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THE CALCULATION METHOD TO ENSURE SAFE PARAMETERS OF VENTILATION CONDITIONS OF GOAF IN COAL MINES*

The article puts forward a 3D modeling method for diffusion ventilation processes in coal mines and an innovative methodical approach to mine ventilation system design. The proposed method enables locating probable gas accumulations, determining increased temperature, dust and moisture content and evaluating endogenous fire risk based on aerologic factors. The method application will ensure reasonable control of the listed parameters under different ventilation modes and mining systems, including critical and emergency situations. Furthermore, the new method will assist in selecting optimized modes of degassing and gas suction.

The method involves construction of an aero- and gas-dynamic model of a mine or a mine area, which, given the proper maintenance and upgrading in conformity with the actual mining front advance, is a tool of air safety control.

The method uses modern computer technologies of three-dimensional modeling of gas-dynamic processes in porous media.

Key words: *gob area, mine, fire, ventilation, modeling, gas dynamics.*

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Introduction

According to the statistics from the Emergencies Ministry of Russia [1], Russia had 91 operating coal mines in 2015. The heaviest damage to underground coal mine performance is caused by fires and explosions of methane. At the same level during recent years (**Fig. 1**), underground fires can end with explosions, especially in goaf. For instance, in 2010 endogenous fire in the goaf in Raspadskaya Mine initiated explosion that took away lives of 91 miners. The causes of that severe accident were assumed poor coal self-heating control, improperly selected mining system and erroneous design and arrangement of mine ventilation.

The same is valid for foreign coal-mining countries. For example, in an American mine methane exploded and 8 people died [2], due to lack of weakly methane leakage control in conformity with Code of federal regulations [3].

Research task

Currently methane control in coal mines involves ventilation, degassing and isolated methane removal using ventilation facilities (gas suction). A gob area is subjected to the effect of different draft sources, which complicates air leak control and detection of possible coal self-heating. Air leaks are the principal cause of all endogenous fires hazardous, among other things, from the viewpoint of deficient air feed in production heading area, which, in its turn, may result in excess of allowable methane concentration.

This being the case, the leakage and concentration control of fire-produced gases (CO and CO_2) lacks clear substantiation since, in accordance with the current standards [4–6], control points are unidentified and potential zones of fire gas release in operating ventilation circuits are undetermined.

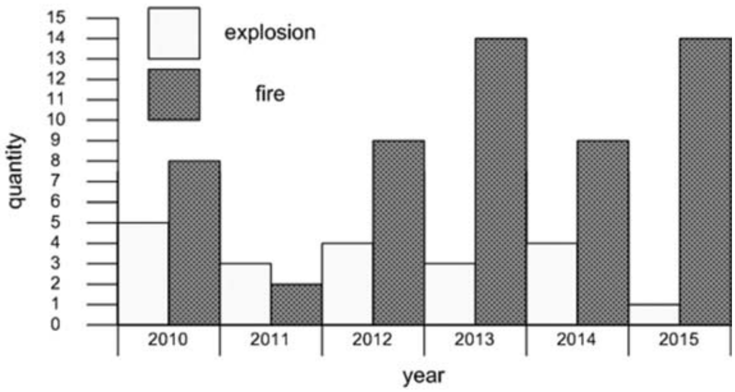

Fig. 1. Number of fires and explosions in coal mines in Russia in 2010–2015

To this effect, it is proposed to use a new and relatively general method of ventilation calculation. Based on this method, it is possible to develop control methods for heat and mass transfer in gob for any ventilation scheme. The description of gas flow in gob needs using laws of gas-and-air seepage flow in porous media characterized with specific parameters governed by the type of enclosing rocks, production heading advance rate and working area ventilation scheme [7]. Consequently, these parameters are to be determined for each coal seam and for each its parts. Then, it is required to find the distribution of speeds of air and methane concentration in a seepage flow in a working section, including a goaf, and risk of endogenous fire depending on ventilation mode. For having reliable results, it is required to take into account the most significant details of a test object.

