

One of the methods describing the process of methane release from coal seams is the J.P. Seidle's methodology (Metcalfe et al., 1992; Olajossy, 1993; Seidle, 2011), used in American mining. Similar to other linear models (e.g. the Crank's unipore diffusion model – Crank, 1975; Wierzbicki, 2013), this methodology presents the mechanism of methane release from a ball shaped grain ($0 \le r \le R$), by means of an effective D_e diffusion coefficient, starting from the equation:

$$\frac{\partial V}{\partial t} = D_e \left(\frac{2}{r} \frac{\partial V}{\partial r} + \frac{\partial^2 V}{\partial r^2} \right) \tag{3}$$

It can be seen that the above equation results from Fick's second law, which determines changes in the concentration of the diffusible component (in this case – methane) in a unit of time, in a given cross-section of the diffusion stream.

The initial condition for the above equation is:

$$V(r,0) = V_0 \text{ (initial gas content – deposit methane content } M_0\text{)} \tag{4}$$

and boundary conditions should take into account the variability in time of the amount of methane content on the surface of the micropore grain:

$$V(R,t) = V_R(t) \quad ; \quad \left. \frac{\partial V(r,t)}{\partial t} \right|_{r=0} = 0 \tag{5}$$

The constant boundary value $V_R = \text{const}$ (residual amount of gas, indicating the sorption capacity of coal in given conditions) is often simply assumed. The solution to this problem, expressed in a series of infinite, after integration into a volume of grain, is as follows:

$$\overline{V}(t) = \overline{V}_\infty \left[1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-n^2 \pi^2 \frac{D_e \cdot t}{R^2} \right) \right] \tag{6}$$

When $\overline{V}(t)/\overline{V}_\infty < 0.25$, the above formula is simplified to the form:

$$\overline{V}(t) = 6 \cdot \overline{V}_\infty \sqrt{\frac{D_e \cdot t}{\pi \cdot R^2}} \tag{7}$$

However, when $\overline{V}(t)/\overline{V}_\infty > 0.7$, then in the equation (6), it is enough to take into account only the first part of the sum ($n = 1$), which gives:

$$\bar{V}(t) = \bar{V}_{\infty}\left[1 - \frac{6}{\pi^2}\exp\left(-\pi^2\frac{D_e \cdot t}{R^2}\right)\right] \tag{8}$$

where:

D_e — value of the effective diffusion coefficient of methane in coal, cm^2/s,
t — time, s,
R — average radius of coal grains, cm.

The equilibrium content of methane in the grains $\bar{V}_{\infty}$ corresponds to an infinitely long duration of the process. In the analysed case – in laboratory conditions, when determining the desorption curve, the balance is achieved after about one day. Of course, in underground conditions, this equilibrium is achieved in a much longer time, even after a few years, depending on the radius of R grains. In the desorption process, $\bar{V}_{\infty}$ value is the difference between the relative amount of gas in the initial and final equilibrium, i.e. desorbable methane content $\bar{V}_d$. If methane is released from the run-of-mine in the longwall, it will be the difference between the values of: the deposit methane content M_0 and the sorption capacity of coal relative to methane, determined for the underground conditions q_d. In the analysed laboratory case, the equations will be solved by taking a relative methane loss in CH_4/g. The sorption kinetics curve (desorption will be analysed) can be presented in two ways:

- expressing what amount of methane has been separated in time t (according to equations (7) and (8)),
- expressing what amount of methane remained to be released in time t (taking into account the residual gas content corresponding to the sorption capacity in given conditions) according to the following equations:

$$\bar{V}(t) = \bar{V}_d\left(1 - 6\cdot\sqrt{\frac{D_e \cdot t}{\pi \cdot R^2}}\right), \text{ when } \bar{V}(t)/\bar{V}_d < 0.25 \tag{9}$$

and

$$\bar{V}(t) = \bar{V}_d \cdot \frac{6}{\pi^2}\cdot\exp\left(\frac{-\pi^2 \cdot D_e \cdot t}{R^2}\right), \text{ when } \bar{V}(t)/\bar{V}_d > 0.7 \tag{10}$$

where $\bar{V}_d$ — desorbable amount of methane.

