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JERZY KRAWCZYK*, JAKUB JANUS*

MODELING OF THE PROPAGATION OF METHANE FROM THE LONGWALL GOAF, PERFORMED BY MEANS OF A TWO-DIMENSIONAL DESCRIPTION

MODELOWANIE PROPAGACJI METANU ZE ZROBÓW ŚCIANY WYDOBYWCZEJ PRZY POMOCY DWUWYMIAROWEGO OPISU

The paper presents results of a research on the migration of methane from goaf into an area of a longwall ventilated by means of the U-type ventilation system. Two-dimensional models of the area in question were prepared. The models encompassed longwalls whose length was 240 m, as well as segments of the main and tailgate whose length was minimum 50 m. The geometry of the models took into account the details that could make three-dimensional models too complex. These details include: the ribs of the arch support of the headings, frictional and hydraulic props, and the ribs of a section of the longwall powered roof support. Additionally, the presence of gaps between the support sections, by means of which an exchange of gases between the longwall and the adjacent goaf could take place – was taken into consideration. Using the 2D description method, an analysis of the flow of air in the area was carried out. The simulation results were shown as profiles of velocity and streamlines in surrounding of intersections of longwall. with main and tailgate Then, the grid depenadncy of numerical solutions was investigated. This was done by comparing results for three grid densities. The process of methane propagation was simulated for shearer located at two-thirds of the longwall length. The fields of methane concentrations for a steady inflow from goaf were calculated. Subsequently, the effects of a sudden inflow of methane along a segment comprising ten recently advanced roof support sections were computed. The results were presented as a sequence of concentration distributions for selected simulation moments.

Keywords: methane hazard, longwall, two-dimensional description, transient states, turbulent flow, scale adaptive simulation

Rozpatrywano migrację metanu ze zrobów do wyrobisk rejonu ściany przewietrzanego w systemie na U. Przygotowano dwuwymiarowe modele rejonu ściany obejmujące ściany o długości 240 m i odcinki chodników ścianowych od długościach co najmniej 50 m. W modelach tych wprowadzono reprezentację geometrii z uwzględnieniem szczegółów, które mogą nadmiernie skomplikować modele 3D. Elementami tymi są żebra obudowy łukowej chodników, stojaki cierne i hydrauliczne oraz żebra sekcji zmechanizowanej obudowy ściany. Uwzględniono również obecność szczelin między sekcjami obudowy, poprzez które

* STRATA MECHANICS RESEARCH INSTITUTE OF THE POLISH ACADEMY OF SCIENCES, UL. REYMONTA 27, 30-059 KRAKÓW, POLAND

może następować wymiana gazów ze zrobami. Przeprowadzono analizę przepływu powietrza w rejonie przy pomocy opisu 2D. Wyniki symulacji pokazano w postaci profili prędkości i linii prądu w otoczeniu skrzyżowań z chodnikami pod i nadścianowym w postaci profili prędkości i linii prądu. Sprawdzono zależności rozwiązania od siatki porównując wyniki dla trzech gęstości siatki. Przeprowadzono symulacje rozpływu metanu dla położeń kombajnu w 2/3 długości ściany. Obliczono pola stężeń metanu przy stałym dopływie ze zrobów a następnie skutki nagłego dopływu na odcinku 10 ostatnio dosuniętych sekcji. Wyniki przedstawiono w formie sekwencji rozkładów stężeń dla wybranych chwil symulacji

Słowa kluczowe: zagrożenie metanowe, ściana wydobywcza, opis dwuwymiarowy, stany przejściowe, przepływ turbulentny, symulacja z adaptacją skali

1. Introduction

Methane hazard is a problem that occurs in the majority of Polish hard coal mines. Numerous actions aimed at ensuring safety of exploitation under the conditions of this hazard are undertaken and carried out routinely. Providing the adequate level of safety in mines is closely linked to the knowledge of the process of methane propagation in excavations. Here, the finite-volume methods are increasingly being used. These methods make it possible to perform two- and three-dimensional simulations of flow phenomena which may take place in excavations – in particular, in the area of a longwall (Skotniczny, 2013; Calizaya et al., 1991).

The original source of methane is gas deposited in rocks. Disturbing the rock mass, which is the result of mining activity, leads to methane release. Through various channels, methane gets to the atmosphere of mine excavations. Among methane sources, there are: the exposed coal face, crushed output, and the disturbed rock mass itself. The focus of the present paper shall be the inflow of methane from goaf, i.e. caverns created during the process of exploitation carried out by means of the longwall method combined with roof caving, and with the U-type ventilation performed from the exploitation field borders.

While searching for spots characterized by an increased methane hazard one may first look for places, where the actual inflow may occur. Then for such inflows its propagation in workings may be investigated. Certain inflow spots can be indicated a priori, on the basis of the present state of knowledge (and of the history of sudden methane releases in particular). In broader context, the object of modeling can be excavations (i.e. the area in relation to which the risk is analyzed), as well as the sources of methane inflow (adjacent goaf). Then the inflow channels shall manifest themselves in the course of the simulation process.

An outflow from goaf involves methane flowing through the boundary between excavations and goaf. An access to the goaf area is quite limited, and therefore it is difficult to present it in a precise way (Karacan, 2010). Additionally, the geometry and flow characteristics of this area are prone to change as the process of exploitation progresses and consecutive rock slides take place. Such changes are usually substantial and difficult to predict. Also, they have an impact on routes through which methane may flow into excavations. Thus, a very simplified model of goaf was adopted for the sake of the research.

The adopted description of goaf encompasses a thin (0.5 m thick) layer adjacent to the longwall goaf. It was assumed that right behind the longwall supports and other forms of goaf isolation there is an empty space (or the rock material is arranged loosely enough so as not to constitute an obstacle to the flow). The methane flows from the neglected goaf area, at the border of the above-mentioned narrow strip of the empty space. For the initial conditions, it was assumed that a steady flow takes place across the whole investigated area. At the opposite border of the strip of the empty space, i.e. on the side of the excavations, there is goaf isolation, or a line of powered roof support sections. Methane flows into workings through gaps between the support sections, or through pores in the goaf isolation. It was assumed that there was no goaf isolation at the intersection with the tail gate which is the most common pravtice. The adopted representation of the goaf border is not suitable for a situation in which the rocks above and below are so weak that finely crushed material gets accumulated right behind the shields and the goaf isolation. In this case, instead of an empty space, the model should include a porous medium of appropriate permeability.

In the Polish hard coal mining industry, the length of longwalls often exceeds 200 meters. With the present efficiency of the available computation systems, calculating the non-stationary propagation of methane for a 3D model of the whole longwall and adjacent heading segments would require a significant simplification of the geometry of excavations. Thus, using a 2D representation becomes a viable alternative. With such a level of simplification, the number of unknowns is reduced 20 times (more or less). Also, a 2D representation makes it possible to carry out simulations for descriptions encompassing the entire longwall and sufficiently long segments of headings, with the acceptable expenditure of time and computational resources. What is more, it is possible to take into account the presence of such elements as the ribs of the heading support, frictional and hydraulic props, or the ribs of powered supports. Additionally, the presence of gaps between the support sections – which constitute an essential route of gas exchange between the longwall and the adjacent goaf – is taken into consideration. A preliminary analysis of the sensitivity of the solutions to the density of the computational grid showed that sufficiently accurate calculations can be carried out for 2 millions of cells, with one workstation comprising one multicore processor. Calculating one second of non-stationary simulations lasts ca. 4 hours. Thus, it is possible to perform – within several months – the following actions: calculate the initial state of propagation, carry out the simulation of a sudden inflow of methane, and present the process of the restoration of the initial state after the inflow has ceased. For a 3D model with just as complex geometry, performing calculations within a similar period of time would require using around 20 dual multicore processor computational nodes, connected parallelly.