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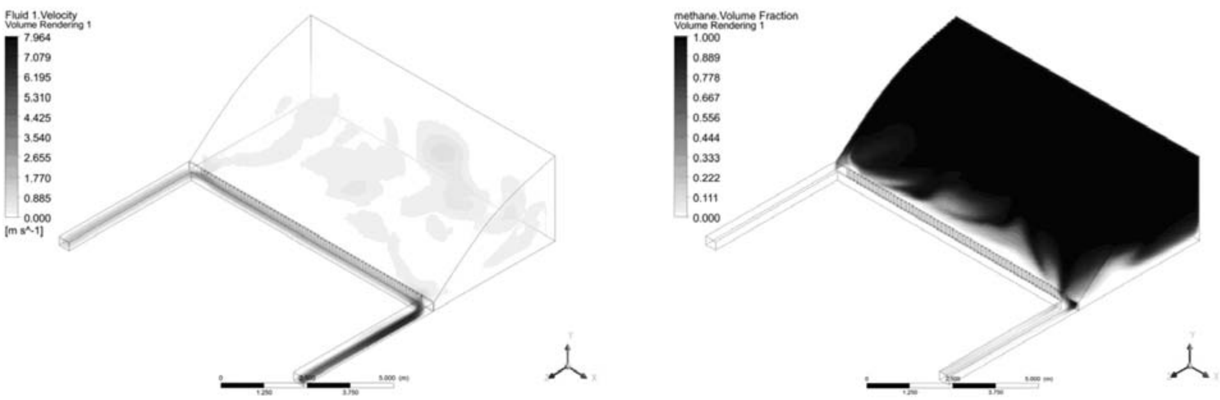

a *b*

Fig. 2. (a) Air flow velocity distribution in tunnels of mine working area and (b) places of methane leaks from gob

Features of gob as test objects

Methane release from goafs to workings is a process of diffusion of active gas in seepage flow of leak air through anisotropic coarse-block porous media. This very complex process can generally be given in a simplified form by the system of equations below [8]:

$$\operatorname{div}(\rho\bar{v}) = 0$$

$$\varepsilon\cdot\rho\cdot g - \varepsilon\cdot\rho\cdot\left(\frac{\nu}{k} + \frac{|V|}{1}\right)\cdot V - \nabla\cdot\varepsilon\cdot P = 0$$

$$\frac{\partial(\varepsilon\cdot c_m\cdot\rho)}{\partial t} + \nabla\cdot\rho\cdot c_m\cdot\bar{V} = \nabla\cdot\varepsilon\cdot\rho\cdot D\cdot\nabla\cdot c_m$$

$$P = R\cdot T\cdot\rho\cdot\left(\frac{c_m}{\mu_m} + \frac{1-c_m}{\mu_a}\right)$$

where μ_m, μ_a — relative molecular weights of methane and air, respectively; D — total diffusion coefficient; c_m — mass concentration of methane; ν — kinematic viscosity of air; V — air flow velocity; ε, l, k — porosity, macro-roughness and permeability of a porous media, respectively; ρ — density of air; P — pressure; R — universal gas constant; T — absolute temperature.

This system neither has analytical solution nor gives an exact description of processes running in goaf for reasons that condition specific properties of goaf in coal mines with high volume of gas.

The sources of gas establish pillars, unmineable coal bands, unloading close seams and gas-bearing enclosing rocks, coal lost during mining) contain in the goaf unequally, their lay-out is individual in each working area, and the intensity of these sources changes as mining is advanced. It is very difficult to carry out experimental studies of gas sources in goafs.

The boundary conditions of the system of equations above are determined by the positional relationship of goaf and adjacent workings.

The currently applied ventilation schemes is characterized numerous combinations of relative positions of gob area and workings. Consequently, air flows in goafs possess wide spatial transformation.

The straightforward seepage flows are the simplest. For this reason, the quantitative evaluation of seepage flow parameters in many researches tended toward transiting by any means from spatial analysis to unidimensionality. As a matter of fact, it is easy to reduce to one-dimensional flows in longwall mining system and in goafs of mine with steeply dipping seams aerodynamically connected to ground surface through caved zones. For most ventilation schemes, seepage flows possess the pronounced spatial nature. In this case, it is unallowable to decline from the three-dimensionality of seepage flows.

Average air flow velocity in gob is the function of the coordinate in the direction of the flow, i.e., we have air flow of variable rate.

