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SOLVING COUPLED PROBLEMS OF GEOMECHANICS AND GAS FILTRATION FOR MINING SAFETY ENSURING

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Abstract. Some features of combined progress for the coupled processes of coal bed deformation and gas filtration are considered in the study, the mathematical model is developed taking into account the mutual influence of these processes. Simulation flowcharts for the following tasks related to the safety of mining operations in coal mines are presented: methane filtration into the mine working, which is arranged in a gas-bearing coal bed; filtration flows motion in the presence of methane drainage boreholes as well as and protective structures used within a gateroad; influence of water in the fracture-pore space of coal on the origin of gasdynamic phenomena; dependence of unloading of gas-bearing outburst prone sandstones on rock pressure within the zone of the working face influence.

Calculations show that a zone of increased fracture spreads around the mine working over time. At the same time, the filtration area grows, within which methane can move from methane sources (gas-bearing coal seams and sandstones) to the mine working space. Therefore, the filtration area covers more distant sources of methane release over time. Simulation of drainage boreholes performance in the deformed gas-bearing rocks makes it possible to study the influence of factors such as stoping of a gateroad and the use of protective structures on stability of the boreholes and their efficiency. The calculation results show the following features. In case of underworking of methane drainage boreholes they get broken and stall their performance, if no protective structures are involved. If the protective structures are used, the rock-bolting beam within the underworking space gets sustained. Methane drainage boreholes span beyond the zones of inelastic deformations and remain in operating conditions even after their undermining by means of a working face. Taking into consideration tectonic fault as well as change of the physical and mechanical properties of coal within the perturbed zone provides an opportunity to study behavior of the coupled processes for geomechanics and filtration that occur during mining operations over outburst prone coal seams. Taking into account the influence of water on the change of physical and mechanical properties of coal as well as the formation of the phase permeability field for gas, the influence of moisture on the origin of gasdynamic processes could be studied.

The paper shows that solving complex problems related to gas and outburst safety of mining operations in coal mines requires the use of numerical simulation methods for coupled physical processes. In some cases, the calculation error reaches out large values if the mutual influence of the processes occurring in the rock is neglected.

Keywords: mining safety, coal and methane outburst, rock deformation, coupled processes, methane emission, numerical simulation.

Introduction. A coal-rock massif is a multiphase system consisting of a solid skeleton and flowage structure contained in the fracture-pore space. Any human intervention leads to a balance perturbation of this system and initiates deformation as well as filtration processes. Their progress occurs simultaneously with the following mutual influence: rocks deformation leads to the formation of a permeable area around the mine workings [1, 2], a change in flowage pressure and rock properties during wetting process affect the rock stress state [3-5]. Therefore, during studying many aspects of mining safety, it is necessary to consider not only separate processes, but their integrity as well.

The most common problem of coal mining is gas release within the mine workings [6], which could occur both in a quasi-stationary and transient mode. The increased methane content in the mine workings, methane firings and explosions, coal and methane outbursts are harmful consequences for the combined progress of the coupled deformation and filtration processes over time.

The following problems are considered in this study:

- methane filtration into the mine working, which is arranged in a gas-bearing coal-rock massif;

- filtration flows when methane drainage boreholes are in operation and protective structures are used within a gateroad;

- the influence of water in the coal fracture-pore space on the origin of gasdynamic phenomena;

- unloading rock pressure of gas-bearing outburst prone sandstones within the longwall influence zone.

Solving such a complex problems requires the use of numerical simulation of the coupled physical processes. Therefore, the purpose of this study is elaboration of a method to solve the problems related to the safety of mining operations in coal mines, where gas-bearing and outburst prone seams are operated.

Methods. During simulation the hypothesis of rock continuity is accepted, the coal-rock massif is considered as homogeneous within every single seam. Net force acting on every point of the solid equals the sum of the geostatic pressure forces and flowage pressure. The change in time of stress-strain state of rocks, the formation of a region permeable for flowage [7, 8] and gas filtration are described by the following system of equations:

$$c_g \frac{\partial u_i}{\partial t} = \sigma_{ij,j} + X_i(t) + P_i(t); \tag{1}$$

$$Q^* = \frac{\sigma_1 - \sigma_3}{\lambda H}; \quad P^* = \frac{\sigma_3}{\lambda H}; \tag{2}$$

$$k = \begin{cases} 0 & \text{for } Q^* < 0.6; P^* > 0.25; \\ k_{min} & \text{for } 0.6 \le Q^* < 0.8; \\ e^{0.26Q^* - 4.65} & \text{for } 0.8 \le Q^* < 0.8; P^* > 0.1; \\ k_{max} & \text{for } Q^* > 1.2; P^* < 0.1; \end{cases} \tag{3}$$

$$\frac{\partial p}{\partial t} = \frac{K}{2m\mu}\left(\frac{\partial^2 p^2}{\partial x^2} + \frac{\partial^2 p^2}{\partial y^2}\right) + q(t), \tag{4}$$

where c_g - damping coefficient, kg/(m^3·s); t - time, s; u_i - displacements, m; $\sigma_{ij,j}$ - derivatives of the stress tensor components for x and y axes respectively, Pa/m; $X_i(t)$ - projections of the external forces per unit volume of solid onto axes, N/m^3; $P_i(t)$ - projections of forces due to gas pressure within the crack-pore space, N/m^3; Q^* - geomechanical parameter that describes different kind of nature for a stress field; P^* - geomechanical parameter that describes geostatic pressure unload of the rocks; σ_1, σ_3 - maximum and minimum component values of the principal stress tensor, Pa; γ - average weigh of the overlying rock seams, N/m^3; H - mining depth, m; k_{tech} - filtration permeability caused by mining process; $k_{\min}$ - minimum value of the permeability coefficient required for the beginning of a filtration process, m^2; $k_{\max}$ –

permeability value within the breaking zone, m^2; p - gas pressure, Pa; μ_g – dynamic viscosity of a gas, Pa·s; q - gas release function, that simulates methane desorption.

The initial and boundary conditions for the system of equation are as follows:

$$\sigma_{yy}\big|_{t=0} = \gamma H; \quad \sigma_{xx}\big|_{t=0} = \lambda\gamma H; \quad u_x\big|_{t=0} = 0; \quad u_y\big|_{t=0} = 0; \quad p\big|_{t=0} = p_0;$$
$$u_x\big|_{\Omega_1} = 0; \quad u_y\big|_{\Omega_2} = 0; \quad p\big|_{\Omega_1} = p_0; \quad p\big|_{\Omega_2} = p_0; \quad p\big|_{\Omega_3} = p_{at}; \quad p\big|_{\Omega_4(t)} = p_0,$$

where Ω_1 - vertical boundaries of external contour; Ω_2 - horizontal boundaries of external contour; Ω_3 - internal contour (mine working); $\Omega_4(t)$ - time-varying boundary of the filtration area; p_0 - methane formation pressure, Pa; p_{at} - atmospheric pressure, Pa.

The problem is solved within the elastic-plastic formulation. A Mohr – Coulomb failure criterion is used to describe the beginning of rock failure. The system of equations (1)-(4) is solved by means of the finite element method [9, 10].

Methane filtration into the mine working within a gas-bearing coal-rock massif. Mining operations in coal mines initiate the processes of rocks deformation and filtration of methane contained in the fracture-pore space of coal and gas-bearing sandstones. Increased methane release from the working seam and finished space of massif, methane bleedings and outbreaks, gasdynamic phenomena are the result of the combined progress of two closely related processes: redistribution of the stress field as well as gas filtration.

