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NUMERICAL STUDY OF THE AIR-GAS DYNAMIC PROCESSES WHEN WORKING OUT THE MOSSHNY SEAM WITH LONGWALL FACES

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ABSTRACT

This study was aimed at assessing efficiency of the reverse-flow scheme of ventilation when working out the gas-bearing seam Mosshny of the Vorkuta deposit in the Pechora coal basin of Russia. The parameters of the used return flow scheme of ventilation and the method of degassing with inclined wells drilled from underground mine workings have been analyzed. Numerical studies of the air-gas dynamic processes at the excavation site have been performed, and the limit values of air flow and gas emission have been determined, where methane concentration does not exceed the maximum allowable level. As a result of the performed numerical studies, significant effect has been found of increasing the flow rate of the air supplied to the longwall for ventilation on methane removal from the mine workings. The increased risk of local methane accumulation in the conjunction with the conveyor working in case of the return flow ventilation scheme has been shown. Recommendations have been given for using the combined ventilation scheme of the working area when working out the Mosshny seam, and the scheme of goaf degassing has been proposed. The areas for further studies have been determined.

Keywords: underground mining, coal seams, ventilation scheme, longwall panel, methane emission, goaf.

1. INTRODUCTION

Underground mining of gas-bearing coal seams in Russia is characterized by unacceptably high level of accidents and fatal injuries associated with explosions of methane-and-air mixture. One of the main reasons for the high accident rate is the high complexity of mining and geological mining conditions at most mines. For example, at the Vorkuta deposit ores of the Pechora coal basin, the depth of mining exceeds 1,000 m, and the natural gas content of the producing layers is more than 20 m^3 per ton, and the seams are dangerous in terms of mountain impacts and sudden coal emissions. Over the last 17 years in mining reserves of the Vorkuta field, 42 accidents occurred, the largest of which were associated with methane explosion: in 2016 - 36 people were killed at the Severnaya mine, in 2013 - 19 people died at the Vorkutinskaya mine, and in 2007 - 11 people were killed at the Komsomolskaya mine.

The main working seam of the Vorkuta field is the Mosshny seam, which is divided into two seams, "Third" and "Fourth". The Mosshny seam, which is 3.4-4.24 m thick, is mined in long faces, leaving 15 m wide adjustable solids between excavation areas. To ensure safe mining of the dangerous in terms of sudden outbursts and rock bumps Mosshny seam, advanced mining of the 0.9 m thick seam Fifth is performed in the mines, which is 32 m below the Mosshny layer. Thus, the Mosshny seam is mined in the unloading zone. As a result of primary mining of the Fifth seam not only geodynamic safety of mining in the Mosshny seam, but significant reduction of gas emission at the excavation site are ensured. However, the check of the used ventilation scheme for the risk of local accumulations of methane performed in accordance with the applicable normative document [1] shows that the reverse-flow ventilation scheme in the considered conditions does not exclude the possibility of forming local methane accumulations at the interface with the venting work-out. Analysis of the mining data also shows that even in the conditions of undermining, gas accumulation has been observed in the excavations of the site, which determines the need for studies aimed at assessing efficiency of the used ventilation scheme and developing recommendations for its improvement.

2. METHODS

During the research, data from the gas monitoring equipment in the mines in the Mosshny seam, as well as parameters of the used ventilation scheme were analyzed; then an air-gas dynamic model was developed, and the numerical study of the air-gas dynamic processes at the excavation site was performed with the use of the AnsysCFX software suite. The efficiency of using the Ansys software suite for solving problems of finding the rational parameters of ventilation and degassing schemes has been noted by many authors [8]. The 3D air-gas dynamic model of the excavation area, developed based on the previously implemented approaches of other authors [9, 12], was made in the scale of 1:1, and included a breaking face with sections of mechanized roof support, the undermined space with areas of various permeability, site preparatory workings adjacent to the breaking face, inclined degassing wells drilled from behind the breaking face from a parallel working, secured with a coal solid.

