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Design of gob venting wells for longwall coal mining with the use of computational fluid dynamics

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Abstract
The study was aimed at decreasing the costs of gas generation management in gob workings at the expense of determining the optimum parameters of gob degassing using vertical degassing wells drilled from the surface of the earth. The experience of using various gob degassing schemes in mines of Russia and the United States has been analyzed. A model has been developed for numerical studies of the air-gas dynamics processes in the gob during excavation of beds in long faces, and parameters of degassing schemes have been determined, where methane concentration does not exceed the maximum allowable concentration. As a result of the numerical studies, the use of the degassing scheme has been proposed with the use of one row of drainage holes on the side of the vent working. Costs of degassing have been assessed showing that the use of the proposed gob degassing scheme ensures the cost reduction on the average by $1.3 million per year for a single longwall. The key areas of future research have been determined.
Keywords: underground coal mining, longwall, computational fluid dynamics, gas control, gob ventilation boreholes, methane emission, degassing.

1 Introduction

Continuous improvement of the equipment and the technology of underground coal mining ensures constant growth of coal mines performance indicators. Thus, performance of a longwall when mining thick flat bed "50" in the mine n.a. V.D. Yalevsky (formerly named "Kotinskaya") in the Kuznetsk coal basin (Russia) reached 1 million tons per month in 2016, and 1.56 million tons per month in 2017 [1-2]. However, reaching this high performance of the longwall equipment is ensured only in favorable mining and geological conditions: the depth of the working of 150-200 m, natural gas content in the bed less than 5 m^3/t. At the same mine n.a. V.D. Yalevsky, when working bed 52 at the depths exceeding 300 m (natural gas content of the bed is 10 m^3/t), the maximum productivity of the working face does not exceed 700 thousand tons per month, and the average value is 350 thousand tons per month, which is caused by the presence of the load limitations in terms of methane. The main trend of improving the technological schemes with the use of long working faces is associated with increasing the length of the longwall and the length of the extraction pillar, which when working a suite of coal longwalls leads to increased unload zones from the strain condition of the overworked and underworked part of the rock mass and, consequently, increased gas emission in the gob. Thus, with the growth of the gob parameters, the share of gas emission from a gob is also constantly increasing, currently reaching 80% of the total methane emission at the gob, which requires efficient schemes of degassing and ventilation. However, when mining the beds that are prone to self-ignition, it is necessary to avoid prolonged ventilation of the gods to prevent endogenous fires; this imposes significant limitations on degassing and ventilation of coal mines. It should be noted that at the mine n.a. V.D. Yalevsky, when seams 50 and 52 prone to self-ignition are developed, one of the best available gas emission control technology is used, which involves the use of vertical degassing wells drilled from the surface of the earth [3], as well as isolated methane removal through horizontal boreholes drilled from underground gobs through the coal pillar into the gob behind the longwall (Figure 1). The used scheme of degassing envisages a lot of drilling, since drilling of two rows of wells with 40 to 80 m distance between them is planned [4-5]. Here various schemes of arranging the second row of wells are used: in the central part of the gob, and with an offset to the edge (the first row is located along the vent working). With increasing the depth of mining, drilling costs significantly increase, which requires determining the optimum degassing parameters to ensure minimization of gas emission management costs. Analysis of the experience in gas emission management in Australia and the USA shows the possibility of using the degassing scheme with one row of degassing wells [6-7], which significantly reduces the gob degassing costs. Thus, feasibility assessment of the degassing scheme with one row of degassing wells is an important practical task.

2 Methods

To substantiate the parameters of gob degassing schemes, methods of computational fluid dynamics (AnsysCFX software product) were used. The efficiency of using the Ansys software suite for solving problems of determining rational parameters of degassing schemes was noted by many authors [8-10]. The 3D air-gas dynamical model of the gob was developed on the basis of the approaches of other authors [8-9] implemented in the scale of 1:1, and included the following: working face, gob, zonal preparatory workings adjacent to the working face, vertical degassing wells, horizontal wells drilled through the coal pillar from the parallel working. It should be noted that there is the need to determine different permeability of the gob which is pointed out by many researchers [8-9,11]. In the model, permeability of the gob behind the longwall reached $1 \cdot 10^{-6}\,m^2$, and in the remaining part of the gob it reduced to $1 \cdot 10^{-7}\,m^2$. Permeability of the gob area adjacent to the longwall significantly influences the efficiency of degassing and ventilation, because it determines the amount of leaking air [10]. Observations in the mine (the mine n.a. V.D. Yalevsky) showed the presence of residual cross-section of the working behind the longwall that was free for air passage, which had a significant impact on the aerodynamic processes and was taken into account in developing the model. Analysis of the previously performed studies has shown the practicability of modeling behind the longwall of only part of the gob with the length of 300 m [8]. This is because it is in this part of the gob that methane is emitted most intensely, and air currents move, when a combined scheme of ventilation is used. At the initial stage, modeling of the existing degassing schemes with two rows of degassing wells was made. After that, model parameters (gob permeability) were adjusted for achieving compliance with real mine data, and then efficiency of various arrangement of rows of degassing wells was studied.