Simulation of the parameters change for these processes over time was performed. While solving equations (1)-(4) according to the scheme shown in Fig. 1, for each time iteration the values of stresses and strains within finite element were calculated.

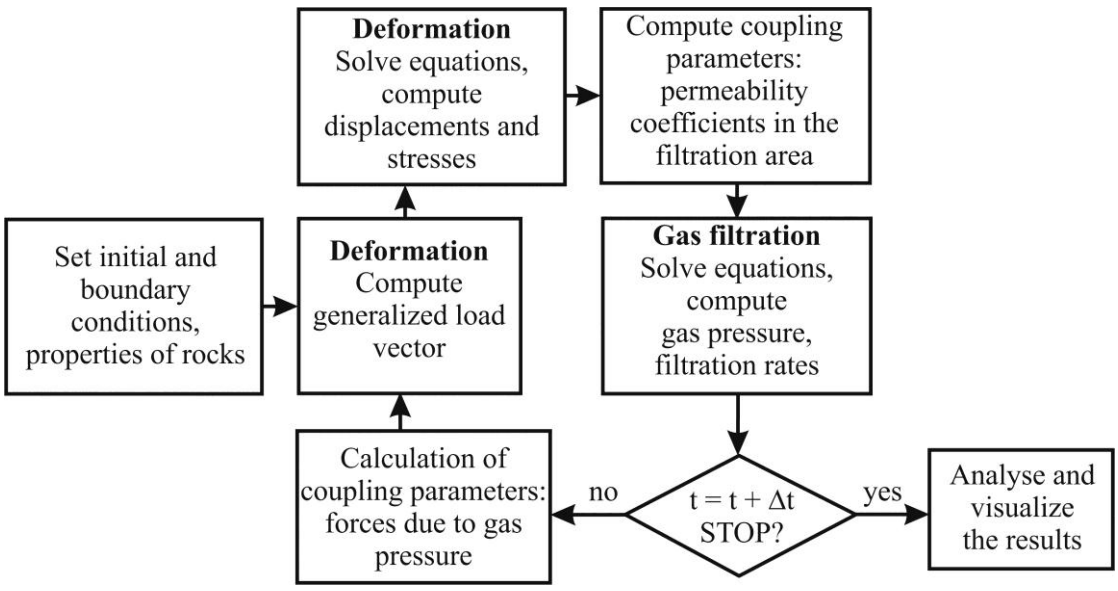
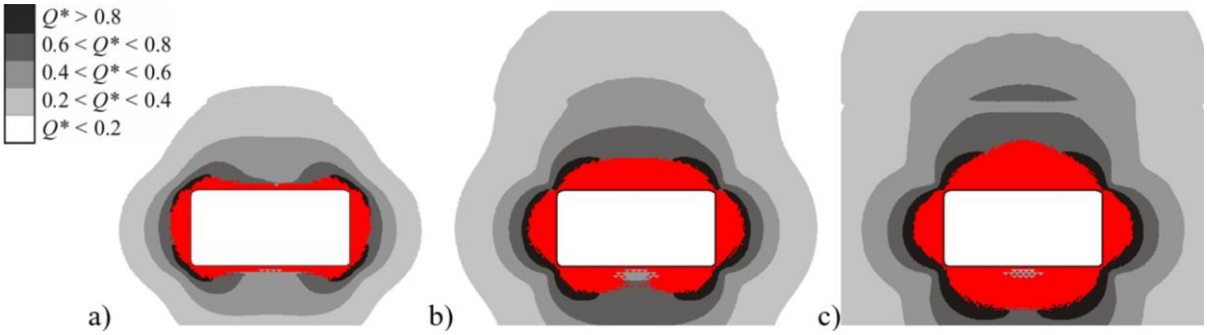


Figure 1 – Flowchart for solving of the problem of unsteady methane filtration in deformed rock

The values of filtration permeability, methane pressure, the direction and filtration rate, methane release at the mine working contour were calculated depending on the components of the tensor's principal stresses. For the next time iteration methane pressure change at nodes of the finite elements was taken into account during the stress field calculation.

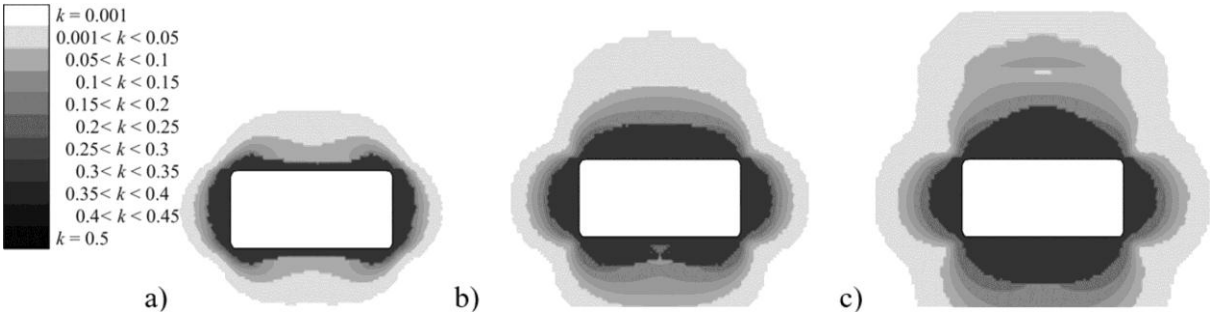
Simulation of deformation and filtration processes was performed for the mine working with a rectangular cross-section located at a depth of 900 m along a gas-bearing coal seam having a thickness of 2 m; coal strength equals 15 MPa. The rock around a gas-bearing coal seam is siltstone. Gas-bearing sandstone with thickness of 10 m is located in the seam's roof. The gas content within coal seam is 22 m^3/t, the gas content in sandstone is 2 m^3/t. The distribution of values for parameter Q^* as well as areas of inelastic deformations (red color) are shown in Fig. 2.



a) t = 1 day; b) t = 3 days; c) t = 15 days

Figure 2 – Distribution of values for parameter Q^* as well as areas of inelastic deformations

Values of the parameter Q^* increases and inelastic deformation zone extends in the rock around the coal seam over time. It could be noted that the presence of more durable sandstone in the mine roof affects distribution of Q^* parameter values, Fig. 2b, 2c. Based on the results of geomechanical parameters calculation, the array of permeability coefficients was determined (Fig. 3).