To summarize: a two-dimensional description makes it possible to carry out multi-variation analyses of the flow within the entire longwall, with the acceptable expenditure of time and computational resources. The authors of the present article shall focus on a selected case of flow in a longwall. The following circumstances will be taken into account: the presence of a stopping at the intersection with the tail gate, the narrowing of the width of the longwall by the presence of the shearer located at a two-thirds through the longwall length, and the web-related changes in the width of the longwall. Also, a change in the width of the longwall caused by moving the sections of the powered supports will be taken into consideration (Fig. 1).

2. The description of the numerical model

For the sake of the simulation, the finite-volume method for a non-stationary, turbulent flow of air was adopted. It was assumed that the flow is incompressible. The entire range of turbulence models was used, starting with the classic k-ε model, through the k-ε model with the enhanced longwall function and the k-ω SST model (ANSYS 2013), and ending with the scale-adaptive simulation (SAS) model (Menter, 2012).

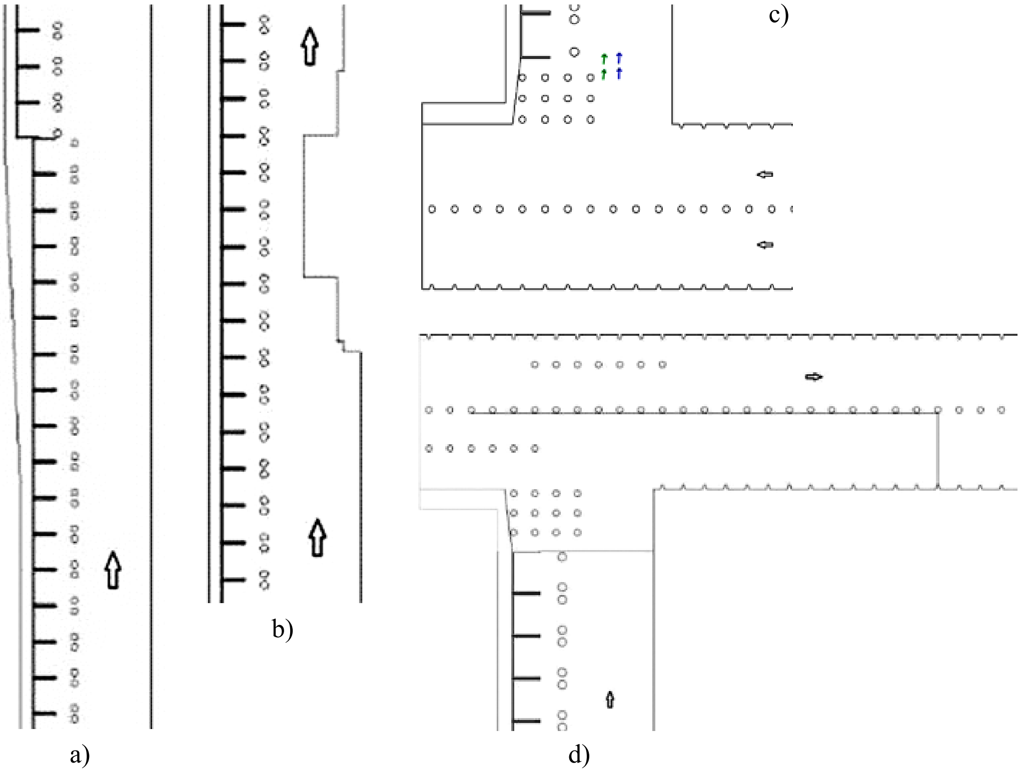

Fig. 1. Fragments of the geometry of a 2D model of a longwall area (a – the segment at the moved support, b – the segment with the heading shearer; c – the intersection with the maingate; d – the section with the tailgate

A significant increase in the grid density at the walls made it possible to apply – for the *k-ε* model – an enhanced description of the flow at the walls (enhanced wall treatment), taking into account the possibility of separation of the boundary layer (which may happen due to the fact that the presence of the ribs of the arch support, the ribs of a section of the powered support, and the frictional and hydraulic props were taken into consideration). According to the user manual for the ANSYS Fluent software (2013), the next reason for which an enhanced boundary area description should be applied is taking account of methane inflow occurring through gaps in the walls of the closed circuit. This happens when the source of the inflow are goaf: in this case, the inflow can occur through the gaps between the support sections.

The model of the longwall area was based on the project documentation of several longwalls in some Polish hard coal mines which are currently exploited. The model encompassed (Dziurzyński et al., 2013):

- a segment of the maingate, 48.74 m long and 5.2 m wide, with the ribbing spacing of 0.75 m. In the axis of this segment, frictional props having a diameter of 0.2 m and supporting each of the ribs were placed. It was assumed that the props are placed along a 50 m segment, before which there is a heading covered by an arch support with no props;

- the intersection of the maingate and longwall, 5.262 m long, supported by frictional props placed at the intervals of 0.75 m;
- a 3 m long blind segment of the maingate that was not liquidated, also with props;
- the initial segment of the longwall, 2.21 m long and narrowing down to the width of 5 m. The segment contained three rows of props whose diameter was 0.22 m. There were 4 props in each row, and they were placed at the intervals of 0.75-0.7 m, closer to the goaf;
- the set of 155 sections 1.5 m wide, with hydraulic props 0.29 m in diameter. Between the sections, there were gaps 0.02 m wide, through which gas exchange with the adjacent empty space in goaf took place. The width of the gaps was such as to take into account the possibility of flow occurring along other routes, impossible to be included in a 2D description. The width of the support ribs was 0.974 m, which narrowed down the cut of the wall open to the flow from 4.96 m to 4.03 m;
- for a 2D representation, the narrowing of the width of the flow channel from 5.2 m (heading) to 4.02 m (longwall channel), in the same proportion, results in the contraction of the cross-section, which corresponds to a longwall whose height is 3.1 m;
- the entire length of the longwall was 240 m (the segment covered with the powered support was 235.6 m long);
- additionally, the narrow space of goaf not influenced by caving and adjacent to the corner and the longwall was modeled. In the corners, as well as in the initial and the final segment of the longwall, the space in question is separated from the headings and the upcut with a porous stopping which represents isolation layers. Also, the gaps between the support sections make the exchange of gases possible;
- the dimensions of the longwall-tailagate intersection and blind end were the same as the dimensions of the maingate-longwall intersection and maingate's blind end. The only differences concerned the racking, i.e. the additional rows of props in the corner and at the intersection next to the sidewall opposite to the longwall outlet;
- in the tailgate, whose width was the same as the width of the maingate (i.e. 5.2 m), the length of the segment supported with props was ca. 50 m. The remaining part, which was 55 m long, was covered with support ribs, just like the initial segment at the walls;
- in the tailgate crossing, there is a 16.5 m long curtain directing flow towards the blind end of tailgate. It was assumed that it is leakproof (Fig. 1d).

