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THE BEST AVAILABLE TECHNOLOGIES FOR HORIZON MINING OF FLAT-LYING GASEOUS COAL SEAMS: PROSPECTS FOR DEVELOPMENT IN RUSSIAN MINES

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ABSTRACT

This paper analyzes the current situation and development prospects of coal mining industry of Russia. The data on the largest industrial disasters in Russian coal mines are given. The basic reasons of high accident rate during underground mining of coal seams have been studied. It was shown that the main condition to ensure economically efficient and safe extraction of flat gaseous coal seams during longwall face mining is the improvement of methods and schemes of gas release control. The need to improve the methodology to forecast gas release in mine workings and instructions to choose and rationalize ways to control gas release in mines working with gaseous seams was shown. Mining data were submitted on gas release into workings of extraction areas at high output per face under the conditions of one of the most productive coal mining enterprises of Russia – Kotinskaya mine of OAO SUEK-Kuzbass. The structure and parameters of the models for numerical study of aerogasdynamic processes at extraction areas of gaseous mines were rationalized. The results of numerical studies were submitted and conclusions were made on the efficiency of gas release control by mines. The area of rational use of draining-out of gases from the mine goaf with vertical holes from the surface was identified. The directions for further research to ensure efficiency and safety of mining in the course of intensive development of highly gaseous seams were identified.

Keywords: underground mining, multiple coal seams, mining accident, longwall mining, numerical simulation, CFD, coal seam gas, high gas emission, GOB, surface drainage hole, explosion prevention, gas management.

1. INTRODUCTION

The Russian coal mining sector for the recent fifteen years has been stably growing both in terms of production output and export of coal. In 2002-2015, the level of national coal production grew from 231 to 373 million tonnes. Only in 2009 coal production greatly (by 8.7%) reduced compared to the preceding year which was conditioned by the effect of the global financial crisis and slumping demand on coals in domestic and international markets. The main coal mining area of Russia is Kuznetsk coal basin (Kuzbass) accounting for about 57% of the total production (215 million tonnes) in 2015.

Despite the stable growth of performance in the coal mining sector, it sees a range of problems, first, related to safety of coal seams underground development the portion of which is declining gradually and accounts for 40% of the total production to date.

The achievements in recent years by some enterprises of record high for Russia engineering and economic performance in underground coal mining, compliant with the level of top coal mining countries, has not changed the situation in the sector in general, which is characterized by low competitiveness of most of the Russian mines. Besides, the success of the leaders was saddened by large disasters: Taizhina mine (Kuzbass) in 2004, 47 people died, Yesaulskaya mine (Kuzbass) in 2006 - 25 people, Ulyanovskaya mine (Kuzbass) in 2007 - 110 people, Raspadskaya mine (Kuzbass) in 2010 - 91 people, Severnaya mine (Pechora basin) in 2016 – 36 people. It should be noted that all above tragedies in coal mines are connected with methane explosions while modern high-productivity equipment was used. The specific weight of the said disasters in total accident rate in the sector exceeds 30%, which evidences the sharp necessity to solve the problem of safe development of high-category gaseous mines.

We opine that one of the basic reasons of high accident rate in underground coal mining is the unavailable resource basis, as paradoxical as it sounds for the country having 18% of the global coal reserves as estimated. In the Russian Federation, among balance sheet reserves of operating enterprises 1/3 are bad as they are rather hard to develop using modern technologies and equipment while 1/10 are extremely bad and do not allow for all-around mechanization for coal-face work (Sidorenko, 2010). Besides, good reserves are unevenly distributed by mining areas. Kuznetsk and Kansk-Achinsk basins are the main areas covering about 70% of all good reveres in Russia. The analysis enabled to ensure that most mines have reserves which are bad for development on their balance sheets. Also, it should be noted that one of specific features of Kuznetsk coal basin is gas-bedding formations which accounts during working for both the impact of worked-out seams to adjacent superimposed seams – due to establishment of increased rock pressure and de-stressed zones - and a great portion of gas penetrating into working areas of the seam being developed from superimposed underworked and overworked seams which is observed even while mining good reserves.