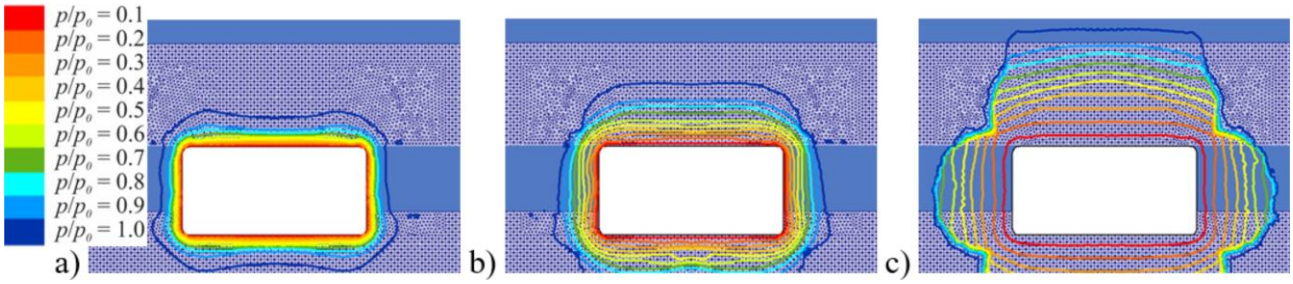
a) t = 1 day; b) t = 3 days; c) t = 15 days

Figure 3 – Distributions of permeability coefficients values in the vicinity of the mine working

The filtration area, where $k > 0$, includes the walls of coal seam of mine working as well as the part of the gas-bearing sandstone located in the mine roof. Inside this

filtration area, methane can move from the gas emission sources into the mine working space, where the pressure is 0.1 MPa that is much lower than the methane pressure (8 MPa) within the unperturbed massif.

The isobars of relative methane pressure p/p_0 (p_0 is a methane pressure within the unperturbed massif) in the rock around the mine working are shown in Fig. 4.



a) t = 1 day; b) t = 3 days; c) t = 15 days

Figure 4 – The isobars of relative methane pressure

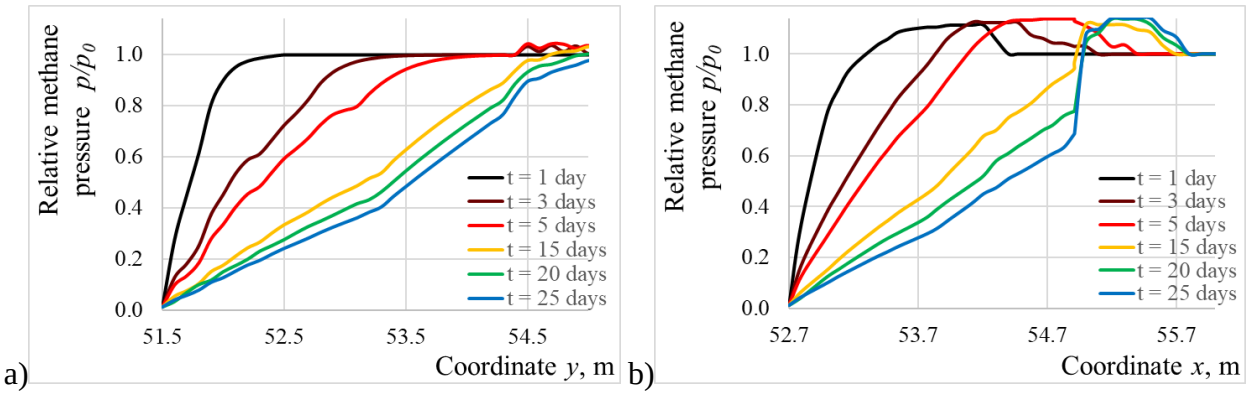
Methane pressure drops over time in those parts of the coal seam which are adjacent to the mine working (Fig. 4). It indicates that the coal seam is degassed; methane moves from the seam into the mine atmosphere. After 2 weeks, the area of low methane pressure captures the lower part of the gas-bearing sandstone, Fig. 4c. The process of methane filtration actively takes place around the mine working.

Fig. 5 shows the change of relative gas pressure in the mine roof along the vertical line passing through the center of mine working as well as in the walls of mine working along the horizontal line passing through the center of coal seam over time. Coordinate y = 51.5 m is the roof of mine working, Fig. 5a; coordinate y = 54.5 m is the lowest boundary of sandstone, Fig. 5a; coordinate x = 52.7 m is the right wall of mine working, Fig. 5b. In the mine roof, methane pressure gradually decreases over time. After 15 days, methane pressure begins to decrease in the lower part of the gas-bearing sandstone, Fig. 5a. Fig. 5b shows that in the walls of the mine, in the area of bearing pressure, methane pressure value in the coal seam exceeds initial seam pressure value. The effect of increasing seam pressure in the bearing pressure area is mentioned in [11-13]. This occurs as a result of mechanical compression of rock and a volume reduction of fractured-pore space.

Thus, taking into account an influence of the stress-strain state of the rock massif on its filtration permeability and the effect of the methane pressure change on the redistribution of the stress field, it is possible to adequately simulate the combined progress of geomechanics as well as methane filtration processes.

Filtration flows during operation mode of methane drainage boreholes and protective structures involvement within a gateroad. During mine operations in a gas-bearing coal-rock massif, the main task from the mining safety point of view is to ensure the permissible level of methane concentration in the mine workings.

Within the of working areas being ventilated according to a reverse ventilation system (1-M), outflowing ventilation jet joins finished coal massif while the airway behind the longwall is not serviced and not controlled [14]. If methane drainage boreholes are drilled under such conditions in front of a longwall in upstream direction, the boreholes located immediately near the longwall will operate solely. These boreholes got destroyed and disconnected from a degassing system when operating coal working under the boreholes throat [14].



a) in the mine roof; b) in the walls of mine working

Figure 5 – The change of relative gas pressure

In order to study the influence of protective structures on the degassing efficiency, it was assumed that the coal working moves at a constant speed along with the filtration area that surrounds the coal working. Thus, in this case the filtration process could be considered as steady-state one in the moving coordinate system associated with the longwall. Therefore, the simulation was performed using a quasi-stationary statement according to the scheme shown in Fig. 6. In order to simulate the degassing system, it is necessary to set up parameters of the boreholes (their number, inclination angles, throat coordinates, overall length, sealed length), as well as calculate the nodes' parameters of finite elements belonging to the borehole and the nodes' parameters of the finite-element grid belonging to the filtering parts of the boreholes.

First of all, the values of stresses and strains in each finite element as well as inelastic deformation zone were calculated. According to (3), the values of filtration permeability were determined depending on the components of the principal stress tensor. After that, the filtration area, where the permeability value is greater than zero, was determined; equation (4) was solved, and gas release in the drainage boreholes was calculated by summing the gas release for those nodes that are out of the zone of inelastic deformations.

In order to analyse the influence of protective structures on the sustainability and efficiency of the operation over methane drainage boreholes, let's consider a gateroad supported by frame and bolting with two methane drainage boreholes. The lengths of the boreholes are 45 and 48 m respectively; the sealed depth is 10 m. The seam thickness is 1.5 m. There are two gas-bearing sandstones in the mine roof which breadth is 15 and 17 m respectively, and two coal seams, which breadth is 0.4 and 0.3

m respectively. The gas content of the coal seam is 20 m^3/t, the gas content of sandstone is 1 m^3/t. The mining depth is 600 m.