While creating a model for the „U" ventilation system, with the presence of a shearer and the moving of the section taken into account, the authors tried to ensure the greatest possible geometrical similarity to the conditions in the excavations of the longwall area (Fig. 1). In the investigated case, it was assumed that the shearer is placed in ¾ of the longwall length (the shearer was located at sections #109 to #117; section #97 is the first advanced one). This will be represented by narrowing of the flow, whose shape is presented in Figure 5. Its geometrical dimensions correspond to the dimensions of the KSW-460NE narrow ranging arm low-seam longwall shearer. In the model, the following shearer dimensions were adopted:

- length – 12 m;
- width – 2,3 m;
- width of the mining organs – 0,7 m.

20 sections from the spot where the working of the longwall ceases, the advance of the section of the powered support was designed. The scope of the advance – 0.7 m – corresponded to the shearer's cut width.

3. The boundary conditions and the flow model

The intial calculations were carried out for the most basic model of incompressible flow. The operating pressure that was given corresponded to the conditions in the mine. For non-stationary gas migration, it was necessary to take into consideration the equations of transportation of the mixture components, as well as the model of an ideal gas. This was done in several stages. Once concurrence had been achieved, the model of the transportation of the gas mixture was introduced (Menter, 2012). Initially, a composition corresponding to dry air with no methane was given. After introducing H_2O into this composition, for the humidity of 90%, humid air with no methane was obtained. Subsequently, further calculations were performed, whose results were described in the present report.

In order to generate the outlet conditions, the profile of pressure and turbulence (the k-ε, or the k-ω SST model) was recorded. Then, the profile was processed, and the data included in it applied to the boundary condition. The turbulence parameters, together with the air composition, were applied to the conditions occurring in the case of backflow.

A similar procedure was performed for the inlet conditions. A composition of the air mixture (oxygen, steam) was given, as well as the density of the mass flux and the turbulence parameters. The following parameters were adopted:

- operating pressure – 105000 Pa
- temperature – 300 K (26.84°C)
- the initial composistion of the mixture of humid air and methane:
  - N_2 0.8685 kg/kg
  - O_2 0.2315 kg/kg (for dry air: 0.232336 kg/kg, which gives volume content of 20.946%)
  - CH_4 0 kg/kg
  - H_2O 0.019136 kg/kg, which gives the humidity of 90.0007%.

As a result, the density of the mixture was 1.2 kg/m^3. The oxygen fractions correspond to the typical content of this gas in the atmosphere. The presence of carbon dioxide, as well as other sources of methane, were neglected. The mean velocity at the outlet was 1.304 m/s. Accordingly, the rate of fluid flow at the inlet of the heading was 1267.5 m^3/min.

In order to investigate the sensitivity of the obtained solutions to the density of the computational grid, three models were prepared, differing with respect to the grid density. The most precise model included 8 million cells, the less advanced model – ca. 4 million cells, and the most simple one – ca. 2.23 million cells. Initial calculations were carried out (the migration of methane was neglected). The courses that were subjected to comparison had the same initial state, calculated for the grid of the highest density. The velocity recordings in selected points were compared – the sample readings are presented in Figure 2. As the compatibility of courses turned out to be satisfactory, the most simple model was chosen for further analysis.

4. The description of the flow for stationary conditions

The lengths of longwalls currently adopted in the mining practice – usually exceeding 200 m – make it possible to obtain a fully developed flow within the lonwall. In a sufficient distance from the maingate, the stream fills in the whole cross-section of the longwall channel. Still, three distinct zones can be differentiated here, which is related to the range of velocities:

- the zone where the flow is the most intense, encompassing the area between the coal face and the shield of the auxiliary instruments of the longwall shearer. The shield has the

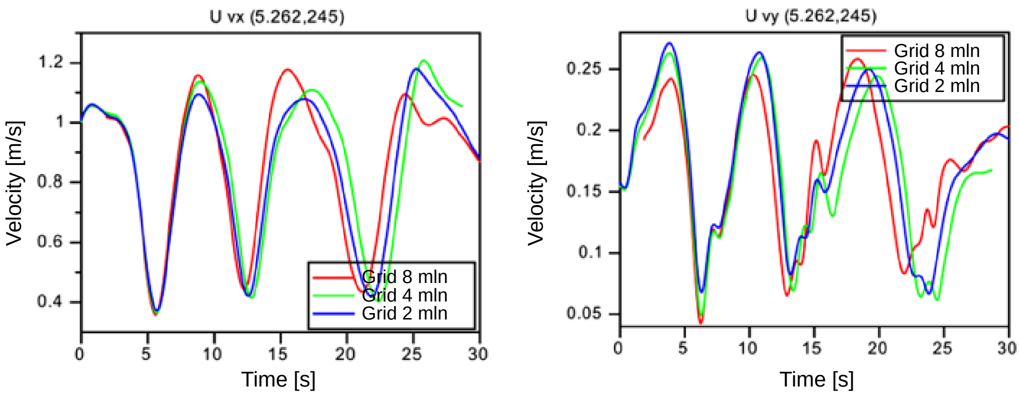

Fig. 2. Comparing the time courses of velocities – the spot at the inlet of the tailgate, parallel components, and components perpendicular to the axis

form of a cubicoid whose height exceeds its width. This constitutes a sort of stopping, which partially divides the cros-section. In this zone, on the floor, a scraper conveyor is placed, whose movement can have an impact on the flow. The coal transported by the conveyor is a mobile source of methane. Another element is the shearer, whose presence within this zone may result in the narrowing of the cross-setion, locally. However, given that the height of the longwalls is ca. 2 m, some flow is possible above the shearer. Unfortunately, this share of flow cannot be represented due to the 2D simplification;

- another zone encompasses the area between the palisade of the hydraulic props and the aforementioned shield. Here is the passage for miners. The measurements indicate that the flow velocities here are lower than in the first zone;
- the third zone encompasses the area between the palisade of the hydraulic props and the caving shields. Here, the flow velocities have the lowest values, which is due to the small crosssectional area and the resistance of the flow connected to the presence of the palisade and the ribs reinforcing the support sections. It is also due to the presence of the ribs that the areas of flow recirculation are created within this zone. Finally, in the third zone, the exchange of gases with the adjacent goaf is possible. This happens mainly through the gaps between the support sections.

In the initial segment of the longwall, the ventilating air reveals a tendency to leak into the goaf. In this situation, small streams flow out of the main stream, and filtrate into the goaf through the gaps. Closer to the longwall outlet, the inflow from the goaf can be expected. Here, the streams containing methane of a higher concentration value will flow into the main stream. The processes of the exchange of gases through shields, as well as of mixing the streams from the goaf with the main stream within the longwall channel, are essential for predicting where the areas characterized by dangerous methane concentrations will emerge (Galeazzo, 2013). Knowledge of this process gives researchers important clues as to the choice of the places where the wireless system sensors should be located; it also makes it possible to assess the potential effectiveness of the sensors. The limitations of the 2D representation made it impossible to separate the passage used by humans and the zone above the scraper conveyor. With the sufficient longwall height, these two areas merge, and the flows within both of them reveal significant similarities.

