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INTERACTION BETWEEN GAS DYNAMIC AND GEOMECHANICAL PROCESSES IN COAL MINES

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ABSTRACT

The aim of this work is to provide safety of underground mining upon intensive excavation of coal measures of flat gas bearing seams at Kotinskaya mine, AO SUEK-Kuzbass. Current approaches to estimation of methane emission under the influence of geomechanical processes at excavating sites are analyzed. Methane bearing capacity of long wall, extraction area and goaf is analyzed as a function of load on longwall faces in the course of mining operations both in the boundaries of area and in the boundaries of field of Kotinskaya Mine. It is demonstrated that complicated character of investigation into interaction between geomechanical and gas dynamic processes in natural conditions is stipulated by low working rhythm of longwall faces. Interaction of gas emission into goaf and mined-out extraction area with roof caving incrementsat Kotinskaya Mine is determined. Significant variation of lithology and physicomechanical properties in the boundaries of extraction areas of Kotinskaya Mine is demonstrated with the consequence of necessity to differentiate zones along the length of extraction area upon calculation of roof caving increments. The performed studies have demonstrated the necessity to account for roof caving increments upon forescat of gas emission and selection of reasonable management parameters of methane emission into mined-out extraction areas.

Keywords: underground mining, coal seams, longwall, gas drainage, gas emission, gas management, roof caving increment.

1. INTRODUCTION

Efficiency and safety of mining upon intensive excavation of coal measures of flat gas bearing seams is determined mainly by management efficiency of methane emission into mined-out extraction areas, which is aimed at prevention of emergency gas accumulations of extraction areas and elimination of conditions for explosion of methane-air mix. The urgency of efficient management of gas emission is evidenced by a series of major accidents involving numerous victims in the last decade at existing Russian coal mines: Severnaya Mine in 2016, 36 dead; Vorkutinskaya Mine in 2013, 19 dead; Raspadskaya Mine in 2010, 91 dead, Ulyanovskaya Mine in 2007, 110 dead; Yubileinaya Mine in 2007, 39 dead.

An obligatory condition for selection of efficient management methods of gas emission into mined-out extraction areas and their parameters is deep knowledge of gas–geomechanical processes running in the bulk disturbed by underground mining. However, at present selection and background of ventilation flowcharts and management of gas emission are based on outdated regulations: Designing of ventilation of coal mines (1989), which do not reflect specific features of mining geomechanical conditions of existing extraction areas: long span goaves, high advance rates of longwall faces, which predetermines significant intensity variation of gas - geomechanical processes. Application of the mentioned regulations is unjustified and leads to difference between actual and calculated values by some orders of magnitude (Kaledina and Karpukhin, 2007).

This work is aimed at provision of safety of underground mining upon intensive excavation of coal measures of flat gas bearing seams at Kotinskaya Mine, AO SUEK-Kuzbass due to efficient management of gas emission into mined-out extraction areas with accounting for interaction of gas dynamic and geomechanical processes.

2. EXPERIMENTAL

Recent investigations for high productivity longwall revealed interrelations between the intensity of methane emission from excavated seam and average daily coal production in longwall face (Zaburdyaev and Mazanik, 2009; Zaburdyaev, *et al.* 2011). The interrelation between methane emission in longwall face I_{lf} (m^3/min) and daily coal production A (t/day) is described as follows (Zaburdyaevand Mazanik, 2009):

$$I_{lf} = i \cdot A + I_{bg} \tag{1}$$

where i is the specific methane emission, characterizing increment of methane amounts with each mined ton of coal, m^3day/(t min); I_{bg} is the background methane emission in longwall face prior to operation of coal mining machine, m^3/min.

In another work (Zaburdyaev, *et al*. 2011) on the basis of actual data the methane emission intensity ($\overline{I}, m^3/min$) in excavation and extraction area was determined as a function of average daily coal production ($A_d, t/day$) in the range of 10-26 thousand ton for Kotinskaya Mine. Empirical equations obtained in (Zaburdyaev, *et al*. 2011) for working columns 5203 and 5207 are as follows:

$$\overline{I} = 2.59 \cdot 10^{-4} \overline{A}_d + 3 \tag{2}$$

$$\overline{I} = 1.92 \cdot 10^{-4} \overline{A}_d + 3.5 \tag{3}$$

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More detailed analysis of data on gas emission for Kotinskaya Mine demonstrated that under steady loads on longwall face the actual gas emission both in mined-out extraction area and in the boundaries of overall site (with account for degasification and isolated gas extraction) varies significantly (Figure-1). It can be seen in Figure-1 that at the load on longwall face of about 16 thousand t/day the amount of methane emission in mined-out extraction area varies from 7 m^3/min to 23 m^3/min at total amounts of methane removed by ventilation and isolated gas extraction removal from 45 m^3/min to 200 m^3/min. Therefore, the aforementioned linear dependences do not reflect regularities of progression of gas dynamic processes at extraction areas but instead determine common trend of increase in absolute gas bearing capacity with increase in loads on longwall face.