During mining, methane is released into the longwall heading from both, the mined coal and the coal sidewall, while after mining – from the coal sidewall. For the safety of works, when selecting methane prevention measures in the longwall, it is important to know both methane release values. In the mathematical model, with the above in mind, the amount of methane released from the exploited seam to the longwall heading $\dot{V}_{ms}$ is considered as the sum of:

- the volume of methane emitted from the run-of-mine during the execution of a single cut (web) ($\dot{V}_{msu}$), i.e. on a length equal to the distance (z),
- volume of methane emitted from coal in the desorption zone ahead of the longwall front ($\dot{V}_{mso}$) along the entire length of the longwall.

That is:

$$\dot{V}_{ms} = \dot{V}_{msu} + \dot{V}_{mso}, \ \text{m}^3/\text{min} \tag{11}$$

The release of methane from the extracted coal in the longwall during the mining of a single cut/web $\dot{V}_{msu}$

Methane emission from coal mined during longwall exploitation while mining a single cut or a single web $\dot{V}_{msu}$, can be defined as the volume of methane desorbing from the mined coal while carrying out the cut. Taking into account dependence (8), this amount can be calculated from the formula:

$$\dot{V}_{msu} = \frac{L_S \cdot d \cdot z \cdot \gamma_w \cdot (M_o - q_d)}{\tau_z} \cdot \left[1 - \frac{6}{\pi^2} \cdot \exp\left(-\frac{60 \cdot \pi^2 \cdot D_e \cdot \tau_z}{R_{zz}{}^2} \right) \right], \ \mathrm{m}^3/\mathrm{min} \qquad (12)$$

where:

γ_w — coal density, Mg/m^3,
z — the depth of the cut during mining, m,
L_s — longwall length, m,
d — seam thickness, *m*
M_o — methane content of the coal seam, m^3/Mg csw,
τ_z — duration of a single cut, min,
R_{zz} — substitute radius of coal grains = 0.134 cm.
D_e — effective diffusion coefficient of methane in coal seam, cm^2/s
q_d — sorption capacity of coal in relation to methane in underground conditions at pressure 1at (10^5 Pa), taking into account the total moisture content, ash in coal and the temperature of the primary rock mass, which can be calculated according to the formula (Koptoń 2017):

$$q_d = \frac{q_s \cdot \left[1 - 0{,}008 \left(T_z - 25 \right) \right]}{(1 + 0{,}3 W_t) \cdot (1 - 0{,}01 A^a)}, \ \mathrm{cm}^3/\mathrm{g} \qquad (13)$$

where:

T_z — primary temperature of the rock mass at the place of conducted works, °C,
q_s — sorption capacity of coal under standard conditions, cm^3/g,
A^a — ash content in coal, % (assuming that $A^a < 100\%$),
W_t — total moisture in coal, %.

From the formula (12) it follows that the amount of methane emitted from coal excavated in the face of the excavation during the performance of a single cut $\dot{V}_{msu}$ is proportional to the difference between the values of: deposit methane content M_0 and sorption capacity of coal relative to methane in underground conditions q_d (at the pressure of 10^5 Pa), with taking into account the content of ash and total moisture in coal and the temperature of the primary rock mass. Of course, formula (12) makes sense for values of $M_0 \geq q_d$. In the case when $M_0 \leq q_d$, according to the assumptions for the developed mathematical model there is no methane release.

Methane emission from the coal sidewall of a longwall heading (from the coal of the exploited seam located in the desorption zone ahead of the longwall front) $\dot{V}_{mso}$

Methane emission from the coal sidewall of a longwall heading ($\dot{V}_{mso}$), that is from the longwall face) is defined as the volume of methane emitted from the coal seam (layers of coal seam) in the desorption zone in front of the longwall, taking into account equations (9) and (1)0, expressed as duration of shifts in which mining is carried out. This amount is calculated from the formula:

$$\dot{V}_{mso} = \frac{L_s \cdot d \cdot a_s \cdot \gamma_w \cdot (M_o - q_d)}{1440 \cdot c} \cdot \left[1 - \frac{6}{\pi^2} \cdot \exp\left(-\frac{21600 \cdot \pi^2 \cdot c \cdot D_e}{R_{zz}^2}\right)\right], \ \mathrm{m^3/min} \qquad (14)$$

where:

a_s — the range of the desorption zone in the coal seam ahead of the longwall front, depending on the thickness of the seam, the compressive strength and depth of the coal, determined on the basis of the diagrams in Figures 5, 8 and 11,

w — daily advance of the excavation, m/day,

c — the number of six-hour shifts, during which mining with a heading machine in the longwall (from 1 to 4),

(The remaining designations, as above).