For such detailed geometry, the flow shall be non-stationary, even when the boundary conditions remain constant in time. In a lot of places, vortices are generated. Introducing the curtain and some auxiliary instruments into the geometry of the area would make the flow image even more complex.

Figures 3, 4, 5, and 6 present the vorticity outlines for the neighborhood of the main and tailgate intersections, recorded with the frequency of one second, within a selected time period. Comparing the figures, one can imagine the way in which the vortex structures are evolving. The emergence of vortices would be better shown by means of computer animation – however, this is not possible here, given the written form of the present paper. The adopted range of the vorticity extent does not encompass the whole range of its variability. The majority of the white spots are the areas where the vorticity does not exceed 0.5/s. Only in the spots right next to the props

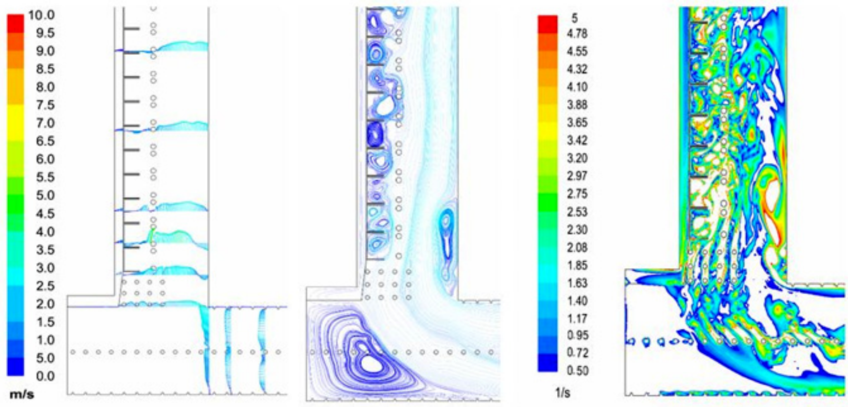

Fig. 3. The velocity profiles, streamlines and vorticity distribution in the initial segment of the longwall

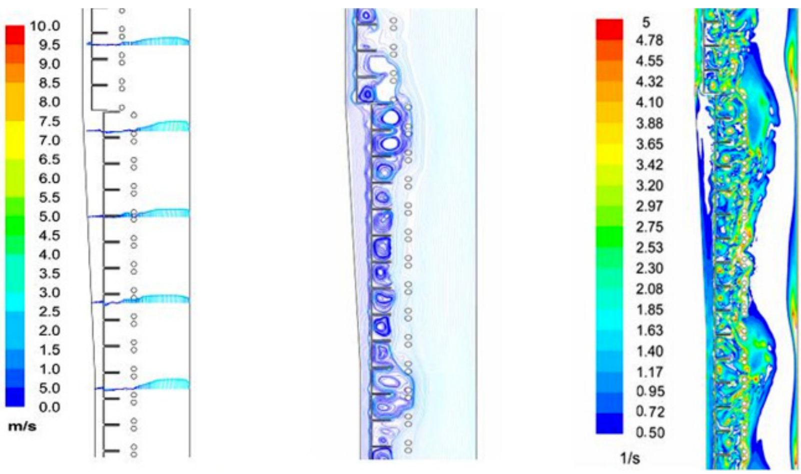

Fig. 4. The velocity profiles, streamlines and vorticity distribution in the segment of the longwall where the moving of the support takes place, with the section advancement taken into account

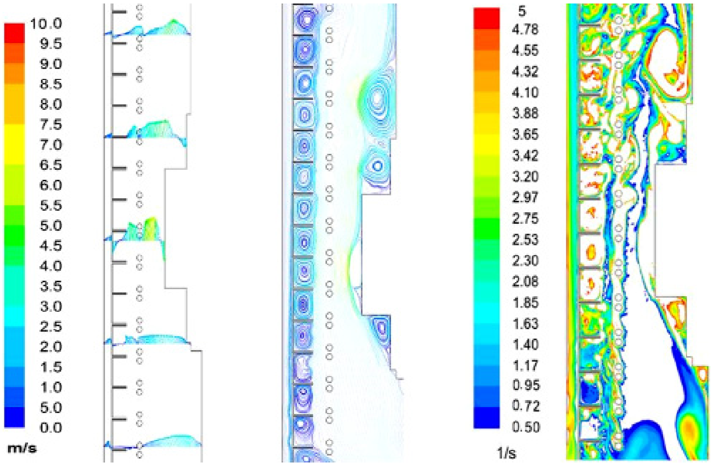

Fig. 5. The velocity profiles, streamlines and vorticity distribution for the neighborhood of the longwall shearer

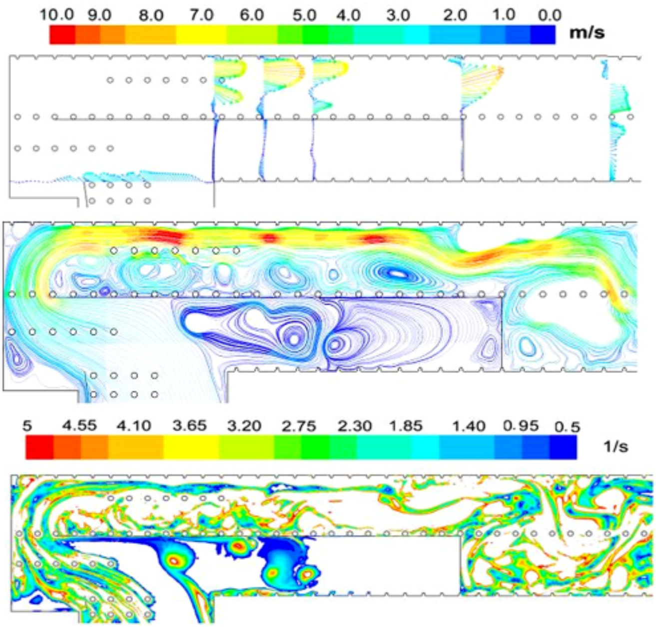

Fig. 6. The velocity profiles, streamlines and vorticity distribution in the neighborhood of the tailgate curtain

does the vorticity exceed 5/s. Such a range resulted in a better depiction of vortex structures. The observation of animated vorticity distributions leads us to the conclusion that, for the flow within the sections, the Karman vortices shed from the alternating sides result in the nonstationarity of the vortices within the caverns created by the support ribs. This is conducive to the process of gas exchange within these areas.

The range of the amplitudes and the frequency with which the velocity changes can be evaluated on the basis of the recordings of the point monitors for these quantities (Fig. 2). The analysis of the state at the initial segment of the longwall already lets us presume that the overlapping of similar frequencies results in slow amplitude changes. At the outlet, the oscillations become strongly non-linear, which is probably due to the fact that numerous vortex structures, genertaed by the obstacles within particular sections and the props at the longwall ends, overlap in this area. Along the entire length of the longwall, the exchange of mass between the longwall itself and the goaf took place. This happened as a result of leaks through the system of gaps between sections. The velocity distributions and the extent of the leakage are shown in Figure 7. Due to the pulsatory nature of the flow, these distributions change in time.