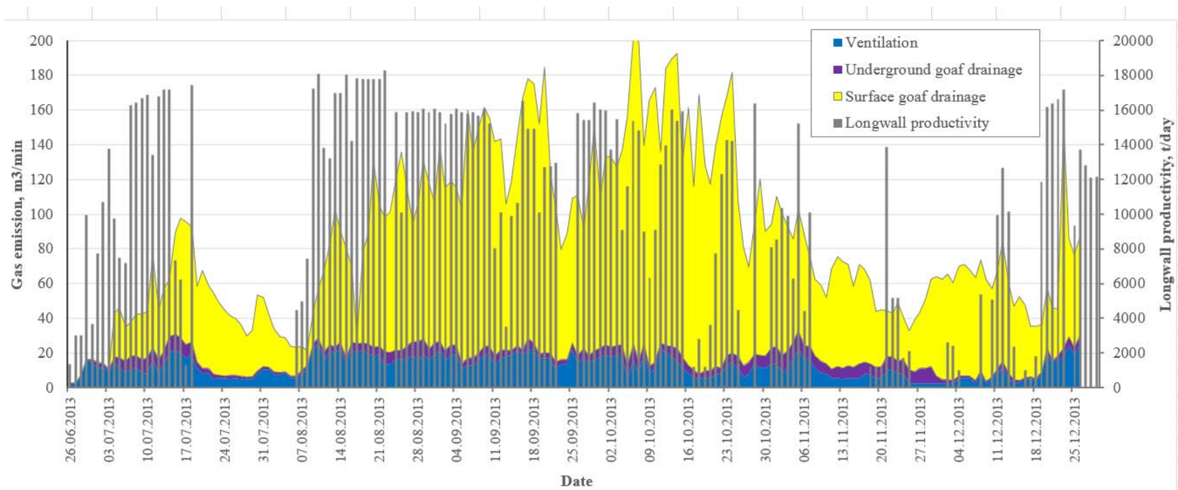

Figure-1. Dynamics of loads on working face and gas bearing capacity of extraction area 5209.

Other researchers also mention more complex interrelation between loads on longwall face and gas emissions for instance, in (Kudinov, 2016) the author mentions retention of high methane bearing capacity without production (upon maintenance) and indicates at necessity to account for response time of geomechanical processes and recent events.

3. RESULTS

Upon excavation of reserves in extraction areas using longwall faces with roof management by complete caving in the course of longwall advance the layers of immediate and main roofs are formed, overhanged and caved in the goaf. This process is periodic and directly influences on stresses in the area of abutment pressure. Herewith, the area of abutment pressure can be traced not only in the boundaries of developed seam but also propagates significantly into the roof and seam ground - with advances over and under the goaf. At the same time unload areas are formed over and under the goaf. The sizes of unload areas in underworked seam exceed significantly those of overworked seam, since after excavation the height of area of complete caving is from 2 to 6 extracted seam thicknesses, and over the area of intense fracturing - up to 20–30 extracted seam thicknesses. In the area of abutment pressure due to action of increased stresses the seam permeability decreases, whereas in the unload areas it increases significantly. In the course of longwall face advance, caving of main roof and settlement of above layers in the goaf at the distance of 2-6 roof caving increments to the longwall face there occurs continuing recovery of the seam stressed state up to initial level, which is accompanied by increase in stresses and decrease in permeability of both goaf and underworked and overworked seams.

Therefore, in the goaf of extraction area the zone of active gas emission is formed, its boundaries are as follows: in front of longwall face - the area of abutment pressure and behind longwall face - the area of stress recovery. Upon longwall advance the main roof rocks are caved and the area of intense fracturing is developed accompanied at first by increase in gas emission into the goaf due to increase in permeability of undermined seam and then by its slow decrease with decrease in gas pressure in undermined seams. Therefore, the intensity of gas emission increases generally with some time delay from caving of main roof.