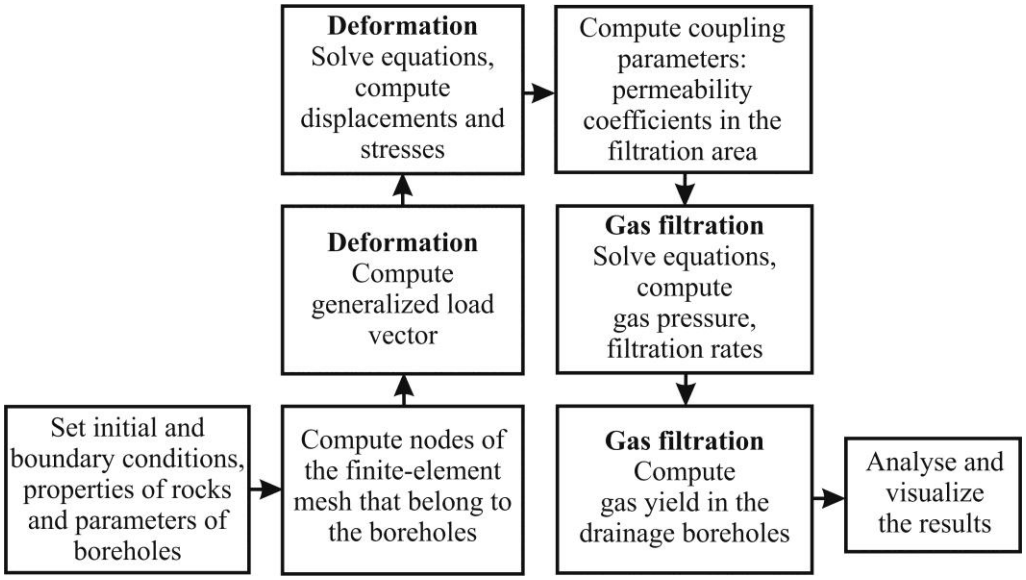
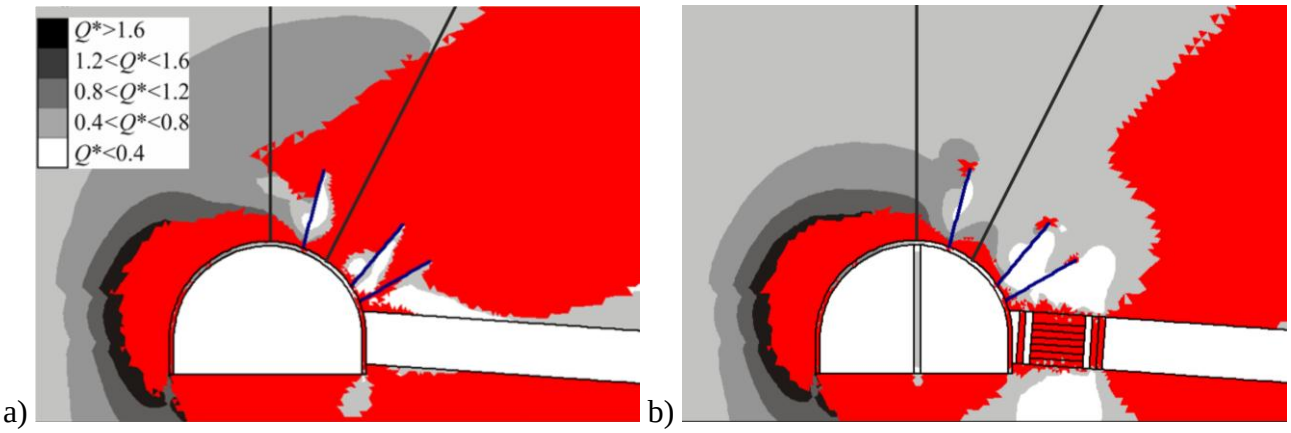


Figure 6 – Flowchart for the problem solving of steady-state methane filtration in the coal-rock massif when methane drainage boreholes are in operation

The calculation is performed for two cases: 1) without protective structures; 2) anchor jack, relief post, fence row and two rows of breaker props are used. As a result, fields of stresses and zones of inelastic deformations (red color) were obtained, Fig. 7.



a) without protective structures; b) anchor jack, relief post, fence row and two rows of breaker props

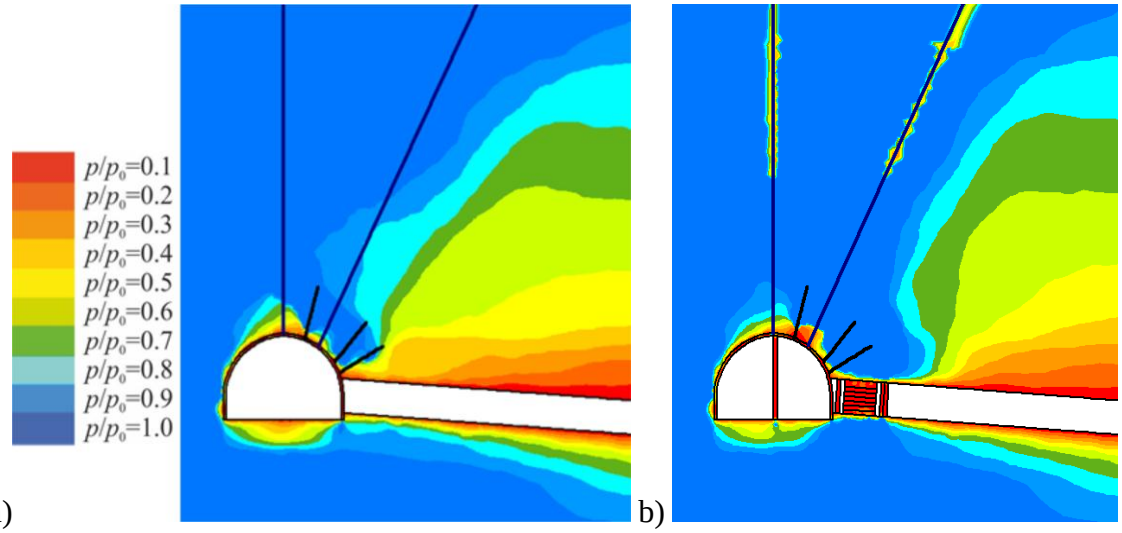
Figure 7 – Distribution of parameter Q^* values and zones of inelastic deformations

In the vicinity of the mine working contour and above the finished space of the massif, minimal stress component approaches its zero value. Under such conditions, the rock mass near contour is broken by means of the mass division into separate weakly interacting blocks [15]. A breaking zone includes as a whole the areas within the walls and roof of the mine working where $Q^* > 1{,}2$ and $P^* < 0{,}1$. Roof bolting

restrains partially the rock breaking, however, its effect is not sufficient to keep the beam formed above the finished space of the massif in a fixed position, Fig. 7a. At a distance of 8 m from the mine working contour, borehole #2 is within the zone of inelastic deformations experiencing its breaking that makes it impossible for the borehole to operate. Borehole #1 crosses the breaking zone at a distance of 3 m above the mine working.

Fence row usage in combination with anchor jack, relief post and two rows of breaker props changes the situation considerably, Fig. 7b. However, a stress-strain state of the rock within the left wall and in the roof of the mine working has decreased to such an extent that borehole #2 has gone beyond its boundaries. The methane drainage boreholes are still in operating mode even within the area behind the longwall. The area of unperturbed rock within the roof-bolted rock massif has significantly increased. Roof bolting along with the protective structures restrain the breaking of rock-anchor beam formed above the finished space of rock massif which is now in a stable condition.