Due to the pressure distribution in the desorption zone from the value corresponding to q_d to the value corresponding to M_0, the average value $(M_0 - q_d)/2$ is adopted for the desorption equation. In addition, the entire amount of methane release from the longwall front is taken as the average value (commencement and termination of mining). The expression in square brackets results from taking into account the difference between the relations (9) and (10) in the time interval (from 0 to t), to express the amount of methane that desorbed in this time interval. From the formula (14), it follows that the amount of methane emitted from the coal in the desorption zone ahead of the exploited longwall front ($\dot{V}_{mso}$), is proportional to the difference between the following values: deposit methane content M_0 and sorption capacity of coal in relation to methane in underground conditions q_d (at the pressure of 10^5 Pa), taking into account the ash content and total moisture in coal as well as the primary rock mass temperature. Of course, the formula (14) makes sense with the value $M_0 \geq q_d$. In the case where $M_0 \leq q_d$, according to the assumptions to this mathematical model, methane release does not occur.

4. Verification of the developed model of methane emission from coal sidewall of longwall heading in mines

The verification of the developed emission model will consist in the comparison of the actual methane release to the selected longwalls in the USCB with the values calculated according to the model developed for the given conditions and the estimation of its correctness. The methane release values, calculated on the basis of the mathematical model developed, will be *ex post* forecasts calculated for the so-called expired forecasts – for which the actual values of the forecasted variable are known at the time of data compilation (Gajda, 2001). In order to carry out the verification, data on 17 longwalls mined in the seams classified as II, III and IV methane hazard category will be used. The assessment of the accuracy of the forecasts developed will be carried out by determining the average relative error of *ex post* forecasts (Gajda, 2001). It was assumed that the prepared forecast will be considered acceptable if the average relative error *ex post*, does not exceed 25%. Table 1 presents the values of actual methane emission to longwall workings during and after mining, the value forecasted for the obtained daily advance and the relative values of *ex post* errors of the forecast for individual longwalls.

TABLE 1

Summary of the actual methane release to the longwall workings and the *ex post* forecast value calculated according to the developed mathematical model and the relative values of the *ex post* error forecasts for the 17 longwalls selected for analysis

Longwall no.	**Extreme emission during cut performance – actual**	**Emission from sidewall – actual**	**Extreme emission during cut performance – forecasted**	**Relative errors of the ex post forecast**	**Emission from the sidewall – forecasted**	**Relative error of *ex post* forecast**
	m^3/min	**m^3/min**	**m^3/min**	**%**	**m^3/min**	**%**
1.	12.80	5.60	11.32	11.58	6.074	–8.46
2.	21.60	7.20	20.77	3.85	8.957	–24.41
3.	28.00	9.80	28.04	–0.15	10.977	–12.01
4.	4.80	0.84	3.80	20.86	0.891	–6.11
5.	16.80	4.20	13.18	21.57	4.201	–0.02
6.	4.40	1.10	4.30	2.22	1.092	0.75
7.	20.40	8.40	18.66	8.55	9.093	–8.25
8.	22.80	8.40	19.84	12.99	7.626	9.22
9.	11.70	4.50	9.76	16.58	3.510	22.00
10.	23.13	4.38	21.54	6.87	4.166	4.77
11.	20.52	5.70	18.87	8.02	5.402	5.22
12.	6.30	1.80	6.16	2.19	1.546	14.09
13.	15.52	5.34	13.78	11.24	5.559	–4.20
14.	14.72	4.14	13.28	9.77	3.781	8.68
15.	6.50	2.60	7.75	–19.16	2.537	2.43
16.	22.40	6.40	19.29	13.89	6.884	–7.57
17.	15.68	4.48	16.44	–4.87	3.832	14.46
The average relative error of *ex post* forecasts Ψ, %			**10.26**		**8.98**	