During the calculations, it turned out that – even for the unvarying release of methane from goaf – the vortices generated in the flow (in the headings and the longwall) induce sudden methane inflows. This is due to the fact that the vortices carried by the flow are accompanied by pressure fluctuations. These fluctuations force, in a way, a bidirectional exchange of mass between the longwall channel and the adjacent goaf. At irregular time intervals, over several sections of the gap system, the inflow of methane occurs. The streams of methane flowing out of the gaps are carried away by the air current within the longwall, and then carried by the vortex structures. As the latter disintegrate, the methane becomes diluted.

One particular place where a sudden inflow occurs is the width change starting where the first support section has not been moved yet. Close to this spot, there is an area of an increased inflow of methane. In the unmoved sections, the area of the longwall crossection is bigger. This corresponds to the widening of the cut in the system of the flow within the longwall. Under such

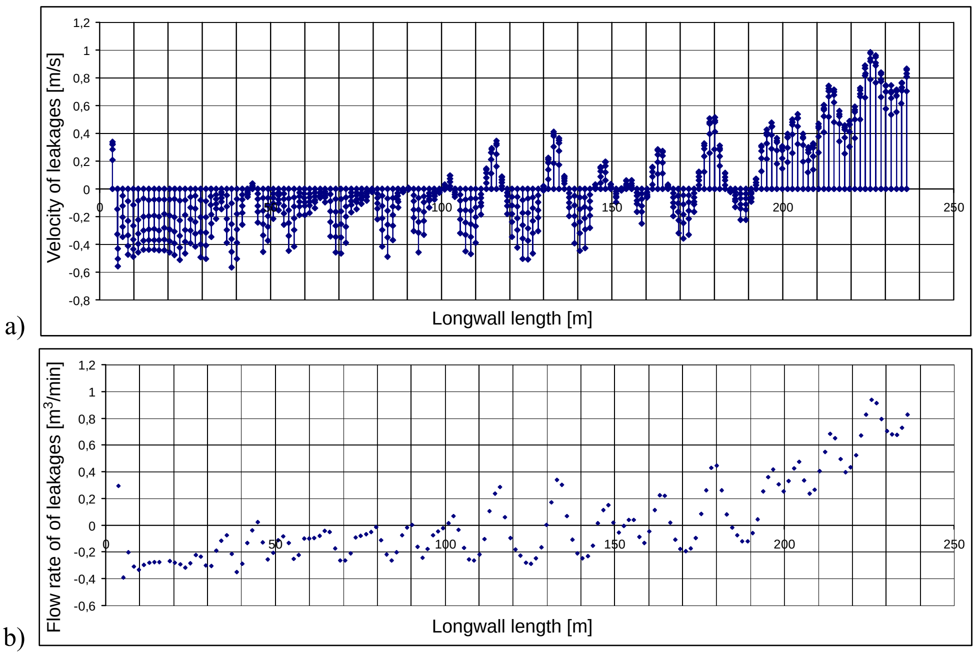

Fig. 7. The leaks through the gaps between the sections of the powered support for the variation without the shearer and the stopping – the flow velocity (a) and the flow rates (b)

conditions, following the incremental widening, the drop of the static pressure occurs. This drop causes an increased inflow of methane from the goaf. The pulsatory, spinning flow results in the emergence of areas (changeable in time) characterized by an increased concentration. These areas are carried away, and subsequently diluted. They emerge and disappear in a manner similar to the periodic one, which assumes the form of a limit cycle of a complex frequency spectrum, or a solution in the attraction zone of a strange attractor.

In the close vicinity of the shearer, the oscillations of concentrations decrease, and a part of the stream flowing through the longwall is directed into the goaf. Behind the shearer, the flow in the gaps reassumes the direction from the goaf and into the longwall. In the investigated case, the segment of the longwall between the shearer and the intersection of the longwall and the tailgate is sufficiently long for the tide of the distortion generated by the shearer to remain unnoticed, both at the intersection and in the tailgate.

The calculations were performed for constant boundary conditions. The pattern of velocity field variability did not change, too. The calculations prove that – even if we take into consideration only the flow in the headings, the longwall, and the narrow layer of the adjacent goaf – the processes of the stabilization of concentrations last between ten and twenty minutes, at least.

The result of the simulation was the initial state for a sudden inflow of methane. This state is characterized by almost periodical oscillations of velocities and concentrations. Further simulations will let us evaluate in what way the flow will change, and assess the propagation of the area of an increased methane concentration, created as a result of methane inflow at the boundary of a selected goaf fragment, given in the form of a short-term impulse.

5. The propagation of methane resulting from a sudden and local inflow surge

After generating the initial state for the steady inflow, a local inflow surge along the segment of 10 recently moved support sections was given. The course of the flow is presented in Figure 8. Its shape corresponds to the data found in the relevant sources (Mc Pherson, 1995; Fowler & Sharma, 2004), concerning the results of a sudden rock slide in goaf.

The course of the transitory state was monitored by means of comparing the distributions of methane concentrations for the whole computational area, and by observing the courses of changes in the concentrations of this gas in selected points. When analyzing the results of the inflow, one should consider the fact that the model took account of a quite narrow empty space between the longwall and the borderline of the goaf, which was the source of the inflow. Even such a small volume significantly delayed an increase of the concentrations within the longwall channel. This took place after ca. 10 seconds counting from the start of the sudden increase.

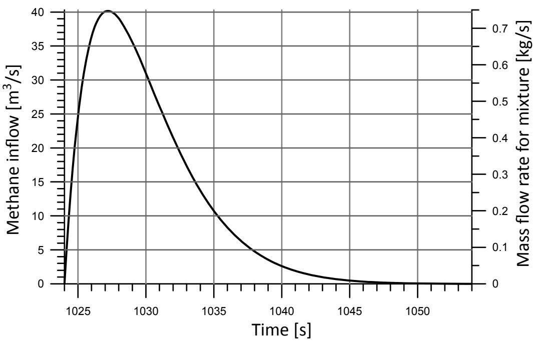

Fig. 8. A sudden methane inflow – the courses of the changeability of the release

The computational area was divided into three zones. The first one encompassed the neighborhood of the intersection with the maingate, the second one – the longwall itself, and the third one – the neighborhood of the curtain in the tailgate. For particular zones, the distributions of concentrations, as well as methane concentration courses in selected points, were shown. In qualitative terms, the image of the flow is similar to the conditions of the stationary flow.

Due to the existence of the empty space behind the longwall support, the methane can be pushed from the goaf in various places. The fields of increased concentrations appear not only in the vicinity of the spot where the inflow occurs, but also behind the shearer and in the corners of the intersections with headings. The boundary of the goaf area is immersed in a flow pulsatory in its nature. This results in periodical drawing in of the succeeding portions of goaf gases. At an increased flow, an adequately greater amount of methane is released to the goaf, creating vortex structures characterized by an increased methane concentration. On the way to the outlet of the investigated zone, the structures gradually disintegrate. A quite precise numerical model shows the mechanisms that lead to the process of mixing methane with air. This takes place – firstly – as a result of the disintegration of vortices, and, secondly, through diffusion.