According to the calculation results of a stress state of coal-rock massif, coefficients of rock permeability, distribution of methane pressure, Fig. 8, as well as methane release within the drainage boreholes have been computed. In this context, if any node of a borehole gets into the zone of inelastic deformations, it was considered that the borehole section located farther is out of operating mode.



a) without protective structures; b) anchor jack, relief post, fence row and two rows of breaker props

Figure 8 – Distribution of relative methane pressure p/p_0

Along with the longwall movement, the areas of decreased methane pressure get expanded, covering all the finished space of rock massif. Barely supported right wall of a mine working gets broken; borehole integrity is violated thus, they operate no more. Around the boreholes (Fig. 8a), methane pressure value corresponds to that one within the unperturbed rock massif. It means that there is no gas filtration from the gas sources into the degassing system. In this case, methane release into methane

drainage boreholes #1 and #2 is approximately equal to zero. Methane from the sources located within the roof flows into the finished space of the massif instead of degassing system.

If protective structures are used, Fig. 8b, then the rock-bolting beam located above the finished space of the massif is kept stable; whereby, methane drainage boreholes do not cross the boundary of inelastic deformations, so they keep operating even after the coal working has been cut. Methane release in boreholes #1 and #2 is equal to 0.9 and 3.7 m^3/min respectively for given boundary and geological conditions.

The calculation results show the following: in case protective structures of methane drainage boreholes are not involved, those methane drainage boreholes get broken and stop operating. If protective structures are used, then the rock-bolting beam above the finished space of rock massif is kept stable. Methane drainage boreholes do not cross the boundary of inelastic deformations so they keep operating even after the coal working has been cut.

The influence of water in the fracture-pore space of coal on the gasdynamic phenomena origin. According to the Rules for mining operations on outburst prone coal beds [16] coal seams wetting is used for preventing gasdynamic phenomena. This method is provided by water injecting through long boreholes drilled within the coal seam from gateway in front of a longwall.

In order to study the effect of saturation moisture content s_w on the outburst prone properties of the coal seam, numerical simulation of the combined progress for the coupled processes of coal-rock massif deformation as well as methane filtration was performed taking into account the presence of moisture in the fracture-pore space of coal according to the scheme presented in Fig. 9.

Simulation of the outburst prone zone near the tectonic fault was done in the following way. The fault parameters, such as the coordinates of the tectonic fault, the displacement amplitude, and the length of the disrupted zone were set up. The values of the variables at the finite elements' nodes belonging to the disrupted zone were calculated. The following variables were specified within these finite elements:

- coal adhesion value C decreases linearly as well as the tectonic permeability value k_{tect} increases linearly from the boundary of the disrupted zone to the tectonic fault zone [8];

- tensile strength σ_t is approximately equal to zero;

- the modulus of elasticity E and Poisson's ratio μ are calculated depending on the s_w value according to the regression equations derived from the experimental data [19, 20]

$$E = -1608 \cdot \ln(s_w) + 7088 \ (R^2 = 0.9999);$$
$$\mu = 0.3076 \cdot s_w^{0.1135} \ (R^2 = 0.9988).$$

At each time iteration for each node of the finite element model computed the values of stresses, zone of inelastic deformations, the values of permeability k_{tech} (Q^*, P^*), caused by mine operations, the coefficients of absolute permeability K

as the sum of k_{tech} and k_{tect}, the coefficients of gas permeability k_g, the values of gas pressure and filtration rate were calculated. In addition, if the modulus of the gas filtration rate V_g reaches large value, the gas flow expands fractures within coal massif, therefore, gas permeability value increasing within the areas of high filtration rates depends on V_g values. Further, the geometry of the outburst cavity was calculated according to the criteria of finite elements reference to the zone of inelastic deformations caused by tensile stresses, the critical values by the methane filtration gradient exceeding were calculated as well. At the next time iteration, the change in gas pressure at each node of the finite element was taken into account while calculating the stress field.