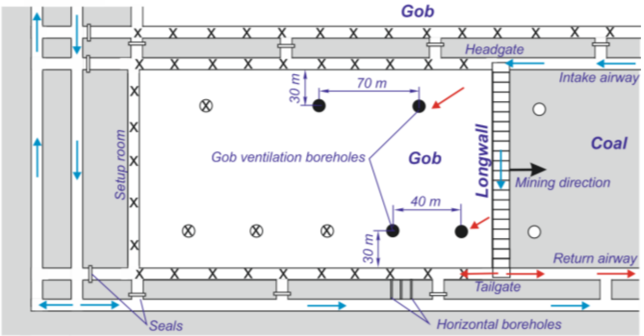

Figure 1. Scheme of ventilation and arrangement of degassing wells

3 Results

As a result of the studies, methane, oxygen concentrations fields, air velocities have been obtained, as well as air paths in the workings of the gob and in the gob with various arrangement of degassing wells (Figure 2). As can be seen from Figure 2, an additional row of wells, both when located in the center of the longwall, and when shifted to the air-supplying working, has no significant effect on methane distribution in the gob, which is determined by the significant airflow in the gob (2,800 m^3/min). However, the location of wells has an impact on methane concentration both in the methane-and-air mixture removed with the use of vertical wells, and on methane concentration when it is removed via isolated horizontal wells drilled from a parallel working into the gob through the coal pillar. Studies have shown that the necessary prerequisite for efficient gas emission management in the gob is the arrangement of a row of wells on the side of the venting working (Figures 2,A; 2,B and 2,C). The use of only one row of wells located in the center of the longwall (Figure 2,D) or shifted to the side of the venting working (Figures 2,E) results in a decreased methane concentration in the vertical degassing wells, and in an increased methane concentration in horizontal wells with exceeding the maximum permissible concentration (3.5%) in the vent piping laid in the workings of the mine. With that, the more the row of wells is shifted towards the air feeding working, the lower methane concentration is observed in the vertical wells, and the higher concentration is observed in the horizontal wells. The use of two rows of vertical wells reduces methane concentration in the degassing pipeline connected to the horizontal wells. With that, complete refusal to use degassing wells results in the expected increase of gas concentration in the gob (Figure 2, F).

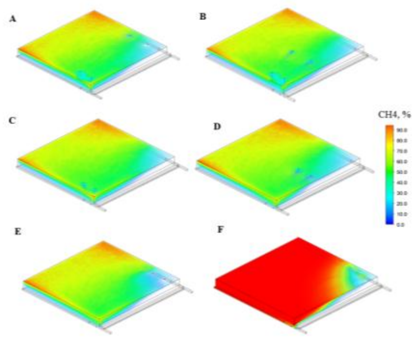

Figure 2. Methane concentration (%) with various arrangements of degassing wells

4 Discussion

The studies have shown the possibility of implementing the gob degassing schemes with the use of a single row of wells shifted 30 m towards the venting working in combination with isolated methane removal. With regard to the available data about the cost of wells' drilling, the depth of mining operations and the degassing parameters adopted at the mine n.a. V.D. Yalevsky, the cost of drilling an additional row of wells has been calculated. It has been found that due to removing the additional row of wells, and in case of maintaining other gas emission control parameters, the economic effect will amount to 1.3 million dollars a year for a single longwall. The successful experience of using a single row of degassing wells has been seen in Australia [6] and in the USA [7], where degassing wells were also located on the side of the venting working. Defining the rational location of wells relative to the vent working, as well as defining the rational distances between wells in a row, is also an important practical task [9], the solution of which is not covered in this article. The relevance of this problem is confirmed by the difference of the parameters used in mines [4-5], and the optimum parameters obtained in numerical studies of other authors [9].In our opinion, the use of isolated venting is essential for efficient gas removal from the gob when beds prone to self-ignition are developed, since where the U-shaped (return current) scheme of ventilation is used, there is a need to avoid returning to the working face part of the air that moves along the gob. The use of only means of ventilation, or ventilation in combination with only degassing wells in a U-shaped scheme of ventilation in case of a significant gas emission is a significant limiting factor that makes working the longwall inefficient. Thus, when developing a suite of gas-bearing coal seams prone to self-ignition, the use of a U-shaped venting scheme is impractical, and combined ventilation schemes should be used with isolated removal of methane-and-air mixture, which ensure controlled removal of air through the gob. However, the presence of limitations to methane concentration both in mine degassing pipelines (3.5%) and at the exit from the mixing chambers determines the need for removing main amounts of methane via wells drilled from the surface of the earth, since this method is the most efficient for gas emission management [4].

5 Conclusion

Numerical studies have allowed to compare efficiency of various arrangements of vertical degassing wells used for gob degassing when coal seams are developed in the conditions of the mine n.a. V.D. Yalevsky. The studies have shown the influence of the number and arrangement of rows of wells on methane concentration in methane-and-air mixtures produced in vertical degassing wells and degassing pipeline connected to horizontal wells drilled through a coal pillar into the gob from a parallel working. The research shows that in order to ensure the efficient gas emission management during development of thick gas-bearing seams 50 and 52 in the conditions of the mine n.a. V.D. Yalevsky, the gob should be vented with a single row of degassing wells. The economic assessment has shown that reducing the number of degassing wells will reduce the cost of gas emission management in the gob by approximately 1.3 million dollars p.a.

The areas of further studies will be associated with defining the rational distance between the wells in a row and arrangement of rows of wells related to the vent working, as well as with assessing the possibility of forming areas with explosive concentrations of methane-and-air mixture based on modern methods and approaches used by other researchers [9,12].

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