And, finally, gob (as a medium where seepage and diffusion processes run) is not a static continuum, it has a comparatively complex structure, and its basic characteristics (macro-roughness and permeability k) also continuously change in time as the production heading is advanced. The rate of this change can vary within a wide range and depends on many other factors. Given the complexity of mass transfer processes in a goafs for the solution of system (1) we propose a method, based on computer modeling aero gas dynamics processes in the system "workings — goaf".

Calculating air leak distribution in gob

Goaf plays an important role in mine gas balance; nevertheless, gas and air seepage through caved rocks is insufficiently studied as it is difficult to accomplish field measurements. The present day is a witness to active and successful development in computer-aided modeling of various aero- and gas-dynamic processes, including the mining industry [9–12], and it seems most promising to study aero- and gas-dynamic processes in coal mines using mass transfer models.

It is suggested to use 3D numerical modeling to locate hazardous gas accumulations and to determine air leaks in gob area. The calculation takes into account complex transitional aero- and gas-dynamic processes connected with air leaks from workings (free volume) into gob (porous media). In order that modeling results are reliable, it is required to account for powered support and other equipments in the stoping face. This will enable correct distribution of air leaks into gob areas and air flow rate through the longwall (**Fig. 2a**).

The problem on endogenous fire risk is suggested to solve with ANSYS software. The in-built models of turbulence and air seepage in porous media [13] allow highly reliable identification of zones where air flow velocities are favorable for endogenous fire initiation (**Fig. 2a**), places of methane accumulations and release with air leaks from gob areas (**Fig. 2b**) and places of leaks of fire-produced gases (**Fig. 3**).

It is optimum to calculate air flows in goafs in coal mines using Porous Momentum Loss model.

This model describes an isotropic source in the momentum equation using the linear and quadratic permeability coefficients C_{R1} and C_{R2}. These factors depend on indexes of permeability and loss:

$$C_{R1} = \frac{\mu}{K_{perm}}, \quad C_{R2} = K_{loss}\frac{\rho}{2},$$

where K_{perm} — permeability index that is in our case equal to porous media permeability to be found empirically [14], or to be assumed in the initial conditions based on the plot in **Fig. 4** depending on roof rocks;

K_{loss} — loss index given by:

$$K_{\text{loss}} = \frac{1}{2 \cdot l},$$

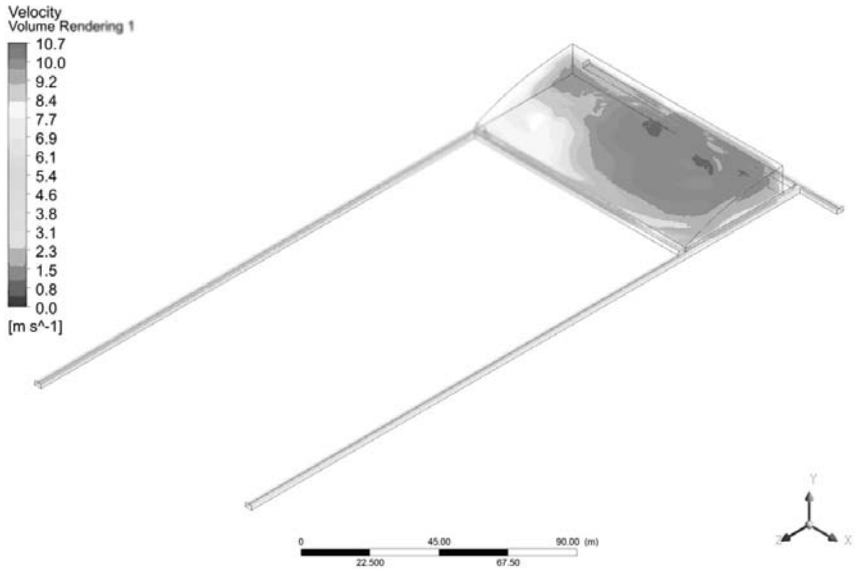

Fig. 3. Visualization of air flow velocity distribution in gob area void of working area and places of air leaks

where l — macro-roughness of porous media to be found empirically [14], in the set problem solution, its value is only taken for the initial conditions from the plot in **Fig. 4** for operating mines, these coefficients are adjusted according to the results of the measurements of mine.