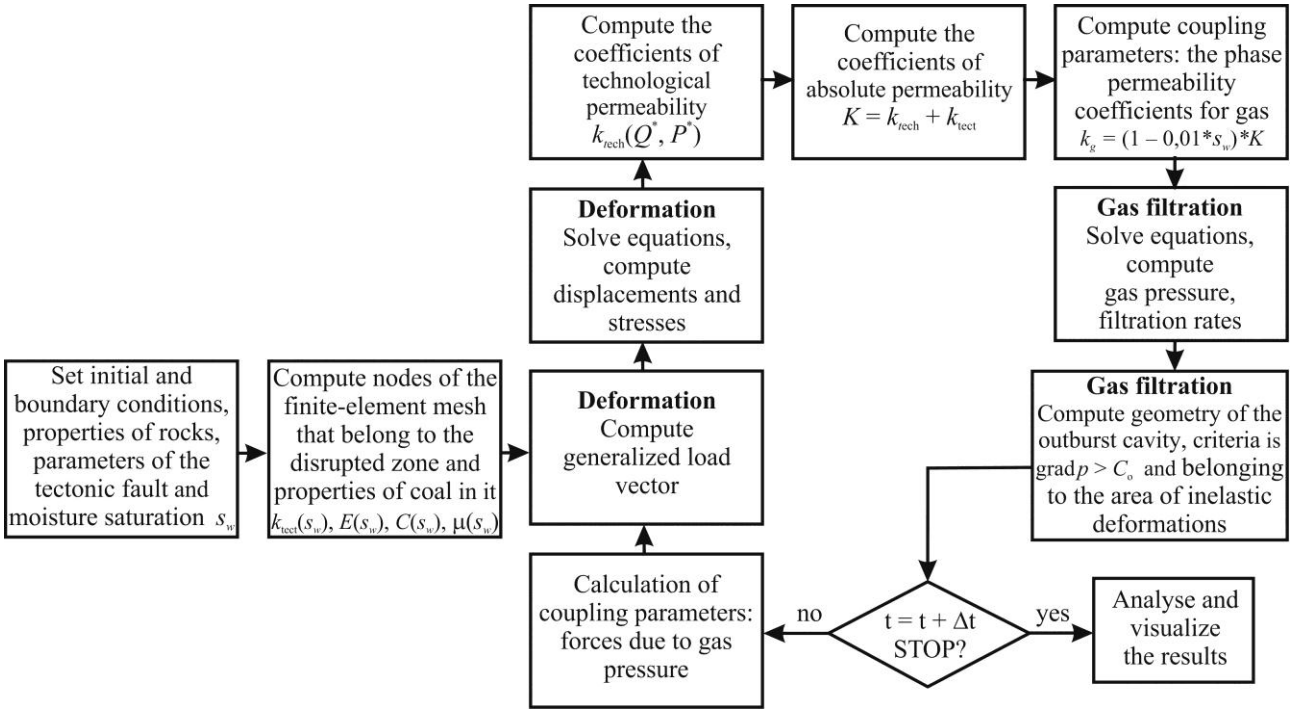


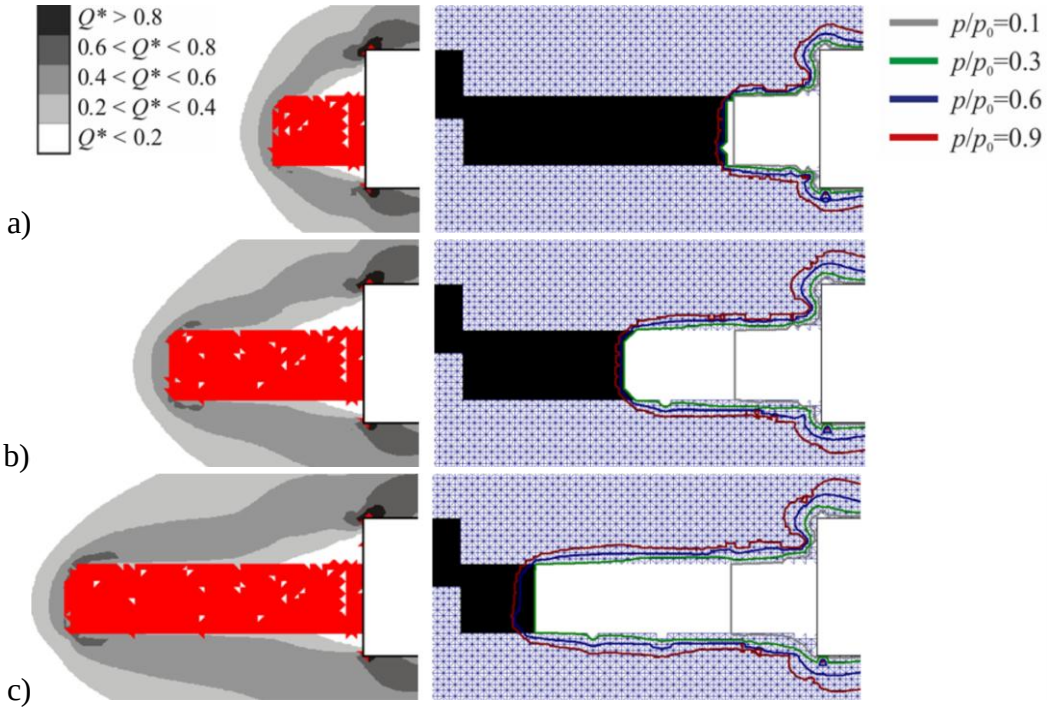
Figure 9 – Flowchart for the problem solving of the combined progress for the rock deformation and methane filtration taking into consideration an influence of water contained in the coal's fracture-pore space

Two types of calculations were performed: before coal seam wetting (s_w = 1 %, E = 7000 MPa, μ = 0.3) and after coal seam wetting (s_w = 20 %, E = 2270 MPa, μ = 0.43). The value of saturation moisture content s_w = 20% corresponds to the value of humidity w = 2%. It was assumed that the mine face is located at a distance of 7.75 m from a tectonic fault with a displacement amplitude of 1 m; the rock comprises argillite; H = 1000 m; m = 10%; the length of the disrupted zone on both sides of the tectonic fault is equal to 10 m; 10 m; p_0 = 8 MPa; $C_o = 2 \cdot 10^7$ Pa/m.

The results of the calculations are shown in Fig. 10 and Fig. 11.

If the mine face penetrates the disrupted zone near the tectonic fault before the coal seam is wetted, under the condition s_w = 1 %, E = 7000 MPa, μ = 0.3, the area of increased stress components values (Q^* > 0.4) rapidly increases deep into the coal seam. Zone of inelastic deformations rapidly grows starting from the mine face along

the coal seam (Fig. 10, left side). Methane pressure in the coal seam quickly decreases, so the relative pressure isobars are located next to the exposed surface (Fig. 10, right-hand side figure). The pressure gradients and the methane filtration rate reach very high values at the destruction front; the permeability of coal grows rapidly. Coal and gas outburst takes place that leads to the cavity formation in the coal seam, the length of which reaches 6.125 m under the given initial and boundary conditions.



a) t = 2 s; b) t = 4 s; c) t = 6 s

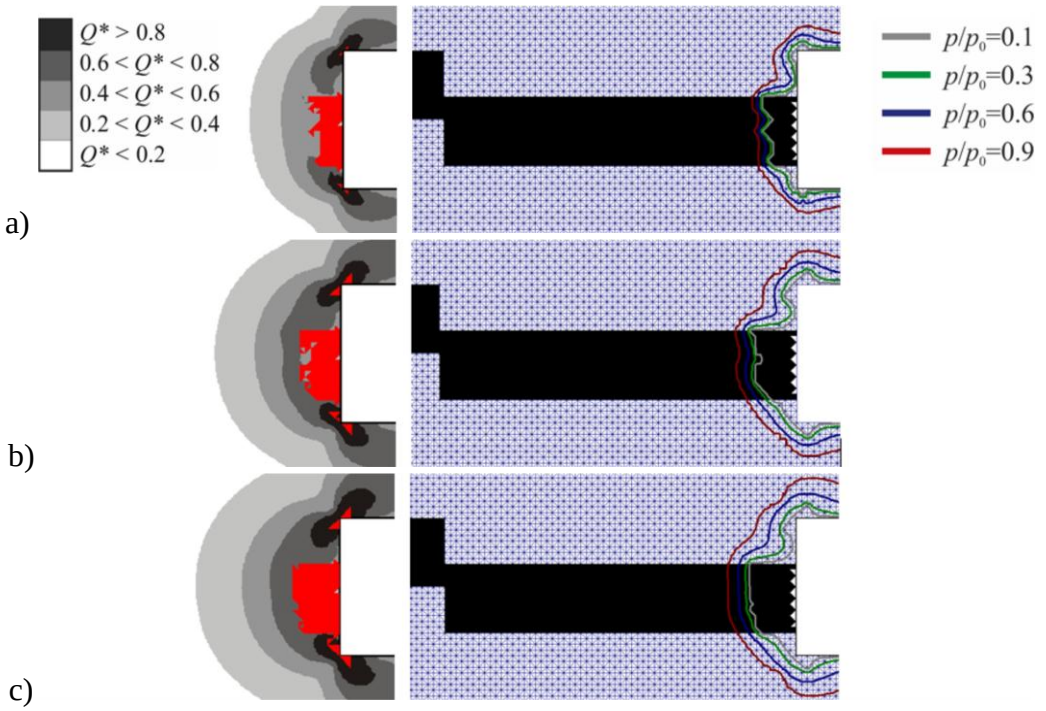
Figure 10 – Distribution of parameter Q^* values and inelastic deformation zone (left-hand side figure), outburst cavity and methane relative pressure p/p_0 (right-hand side figure), in case, when s_w = 1 %, E = 7000 MPa, μ = 0.3 within the coal seam

After that the growth of the cavity halts (Fig. 10c); methane pressure in the coal seam continues to decrease slowly. Geomechanical processes as well as the process of methane filtration get back to the quasi-stationary mode. It takes 5.6 s to complete the dynamic process under initial and boundary conditions mentioned above.

If the mine face penetrates the disrupted zone near the tectonic fault after wetting under the condition s_w = 20 %, E = 2270 MPa, μ = 0.43 taking into account mining and geological conditions similar to those ones for the previous case, the area of parameter Q^* high values increases significantly slower from mine working area into the coal seam. Depth of zone for inelastic deformations within the coal seam does not exceed 1 m, the methane pressure in the mine face decreases slowly. The cavity in the coal seam has failed to emerge, Fig. 11.