One of the main parameters of the air-gas dynamic model is the permeability of the worked-out area. The complexity of determining permeability in the mine conditions has determined many used models and worked-out area modeling approaches [5, 7] and a wide range of permeability values of the tumbled rocks filling them used by various authors [6, 8, 10]. Analysis of the previous studies of other authors has also shown the need to divide the worked-out area into segments, permeabilities of which are significantly different [3, 5]. Thus, during modeling of the worked-out area, the following segments

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with various permeability were identified: workings filled after the longwall face, the strip of the worked-out area along the longwall face with the width equal to the roof-caving increment of the main roof, and the remaining worked-out area. It should be noted that for the research, the data about the permeability of the worked-out area in the conditions of the Vorkuta deposit were used, which had been obtained earlier by other authors [11].

3. RESULTS

As a result of the study, information about the distribution of methane and oxygen within the extraction area at various parameters of the ventilation and degassing schemes has been obtained. The minimum air consumption in the working area has been determined, which ensures dilution of methane gas to the allowable concentration (1%) in the outgoing air stream (vent working) at various values of the degassing efficiency coefficient and varying gas emission from the undermined seams (Figure-1).

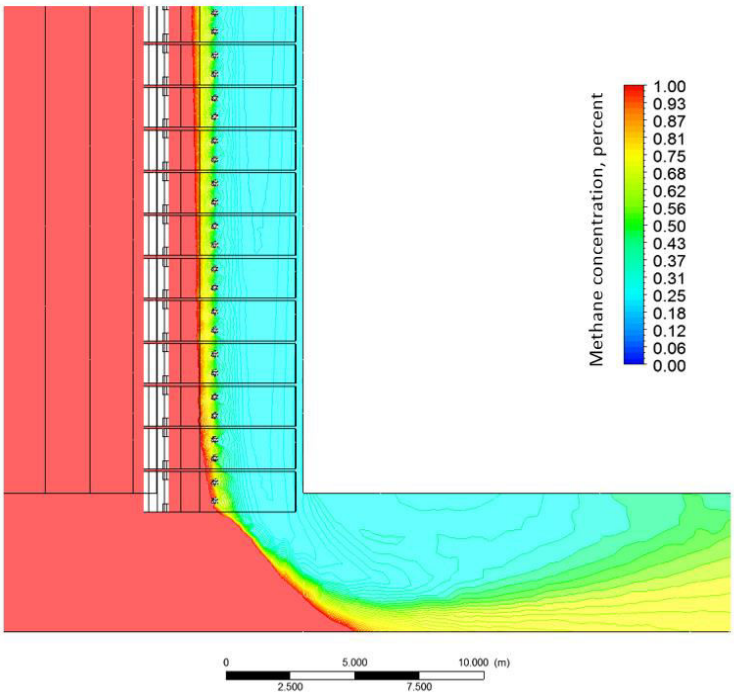

Figure-1. Methane concentration at the interface with the vent working.

The studies have shown high sensitivity of the return-flow ventilation scheme to the changes in gas emission, or decreased efficiency of degassing: if efficiency of degassing is reduced, or gas emission increases, gas accumulation in the worked-out area and the working from a methane jet migrating from worked-out area occurs. The studies have also confirmed a significant influence of transient processes associated with changes in the parameters of the ventilation scheme, namely, air flow supplied to the breaking face, on methane release in the working. In the considered conditions, development of geomechanical processes (soil swelling, roof settling and sides convergence) in the zone of influence of the breaking face in the air-feeding working results in the reduction of its cross section 2 or more times and in an increase in its aerodynamic drag. Changes in the aerodynamic resistance and air flow in the breaking face, other factors being equal, are manifested by temporal changes of the venting areas in a part of worked-out area, directly adjacent to the longwall face and manifestation of the transient processes. For example, an increased air flow results in increasing the venting area and leaks covering a more remote part of the worked-out area, which in case of using the return-flow ventilation scheme causes increased methane removal at the interface with the venting (conveyor) working. Increased methane removal will be observed some time before new conditional equilibrium state is established in the system. And on the contrary, reduced air flow rate is accompanied by a decreased size of the worked-out area ventilation zone (leaks) with consequent reduction in removal of methane generated in the longwall face. However, these processes are transient and have limited duration, and their end is accompanied by establishing quasi-stationary mode, which will change to the transition mode upon the next change of the air flow supplied to the breaking face. The results of the study are confirmed by the readings of the gas control instruments (Figure-2).