Changes in the methane concentrations in selected moments of the simulation were presented in Figures 9, 10, and 11. Additionally, the diagrams of methane concentrations in selected points in the longwall, in the neighborhood of the stopping, and in the tailgate, were presented (Figs 12 to 16).

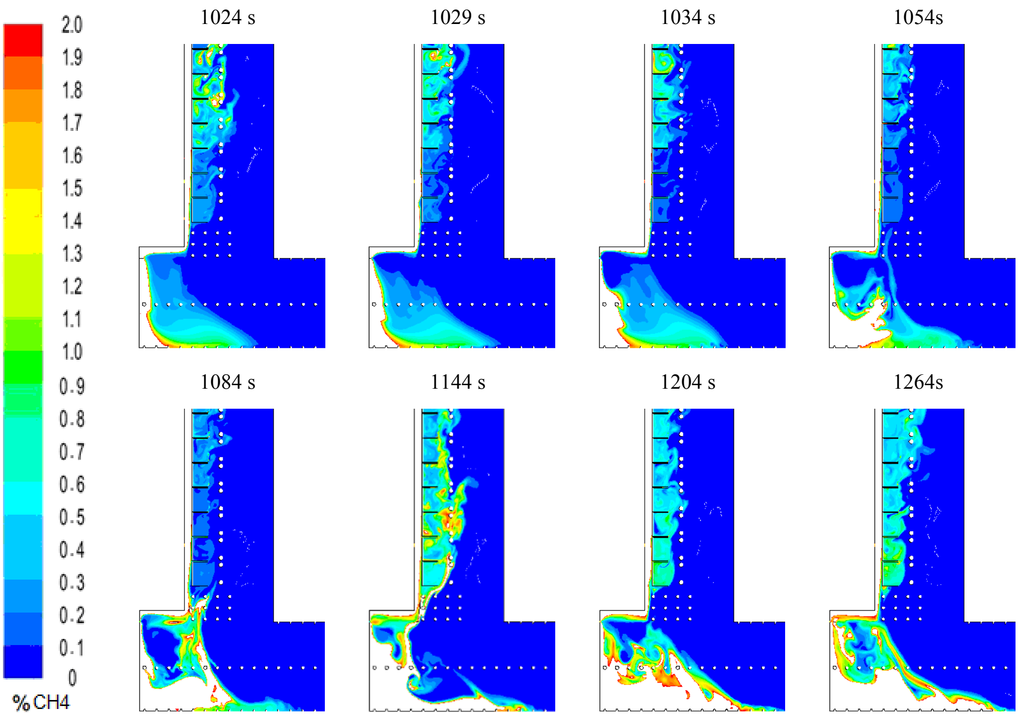

Fig. 9. The courses of the changes in methane concentrations for the initial segment of the longwall, in selected moments of the simulation

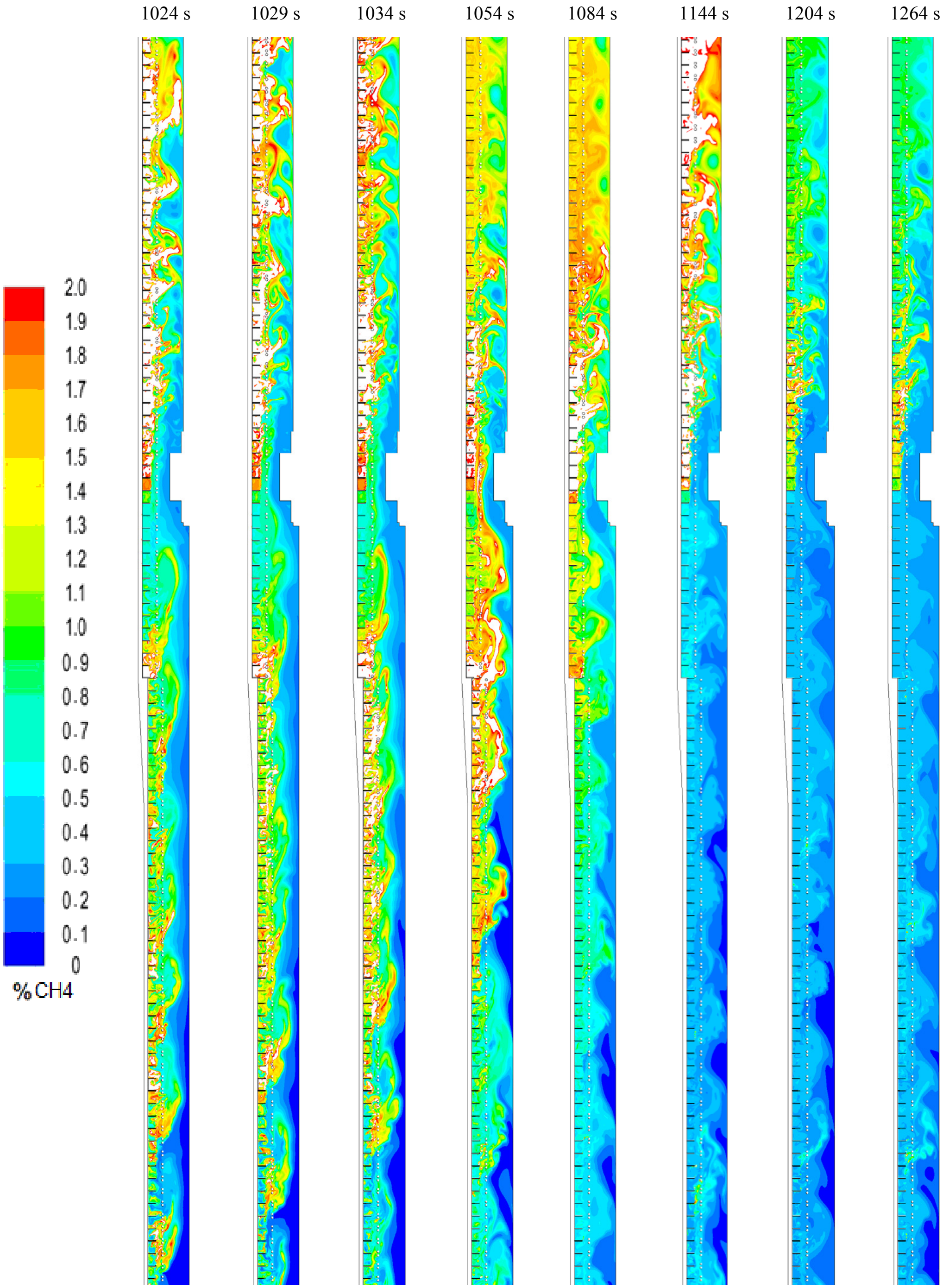

Fig. 10. The courses of the changes in methane concentrations in the longwall, in selected moments of the simulation