Taking into consideration the parameters of tectonic fault as well as physical and mechanical properties of coal in the disrupted zone gives an opportunity to study the

progress of coupled geomechanical and filtration processes that occur during mining operations in outburst prone coal seams. Taking into account the wetting influence on the change of the physical and mechanical properties of coal and formation of the phase permeability field for gas allows to study the influence of moisture saturation on the progress of gasdynamic processes as well as the factors that initiate them.



a) t = 2 s; b) t = 4 s; c) t = 6 s

Figure 11 – Distribution of parameter Q^* values and inelastic deformation zone (left-hand side figure), outburst cavity and methane relative pressure p/p_0 (right-hand side side figure), in case, when s_w = 20 %, E = 2270 MPa, μ = 0.43 within the coal seam

Unloading of outburst prone sandstones within the zone of longwall influence. In case when thick layers of sandstone occur in the roof and bottom of the coal seam, the step of roof settling should be significantly increased. Besides, sections of the powered support in the longwall are often clamped between the seam bottom and the hanging rock beam. One of the ways to shift the support which is normally used in coal mines in Ukraine is dinting of the seam bottom under the support by means of explosives [21]. However, coal seams and sandstones in many mines are hazardous as they able to outburst coal, rock and gas. In order to avoid the initiation of the gasdynamic phenomenon during a pop shooting, it is necessary to study the process of unloading the outburst prone sandstone or to use a shock-blasting mode which leads mining operations shut-down for a long time.

On the one hand, rock unloading during mining operations is a geomechanical process described by the equation (1). On the other hand, the presence of methane in the fracture-pore space of rock also affects the stress distribution. The authors found out how essential this effect is during the study of the gas-bearing sandstone

unloading. For this purpose, a comparison of parameter P^* values that describes geostatic pressure unload of the rock was performed:

1) in case of solving equations (1)-(4) according to the flowchart shown in Fig. 1;

2) in case of solving equations (1)-(2) without taking into account the presence of gas in the fracture-pore space of sandstone.

Simulation is performed according to the scheme of Fig. 12. The depth of mining is 900 m; the seam thickness is 2 m. The rock consists is argillite. There is gas-bearing sandstone within the mine's bottom, which thickness is 10 m. The gas content in coal is 22 m^3/t, the gas content in sandstone is 2 m^3/t.

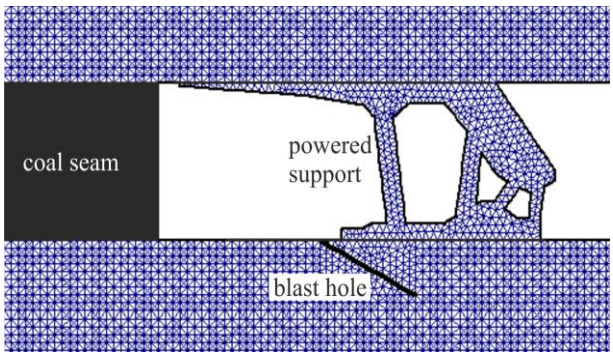
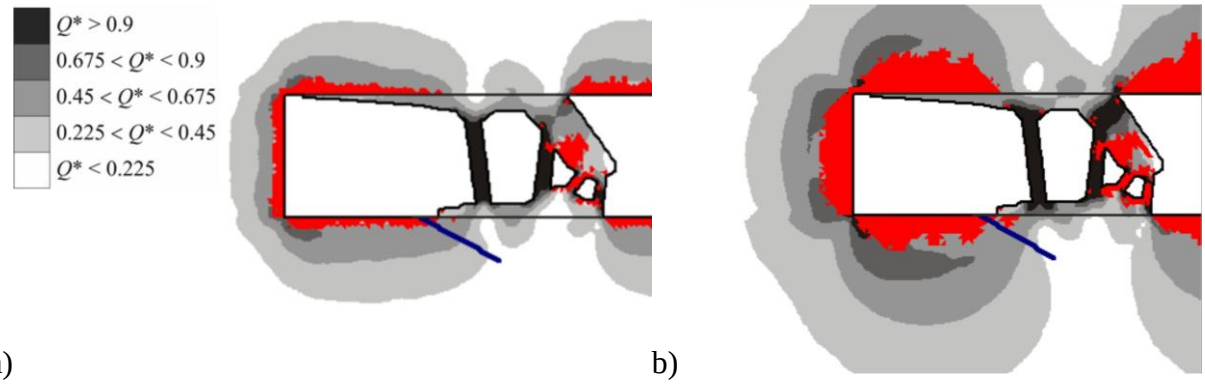


Figure 12 – The central fragment of the finite element mesh

The values of geomechanical parameters at different time steps were computed. The results for the first variant of the simulation are shown in Fig. 13 and Fig. 14.



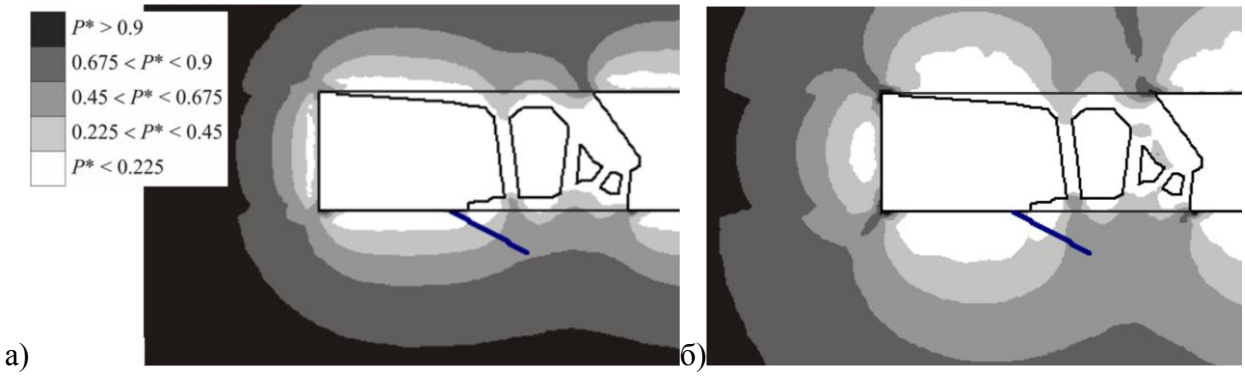
a) b)

a) t =5,4 h; b) t =27 h

Figure 13 – Distribution of parameter Q^* values and inelastic deformation zone (red color), the first variant of the simulation

Fig. 13 and Fig. 14 show zones of rock unload as well as areas with variety of the rock components around the longwall increase over time. Zone of inelastic deformations directly in the roof of the longwall represented by siltstone grows faster than in the longwall bottom represented by the sandstone.

The curves of parameter P^* values change in the longwall bottom along a vertical line at the place of a borehole drilling for explosives, which are calculated for the first and second variant of the simulation, are shown in Fig. 15.