Possibility of sharp short-term increase in gas bearing capacity of mined-out extraction area upon caving of main roof should be mentioned, it occurs more frequently under two conditions: existence of poorly caving roof (significant roof caving increment) and insufficient cleavage of main roof rocks by caved rocks of immediate roof (determined by ratio of immediate roof rock thickness to extracted seam thickness), it is stipulated by displacement of methane–air mix with high methane content from the goaf into working area upon caving of main roof.

Gas emission from face is also related with abutment pressure and roof caving: formation of area of abutment pressure leads to increase in stresses in front of longwall face and decrease in seam permeability, thus,

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intense gas emission occurs mainly in the area of sloughing upon coal destruction of rock pressure. Periodic caving of main roof leads both to decrease in stresses in the area of abutment pressure and slight increase in seam permeability, and to decrease in coal sloughing in the edge area. Intensity of gas emission from wall face depends significantly on longwall face advance rate, since at low rate the role of gas drainage increases and at high rate increased gas emission from edge areas is observed.

Numerous works are available which mention wave shaped pattern of variation of methane bearing capacity of high productive extraction areas upon excavation of flat coal seams by longwall face with complete caving which is related with displacement of undermined rocks (Shinkevich, *et al*. 2010; Polevshchikov and Kozyreva, 2002). In some works (Dolgonosov, *et al.* 2013) it is highlighted that caving of main roof controls intensity of gas emission - upon longwall advance, its peaks precede longwall approach to caving point and vary gas state in longwall and area. Other works (Pozdeev, 2013) state that the caving increment of enclosing rocks is one of the main factors determining the area of active gas recovery. Therefore, existence of strong rocks in over- or undermined seam promotes increase in the length of area of active gas emission, and vice versa,existence of readily caved rocks reduces the area dimensions (Pozdeev, 2013).

It should be noted that the considered flowchart of gas - geomechanical processes (Figure-2) is characteristic for central part of longwall. The necessity to differentiate goaf in terms of permeability was highlighted elsewhere (Yuan, *et al*. 2014; Wedding, 2014). The goaf permeability as a function of rock sizes and porosity was discussed in (Yuan, *et al.* 2014). In addition, the gas emission in goaf as a function of distance to longwall face огозабоя is also reviewed (Qin, *et al*. 2012).

The gas emissions on extraction areas 5208, 5209 and 5210 as a function of longwall face advance were plotted for Kotinskaya Mine aiming at estimation of the influence of periodic caving of main roof. As can be seen in Figure-2, cumulative amount of gas emission on the extraction area 5209 is unstable along the column length and has several peaks, located with periodic increment of 20-45 m and characterized by increase in gas emission by 30-40 %, and in some cases more than twofold with regard to average values. Similar dependence is peculiar for absolute gas bearing capacity of mined-out extraction area. It should be mentioned that similar dependence of gas emission dynamics was also observed at foreign mines upon excavation of high gas-bearing seams (Balusu, *et al*. 2010).

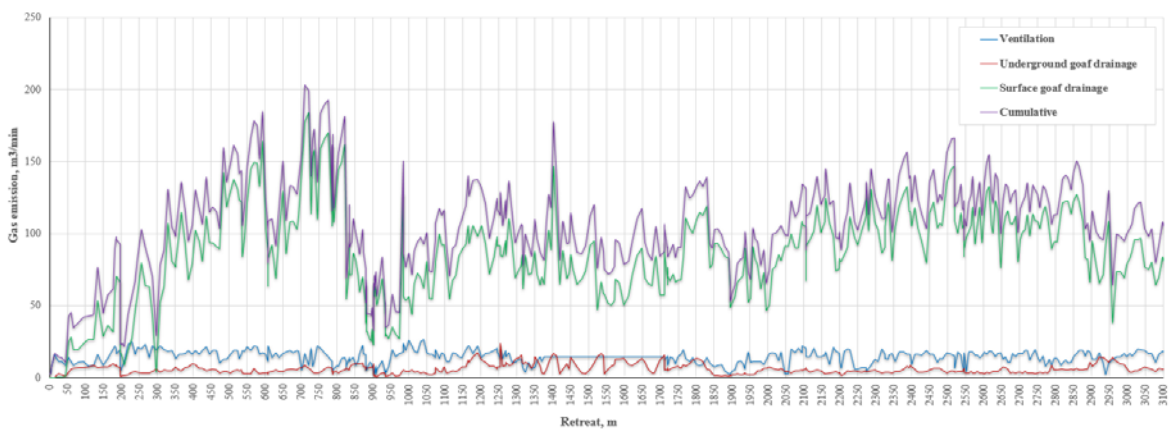

Figure-2. Dynamics of gas emission (extraction column 5209).