The next reason for the large accident rate in mines, as we opine, is the incompliance of engineering and technological solutions with the current mining geological and mining engineering conditions of works. That

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incompliance is caused by a great change in the conditions of underground mining in the recent decade due to the sharp increase of mining intensity of reserves as a result of reliability and power supply capacity rise causing increased productivity of stoping and heading equipment. Multiple load increase on working faces caused the intensity of geomechanical and gas-dynamic processes to grow at extraction areas of mines which was not supported by respective correction of regulations and did not allow doing a reliable forecast and efficiency control over the state of rock mass and gas release into mine workings. For instance, to forecast gas release into mine workings and design ventilation and gas release control parameters in today's mines, the regulation *Design of ventilation in coal mines* of 1989 is still used providing for calculation of gas release into workings of extraction areas with working faces load up to 4 thousand t/day (MakNII, 1989). The use of that document under current condition in mines with load on working faces of 25 thousand t/day and over is caused by the fact that the existing current guidelines do not provide for a reliable gas release forecast (Timoshenko *et al.*, 2009) for a wide variation range of mining geological and mining engineering factors, especially when they are highly exposed to changes.

So, an imperative to ensure the efficiency and safe development of gaseous coal seams is the choice and rationalization of underground coal mining technologies ensuring reliable forecast and comprehensive control over rock masses and gas release into mine workings. The goal of this paper is to choose and rationalize the best available technologies for underground mining of formations of flat gaseous coal seams.

2. METHOD

As the object of research, one of the leading coal mining enterprises was chosen - Kotinskaya mine of AO SUEK-Kuzbass. Kotinskaya mine is mining a formation of gaseous coal seams in Sokolovskoye deposit of Kuznetsk coal basin. Currently, seam "52" from 4.01 to 4.64 m thick is being mined, with "53" seam 38-43 m above and "51" seam 32-37 m below. Bedding angle is 2-7 degrees. Natural methane content of "52" seam is 10 m^3/t. The depth of mining works is 320-380 m. "52" seam is mined using long-pillar along the strike with roof collapse and inter-pillar coal stopes left. The parameters of extraction areas are: face length - 230-280 m, extraction column - under 4,000 m. Extraction areas are developed by paired gates fixed by roof bolting. The equipment of working face is powered roof support DBT and miner Eickhoff SL-500. Blowing of extraction areas is return-air (U-shaped). The ventilation gate is used to feed fresh air flow into working face, deliver equipment and materials, conveyor gate - to transport coal from the stall and deliver the return air flow (Figure-1). It should be noted that to ensure gas release control while working extraction columns in Kotinskaya mine, various variants to drain out gases in the goaf were tried: vertical holes from the surface (with various parameters) and slant holes from district workings, linking holes from parallel gate. Besides, preliminary degassing of the mined seam with holes from district workings was used. Isolated method to drain methane and air mixture through cross slits via degassing pipelines is used.

During the research, the variant to control gas release was considered in the course of mining extraction area 5210, including degassing of the goaf via holes from the surface in advance of the face 30 m from conveyor and ventilation gates at a pitch of 50 m, degassing of goaf via linkage holes and isolated drainage of methane and air mixture (Figure-1).