In addition, it is possible to use permeability and macro-roughness indexes from Puchkov's and Kaledina's studies [7, 14, 15].

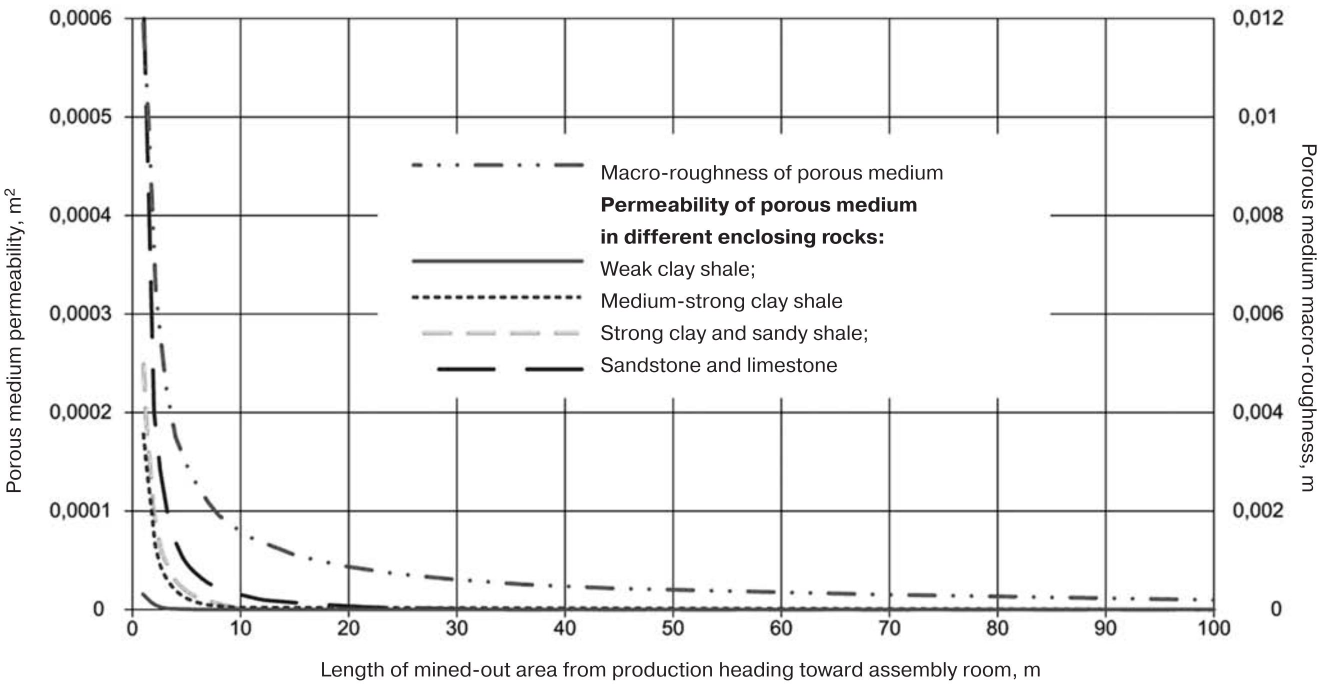

Fig. 4. Plots of change in macro-roughness and permeability of porous medium along gob area void

The air seepage flow velocity distribution is applicable to estimating endogenous fire hazard in gob areas of coal mines [15, 16] since the cause of coal self-heating under low-temperature oxidation is the low-velocity air seepage flow (from 10^{-5} to 10^{-3} m/s) through goaf.

Conclusion

The proposed method allows addressing the integrated issues of coal mine safety. For example, joint registration of ventilation and degassing; endogenous fire control, or location of gas control sensors (currently, these issues are handled by mine personnel under responsibility of a head officer of a mine [5]). Furthermore, this method enables studying various ventilation modes in dynamic models, i.e., with time-variable parameters, which assists in analyzing gas-dynamic transition processes.

At the same time, it is impossible to use this method in all mines due to constraints of computer system resources. For this reason, this method is extensively applied at large scientific and educational institutions [17, 18].

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