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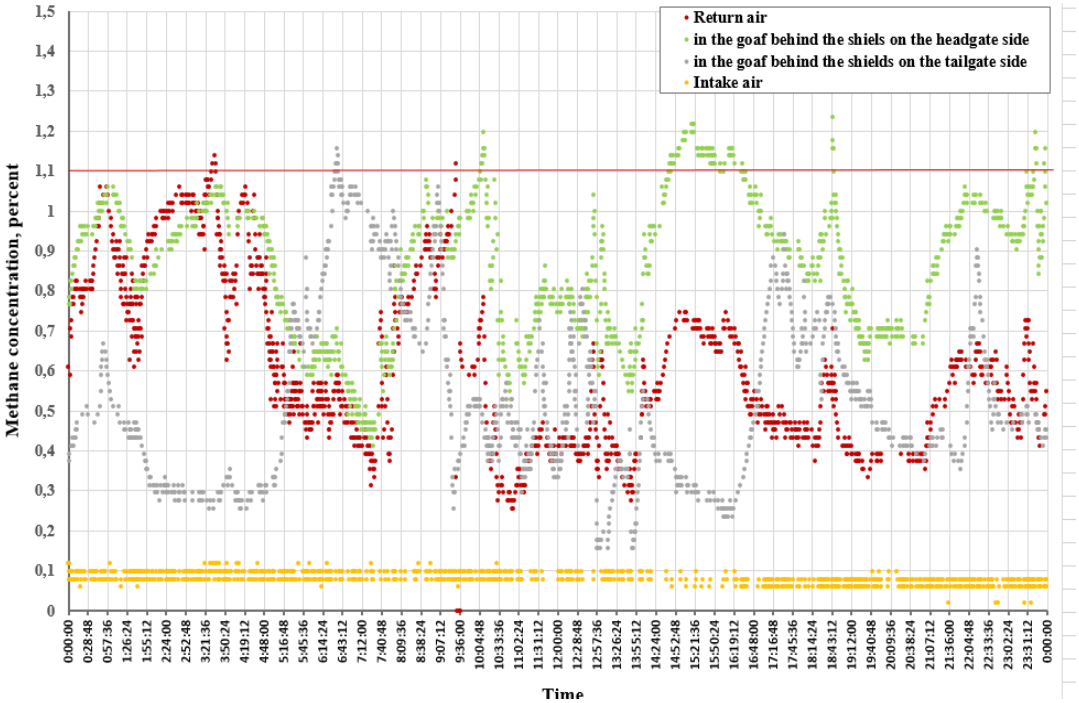

Figure-2. Changes in methane concentration during the day.

Figure-3 allows estimating distribution of air streams and their velocities, starting from the air supplying working - ventilation of the vent run to the exhaust working - a conveyor run within the limits of the breaking face and the adjacent worked-out area. As can be seen from Figure-3, a substantial part of the air moves through the part of the worked-out area adjacent to the longwall face. The permeability of this worked-out area is determined by the main roof collapse step: before the main roof collapses in the worked-out area, free air flow is ensured over the collapsed rocks of the immediate roof, and after the main roof collapses, the permeability of the worked-out area reduces sharply.

The studies show that the formation of explosive methane concentrations in the part of the worked-out area adjacent to the breaking face happens unevenly across the length of the breaking face. In return-flow ventilation schemes, the most dangerous is the filled part of the working behind the longwall face, where high methane concentration is formed, the removal of which into the longwall face results in gas concentration in the extraction area.