It should be noted that the interaction between gas emission and longwall face advance at the interval from installation chamber to longwall advance of about 300 m should be considered individually, since, firstly, in initial time of longwall operation up to the first caving of main roof (at the distance of about 50 m) gas emission from superimposed undermined seams is insignificant; and secondly for the considered extraction column in the mentioned range the longwall length was increased from 230 m to 300 m, which was accompanied by longwall downtime and development of the zone of natural gas drainage.

4. DISCUSSIONS

The obtained results required for subsequent researches aimed at detection of causes of significant variations in roof caving increment and gas emission. Analysis of extraction area map demonstrated that the caving increment is calculated for various longwall lengths by averaged values of rock strength of main rood and averaged longwall face advance rates. Herewith, the calculation procedure is applied (Preliminary manual on calculation of initial and subsequent stages of roof collapse upon mining of coal beds by longwall in Kuzbass, 1973), which considers for bedding angle, roof rock strength, longwall length and longwall face advance rate. Figure-3 illustrates roof caving increment at various rock strength as a function of longwall face advance rate on the basis of the considered procedure (Preliminary manual on calculation of initial and subsequent stages of roof collapse upon mining of coal beds by longwall in Kuzbass, 1973).

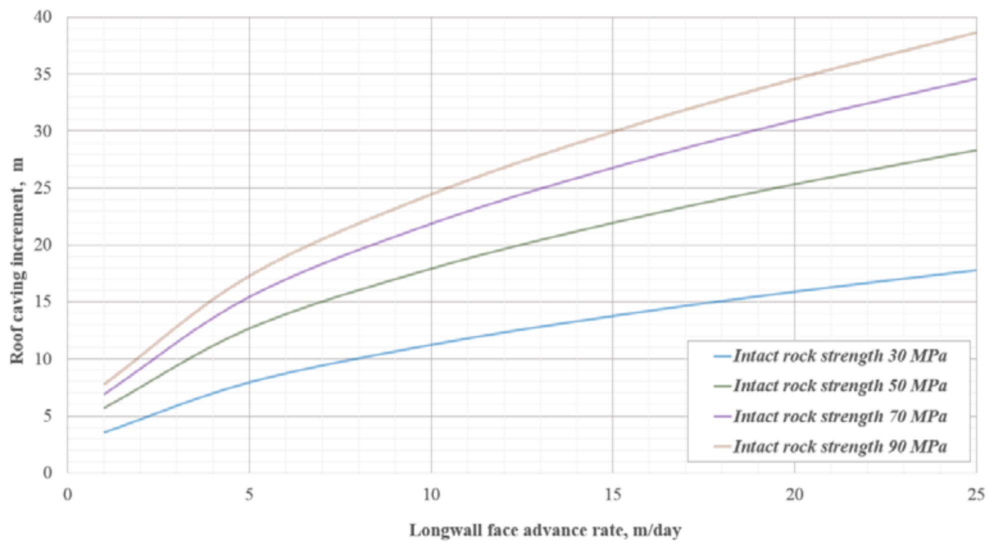

Figure-3. Influence of longwall face advance rate on roof caving increment.

Subsequent researches revealed the causes of wide range of variations of detected periodicity of increased gas emission (20-45 m). The main causes include significant variation of strength and lithology of roof rocks of seam 52 in the boundaries of extraction area, as well as low working rhythm of longwall face resulting in significant variations in longwall face advance area.

5. CONCLUSIONS

The performed researches demonstrated that provision of efficient management of gas emission upon excavation of coal measures of flat gas bearing seams by longwall faces should be based on accounting for interaction between geomechanical and gas dynamic processes at extraction areas. However, such accounting is complicated by combined influence of numerous mining and engineering factors determining intensity of gas-geomechanical processes. The major mining factors are as follows: natural gas bearing capacity of developed seam and enclosing rocks (adjacent seams), gas pressure in superimposed seams, depth of mining operations, capacity and properties of parting rocks, extracted seam thickness, ratio of immediate roof thickness to extracted seam thickness, existence of geological faults. The major engineering factors are as follows: longwall length, longwall face advance rate, applied management method of gas emission into mined-out extraction area and preparation flowchart of extraction area. It should be mentioned that increase in parameters of extraction columns (longwall length and column length) leads to variation of stress related properties of enclosing rocks in their ranges, which stipulates necessity to differentiate extraction columns in terms of length upon calculation of main parameters of gas–geomechanical processes. Increase in loads on longwall faces with increase in their advance rates leads to increase in roof caving increments and increase in heterogeneity of gas emission at extraction areas.

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