The above summary shows that the relative *ex post* error of forecasts of extreme methane release in longwalls during the mining of a single cut is in the range from –19.2 to + 21.6% and in no case exceeds 25%. The error value with the '–' sign indicates that the forecast has been overestimated (inflated). The average relative *ex post* error of forecasts is 10.26%, which is within the assumed range of up to 25%. The above table also shows that the relative *ex post* error of methane separation from coal sidewall ranges from –24.4 to + 22.0%, i.e. in all cases, the error does not exceed the assumed 25%. The error value with the '+' sign indicates that the forecast has been underestimated (understated). The average relative error of *ex post* forecasts is about 9%, which is also within the assumed range of up to 25%.

The performed verification shows that the relative error of *ex post* forecasts calculated on the basis of the developed mathematical model for the data on the analysed set of longwalls is in the range from –19.2 to + 21.6% and in no case exceeds 25%.

The error value with the '–' sign indicates that the forecast has been overestimated (inflated). The average relative *ex post* error of forecasts is 10.26%, which is within the assumed range of up to 25%. The above table also shows that the relative *ex post* error of methane release from coal sidewall ranges from –24.4 to + 22.0%, i.e. in all cases, the error does not exceed the assumed 25%.

The error value with the '+' sign indicates that the forecast has been underestimated (understated). The average relative error of *ex post* forecasts is about 9%, which is also within the assumed range of up to 25%.

5. Conclusions

1. Conducting a detailed analysis and development of dependencies showing the kinetics of methane emission from the run-of-mine and from the coal seam in the desorption zone ahead of the longwall front along with determining the extent of this zone, allowed the assumption of the mathematical model of methane emission in the longwall.
2. Mathematical model of methane emission from the coal sidewall of a longwall heading, describing the amount of released methane:
   - from the run-of-mine when making a single cut in the longwall,
   - from the longwall face,

   was built taking into account the following assumptions:
   - the model includes methane emission to the area of a longwall heading from the exploited seam,
   - the seam in which the longwall is mined is homogeneous in terms of its physicochemical properties,
   - the extent of the desorption zone corresponds to the extent of the destruction zone of the rock mass in the vicinity of the longwall heading, determined on the basis of the Hoek-Brown criterion,
   - methane emission from coal was determined using the formulas resulting from the J.P. Seidle, based on the equation of Fick's second law, and assuming the length of a substitute radius for coal grains in the desorption zone equal to $R_{zz} = 0.1340$ cm,
   - the model will not take into account the sudden inflow of methane to the longwall due to rock mass tremors, bursts, or methane squealers,
   - the model does not take into account methane inflow from gobs and the neighboring seams.
3. The research results show that increase in exploitation depth and longwall height increases the extent of the destruction zone (desorption zone) of the seam ahead of the longwall. The increase in the compressive strength of both, the exploited seam and the roof rocks reduces the extent of this zone.
4. From the performer verification of methane emission model from the exploited seam to the longwall heading, it follows that the relative error of *ex post* forecasts based on the data of the analysed set of 17 longwalls in no case exceeds the forecast admissibility error of 25%. On the other hand, the average relative error of *ex post* forecasts is 10.3% for the extraction forecast during mining and 9.0% for the forecast after completion of mining, and it is also lower than 25%.

5. The analysis shows that the mathematical model of methane emission from coal sidewall of the exploited coal seam into longwall heading has been developed on correct assumptions, with particular emphasis on the impact of sorption properties of coal, which also indicates the possibility of their application in practice when forecasting methane release while conducting mining works in mines.
6. In the light of the results of the analyses carried out for the purpose of this paper, the sorption properties of coal have a significant influence on methane emission, which are currently examined basically only due to the risk of methane and rock outbursts. Extending the scope of these tests will also enable more accurate prediction of methane emission in various conditions, and therefore improving the safety of works.
7. Forecasts of methane emissions are always the basis for the selection of appropriate methane prevention measures, especially the method of ventilation, or the method of methane drainage in the rock mass. The developed mathematical model of methane emission will allow a more accurate estimation of the amount of methane released in the longwall heading during mining, which undoubtedly has a significant impact on the safety of exploitation.

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