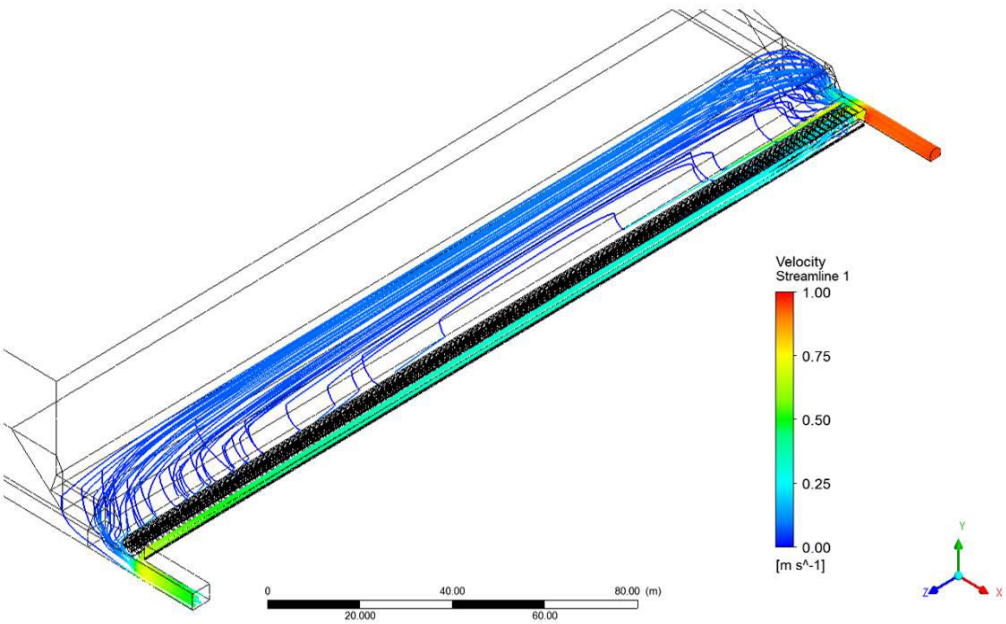

Figure-3. High-speed air current lines at the excavation site.

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4. DISCUSSIONS

Low efficiency of using the return-flow ventilation scheme when excavating a series of gas-bearing coal seams at great depths is due to the insufficient efficiency of degassing the undermined seams with wells (the coefficient of efficiency of degassing does not exceed 0.7) drilled from the underground mine workings, whereby significant amounts of methane come from the worked-out area to the space close to the face area, ventilation of which is limited to the maximum permissible speed of air movement in the breaking face (4 m/s) and its cross section available for air passage [13]. To improve the efficiency of longwall face ventilation in these conditions, a combined ventilation scheme can be recommended, which ensures withdrawal from the part of the extraction area along the conveyor working maintained behind the longwall face. This scheme provides adjustable leaks of significant amounts of air through the worked-out area, completely preventing, or greatly reducing flow of methane from the worked-out area into the breaking face. However, significant challenge is maintaining the conveyor (venting) working behind the longwall face when mining thick layers at great depths, while leaving adjustable solids, due to abrupt activation of soil heaving processes and roof settlement after working the breaking face. However, the practice of mining thick layers shows the possibility to successfully maintain workings behind the longwall face with insignificant (up to 50-60 m) lagging from the breaking face with the use of safety structures. Thus, when ventilation cross slits are located at the distance of 60 meters, this variant of combined ventilation scheme may be implemented in mining thick layers at greater depths, leaving pillars of coal between the mining areas.

To increase the efficiency of degassing (to reduce the amounts of methane in the worked-out space), the method of ventilation can be recommended, which envisages degassing of the undermined rock mass, providing for drilling of long horizontal wells into the rocks of the immediate roof towards the breaking face [2, 4]. The need to drill wells in the rocks mass of the roof is due to the fact that at great depths, the wells drilled in coal are destroyed in the areas of increased stress upon approaching the longwall face. As practice shows, drilling descending wells in these conditions is also inefficient due to the fact that they are filled with water and gas recovery therefore reduces.

5. CONCLUSIONS

The studies have confirmed the low efficiency of return-flow ventilation schemes for the excavation sites, when high gas capacity coal seams are mined. Analysis of the mining data and the performed numeric study of the air-gas dynamic processes at the excavation sites has shown that increasing air flow at the excavation site could result in a temporary significant increase in methane concentration in the air stream coming out from the longwall face, and, quite the opposite, reduced air flow ensured temporary decrease in methane concentration in the stream coming from the longwall face. The studies have also shown the significant effect of the main roof collapse step on both methane distribution in the part of the worked-out area adjacent to the face, and the amount of air moving in the worked out area along the longwall face. It is stated that one of the most likely reasons of frequent gas concentration in the excavation sites with the use of the return-flow ventilation scheme is extrusion of the methane-and-air mixture in case of collapsed main roof in the end sections of the longwall face, where methane concentration in the part of the worked-out area adjacent to the longwall face is the highest. For the purpose of efficient management of gas release in mining the Mosshny seam of the Vorkuta deposit in the Pechora basin, it is recommended to use the combination ventilation scheme with maintaining a part of working behind the longwall face (50-60 m long) and isolated removal of part of the air through the nearest linkage behind the longwall face.

The areas of further studies will involve evaluating the efficiency of using the combined ventilation scheme for the excavated areas in the considered geological conditions, substantiation of the rational parameters, and assessing various schemes for degassing of the worked-out area.

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