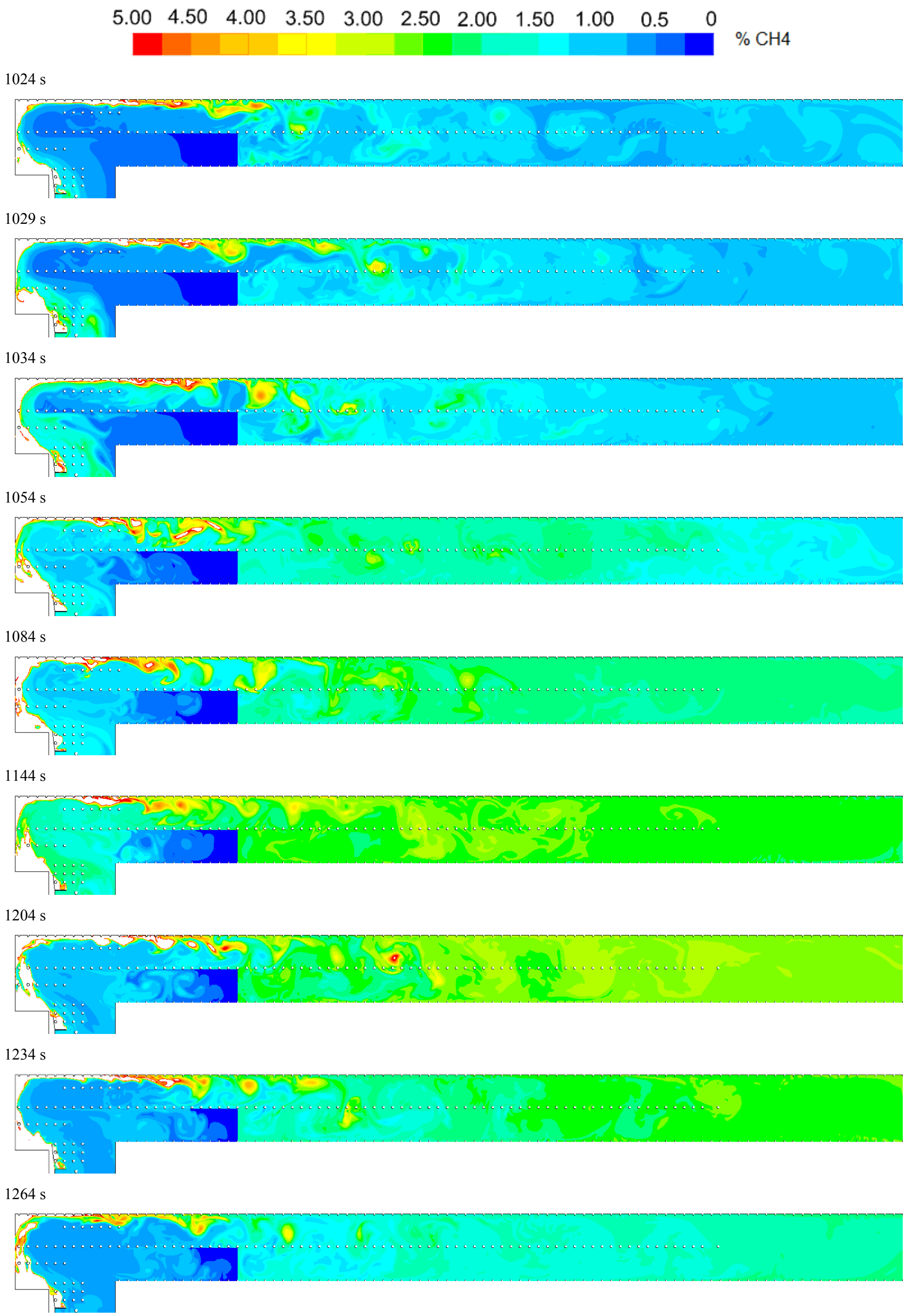

Fig. 11. The courses of the changes in methane concentrations in the neighborhood of the stopping in selected moments of the simulation, scale 0-5% CH_4

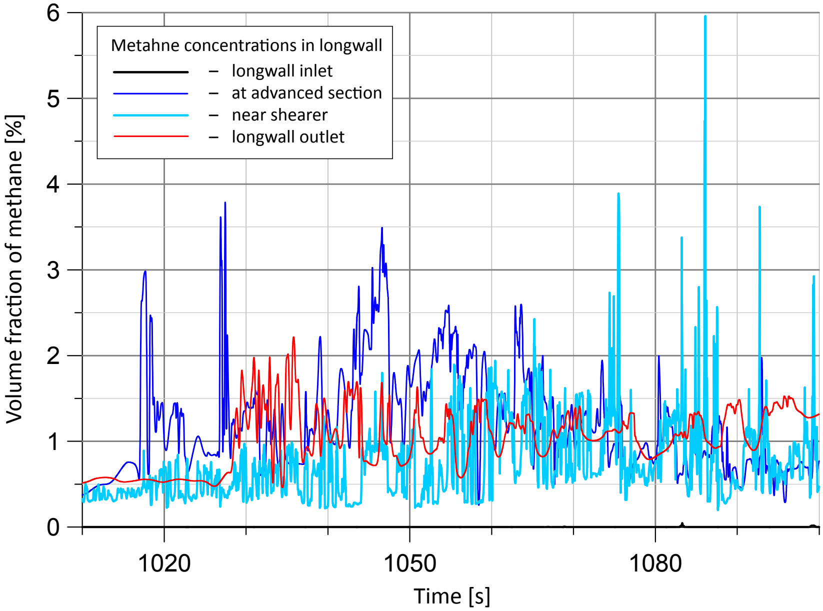

Fig. 12. The concentrations of methane in selected spots in the longwall, in the initial stage of the simulation