а) t =5,4 h; b) t =27 h

Figure 14 – Distribution of parameter P^* values, the first variant of the simulation:

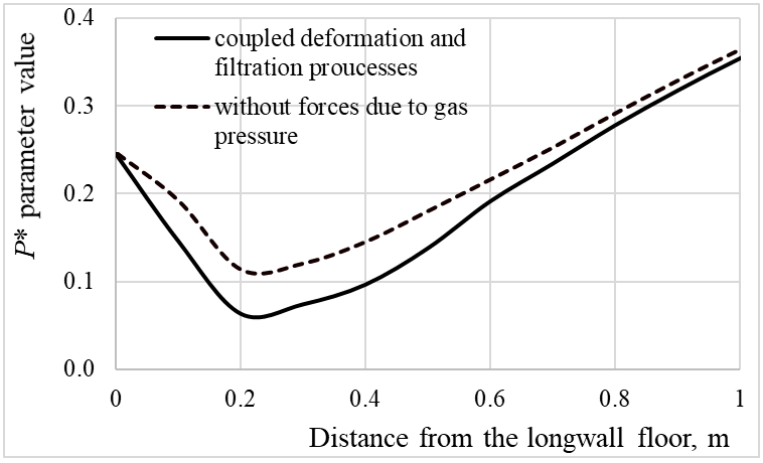


Figure 15 – Parameter P^* values change in the longwall bottom for the first and second variants of calculation

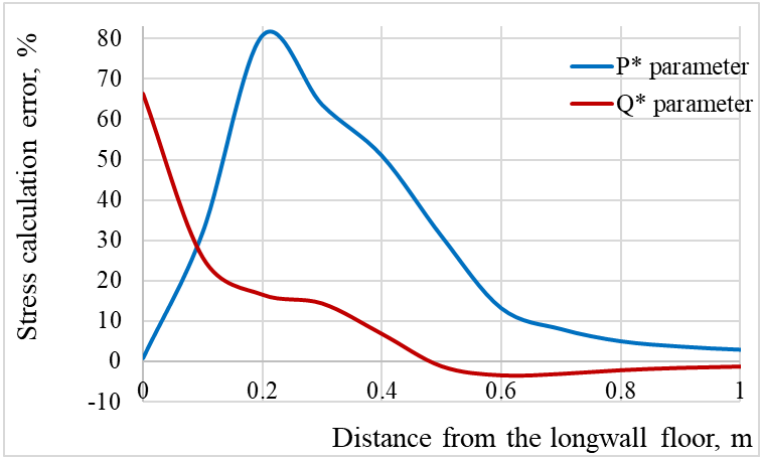


Figure 16 – Calculation error in case when the gas component of the deformation process is neglected

It is obvious that taking into account the participation of the methane filtration process in the unloading of gas-bearing sandstone leads to a decrease of parameter P^* values. That is, gas pressure drop within the filtration area, degassing of gas-bearing rock leads to a more significant unloading. The calculation error in case when the gas component of the deformation process is neglected reaches 80% at a distance of 0.2 m from the bottom of the mine working and decreases with depth, fig. 16.

Thus, while calculating the stress-strain state of gas-bearing rocks at great depths, it is necessary to consider the coupled processes of their deformation and filtration of the gas contained in the fracture-pore space.

Conclusions. The features of the combined progress for the coupled processes of coal-rock massif deformation and filtration of gas contained in the fracture-pore space of coal and rock were analysed In this work. A mathematical model was developed taking into account the mutual influence of these processes. Flowcharts of numerical simulation for a number of problems related to the safety of mining operations in coal mines are presented. Those are methane filtration within the mine working, which is arranged in a gas-bearing coal-rock massif; filtration flows motion in the presence of methane drainage boreholes as well as and protective structures used within a gateroad; influence of water in the fracture-pore space of coal on the origin of gasdynamic phenomena; dependence of unloading of gas-bearing outburst prone sandstones on rock pressure within the zone of the working face influence.

The results of the calculations have shown how the zone of increased fracturing spreads around the mine working over time. Moreover, the filtration area grows, within which methane is able to move from the sources of methane release (gas-bearing coal seams and sandstones) to the mine working space. The filtration area covers more distant sources of methane release over time.

Simulation of drainage boreholes in the deformed gas-bearing rocks makes it possible to study the influence of factors such as supporting of a gateroad and the use of protective structures on stability of the boreholes and their efficiency. The calculation results have shown the following: in case of underworking of methane drainage boreholes, those methane drainage boreholes get broken and stop operating. If protective structures are used, then the rock-bolting beam above the finished space of rock massif is kept stable. Methane drainage boreholes do not cross the boundary of inelastic deformations so they keep operating even after the coal working has been cut.

Simulation of tectonic fault by changing the physical and mechanical properties of coal in the disrupted zone provides an opportunity to study the course of coupled geomechanical and filtration processes that occur during mining operations within outburst prone coal seams. Taking into account the influence of wetting on the change of physical and mechanical properties of coal and the formation of the phase permeability field for gas, the influence of moisture on the origin of gas-dynamic processes could be studied.

The study shows that solving complicated problems related to gas and outburst safety of mining operations in coal mines requires applying of numerical simulation

methods for coupled physical processes. In some cases, the calculation error reaches very large value if the mutual influence of the processes occurring in the coal-rock massif is neglected.

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РОЗВ'ЯЗОК ЗВ'ЯЗАНИХ ЗАДАЧ ГЕОМЕХАНІКИ І ФІЛЬТРАЦІЇ ГАЗУ ДЛЯ ЗАБЕЗПЕЧЕННЯ БЕЗПЕКИ ГІРНИЧИХ РОБІТ

Круковська В.В., Круковський О.П., Кочерга, В.М., Кострицяя А.О.

Анотація. В роботі розглянуто особливості сумісного перебігу зв’язаних процесів деформування вуглепородного масиву і фільтрації газу, розроблено математичну модель з урахуванням взаємного впливу цих процесів. Представлено блок-схеми чисельного моделювання ряду задач, пов’язаних з безпекою ведення гірничих робіт на вугільних шахтах: фільтрація метану до виробки, що проводиться в газоносному вуглепородному масиві; рух фільтраційних потоків за наявністю дегазаційних свердловин і при застосуванні охоронних конструкцій у виїмковому штреку; вплив води в тріщинно-поровому просторі вугілля на розв’язування газодинамічних явищ; розвантаження газоносних викидонебезпечних пісковиків від гірського тиску в зоні впливу очисного вибою.

За результатами розрахунків показано, як із плином часу навколо гірничої виробки поширюється зона підвищеної тріщинуватості. Разом з нею зростає область фільтрації, усередині якої метан може переміщатися з джерел метановиділення – газоносних вугільних пластів і пісковиків – до атмосфери виробки. З часом до області фільтрації потрапляють більш віддалені джерела виділення метану.

Моделювання роботи дегазаційних свердловин у газоносному масиві, що деформується, надає змоги досліджувати вплив таких чинників, як кріплення виїмкового штреку і використання охоронних споруд, на стійкість свердловин і ефективність їх роботи. Результати розрахунків для прийнятих гірничо-геологічних, граничних і початкових умов свідчать, що без використання охоронних конструкцій дегазаційні свердловини при їх підробці руйнуються та припиняють роботу. При використанні охоронних конструкцій породно-анкерна консоль над виробленим простором набуває стійкого стану. Дегазаційні свердловини виходять за межі зони непружних деформацій та залишаються працездатними навіть після підробки очисним вибоєм.

Урахування наявності тектонічного порушення і зміни фізико-механічних властивостей вугілля в порушеній зоні надає можливість досліджувати перебіг зв'язаних геомеханічних і фільтраційних процесів, що відбуваються при проведенні гірничих виробок по викидонебезпечним вугільним пластам. Урахування впливу води на зміну фізико-механічних властивостей вугілля і формування поля фазової проникності для газу дозволяє вивчати вплив вологи на розв’язування газодинамічних процесів.

Показано, що вирішення складних задач, що стосуються газової та викидо-безпеки ведення гірничих робіт у вугільних шахтах, потребує застосування методів чисельного моделювання зв’язаних фізичних процесів. У деяких випадках помилка розрахунку сягає великих значень, якщо знехтувати взаємним впливом процесів, що відбуваються в породному масиві.

Ключові слова: безпека гірничих робіт, викид вугілля і метану, деформування порід, зв’язані процеси, метановиділення, чисельне моделювання.

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