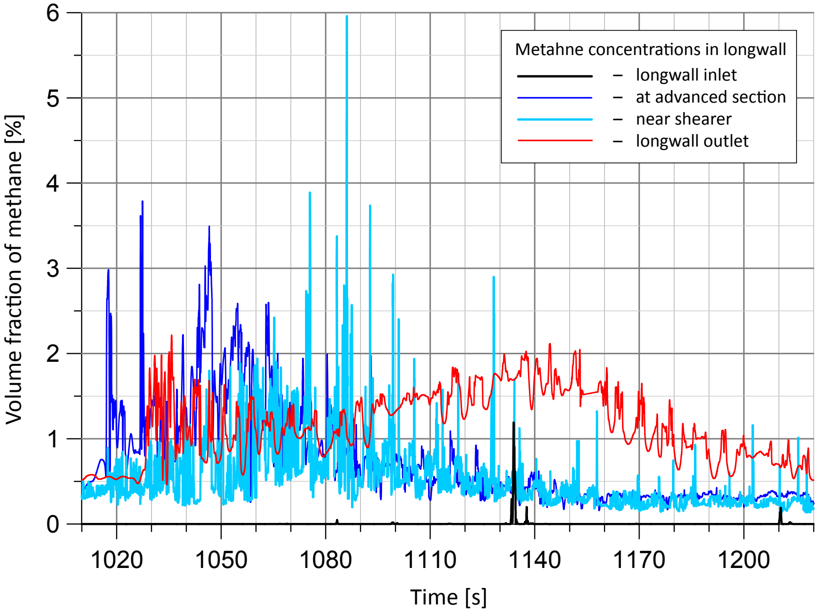

Fig. 13. The concentrations of methane in selected spots in the longwall

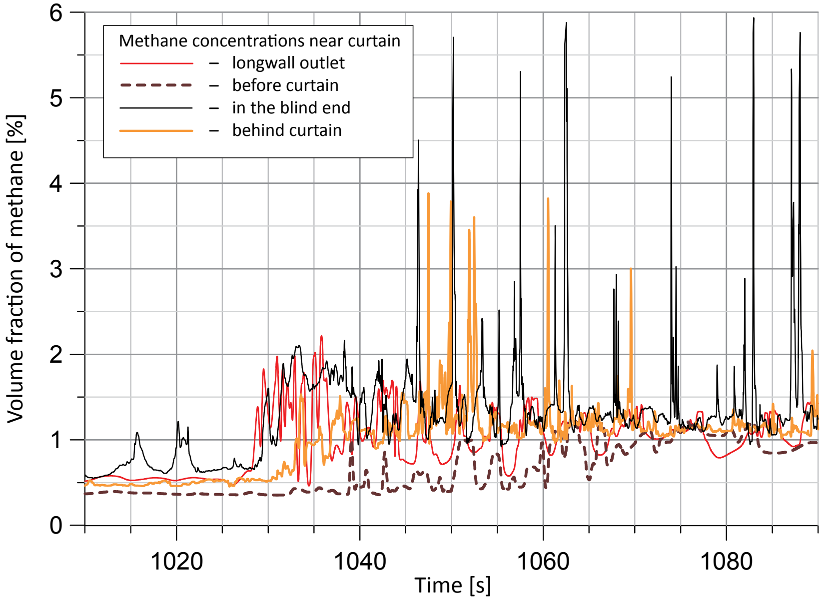

Fig. 14. The concentrations of methane in selected spots in the neighborhood of the stopping, in the initial stage of the simulation

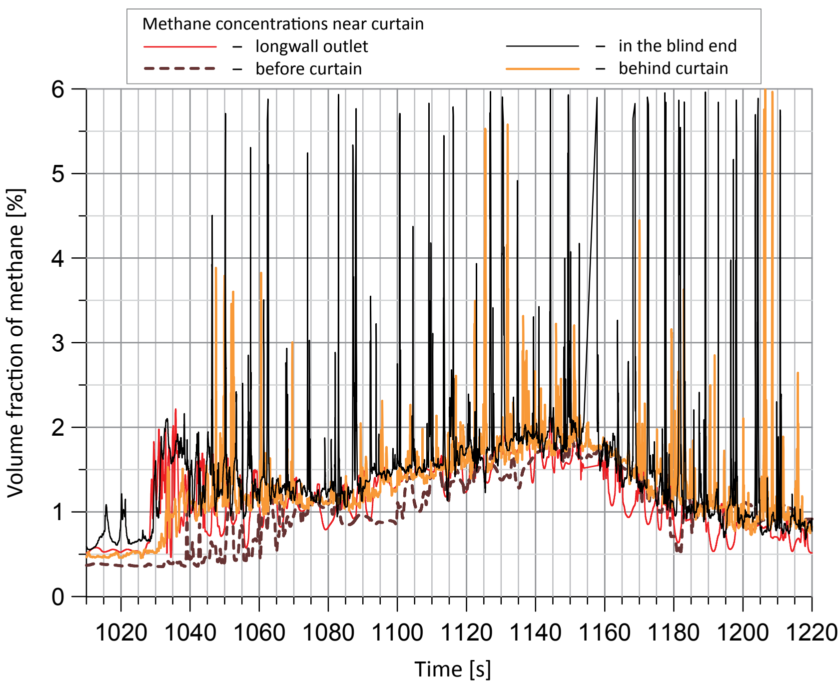

Fig. 15. The concentrations of methane in selected spots in the neighborhood of the stopping

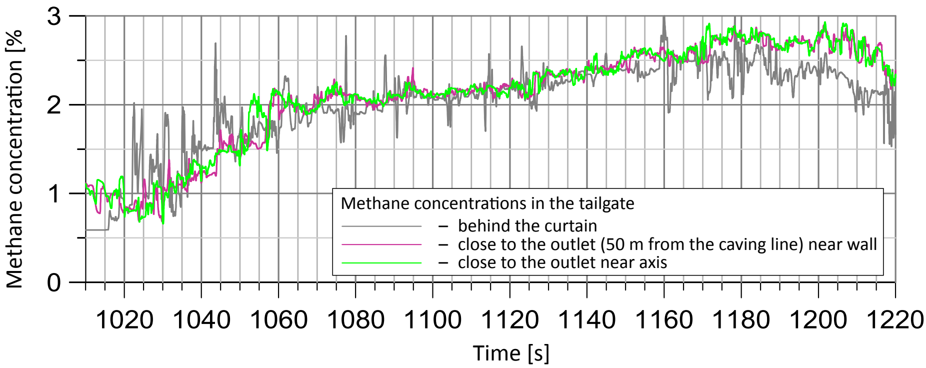

Fig. 16. The concentrations of methane in selected points in the tailgate

6. Summary

For a longwall exploited with caving and ventilated from the borders by means of the U-type ventilation system, two-dimensional models were prepared. The models encompassed 240 m longwalls, as well as segments of gates at least 50 m long. The adopted geometry took account of the details which could excessively complicate three-dimensional models. These elements include: the ribs of the arch support of the headings, frictional and hydraulic props, and the ribs of a section of the longwall powered support. Additionally, the presence of gaps between the support sections, by means of which an exchange of gases between the longwall and the adjacent goaf could take place, was taken into consideration.

The initial calculations were performed for the flow of pure air, and subsequently for the steady inflow of methane from the goaf. It was observed that the obstacles to the flow, such as props, generate complex oscillations in the flow (similar to periodical oscillations), which results from the emergence of Karman vortices. The ribs, in turn, contribute to the emergence of the areas of flow recirculation.

The flow-related phenomena mentioned above can have an impact on the process of mixing the streams of goaf gases with ventilaing air, as well as on the process of determining the areas in which dangerous methane concentrations can occur.

The velocity fields and turbulence parameters, heterogenous and changeable in time, influence the duration of the transportation of methane and the extent of its dilution. This can prove essential while determining the spots in which methane sensors should be located. These spots should be optimal as far as early detection of methane hazard is concerned.

After generating the initial state, the authors carried out the simulation of a sudden, local increase in methane inflow along the segment of goaf encompassing ten recently moved sections of the powered roof support.

Changes in the fields of methane concentrations in the excavations of the investigated area, taking place during the increased inflow as well as during the process of removing methane mixed with ventilating air, were also analyzed.

The method presented in the article could be further developed. Possible ways to achieve this include: differentiating the permeability of the goaf boundaries and excavations, or introducing various extents of the process of moving the support sections. Subsequently, the sensitivity of the obtained solutions to these forms of differentiation would have to be investigated. Additionally, the model could be expanded as to include a wider strap of a porous medium (of adequately differentiated permeability) attached to the strap of the empty space. While doing this, it should be remembered that the filtration velocities are usually much lower than velocities of flow in excavations. Taking filtration into account may significantly lengthen the time needed to calculate the initial states, as the slower flow in goaf means longer time of reaction to changes. An alternative solution would be adopting a multi-scale approach, which would involve introducing a much simpler description of goaf. This is an option offered by the VentZroby software (Krawczyk et al., 2013).

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