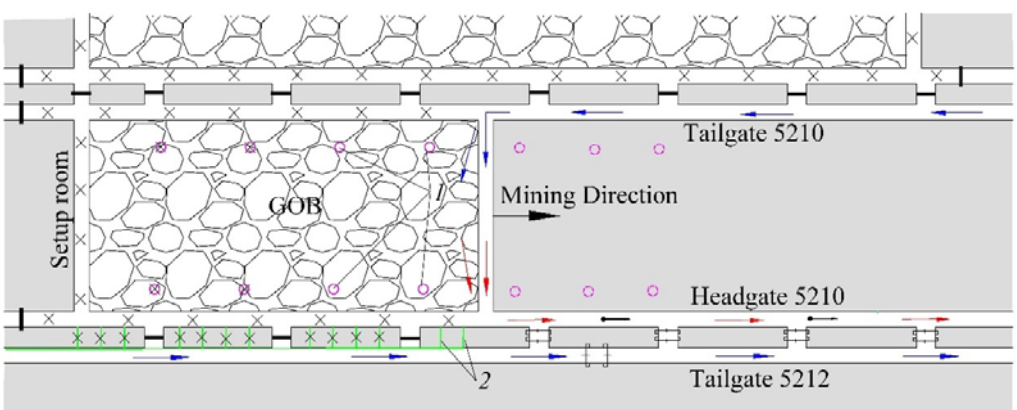

Figure-1. Scheme of ventilation and gas release control at extraction area 5210.

In doing the research, the comprehensive method was used comprising: mine observations of gas release into workings of extraction areas 5209 and 5210 in Kotinskaya mine, data analysis on methane release during mining of worked-out extraction areas 5207 and 5208 (Ruban*et al.*, 2011), calculations of aerogas dynamic processes in extraction areas under specified conditions using ANSYS CFD software package.

To make calculations, 3D model of extraction areas was developed; its principal design scheme is in Figure-2.

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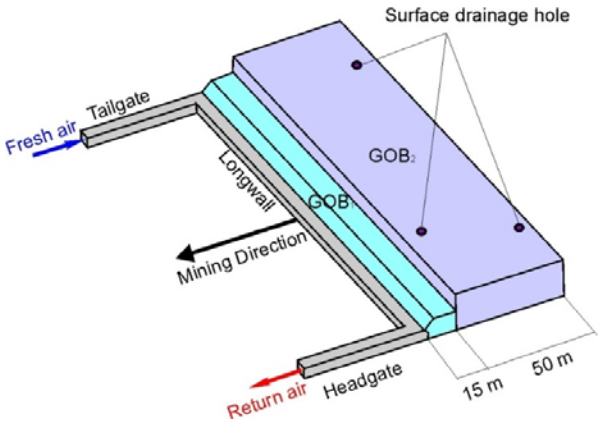

Figure-2. Design diagram for modeling.

The model includes preparatory works and stope faces, goaf; accounts for workings geometry and equipment dimensions (Figure-3), degassing and gas release control tools. One of the core elements of the model is goaf. Modeling of goaf as a porous body was considered and reasoned in a number of works (Bird *et al.*, 2007; De Lemos, 2012). Modeling results were verified in mine studies which allowed acknowledging the relevance of using those models to forecast gas situation and control gas release. The said parameters were determined in compliance with the principles specified in works of other researchers (Esterhuizen, and Karacan, 2007). While modeling and calculating the porosity of goaf, size of collapsed rock pieces and its influence on porosity were taken into account (Karacan, 2010). The Carman-Kozeny relationship between permeability and porosity is expressed in the equation (Esterhuizen, and Karacan, 2007):

$$K_{gob} = \frac{K_0}{0.241}\left(\frac{n^3}{(1-n)^2}\right) \quad (1)$$

where K_o is the base permeability of the rock, and n is the porosity.

In doing the research, unevenness and zoning of change of aerodynamic parameters were taken into account (porosity and permeability). The need to differentiate the goaf zones was considered in (Ren, and Edwards, 2000; Yuan *et al.*, 2005). Methane release was modeled under the principles described in (Ren*et al.*, 1997).

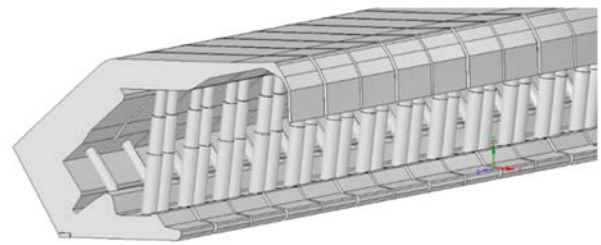

Figure-3. 3D model of extraction area.

Figure-4 displays the 3D model of extraction area divided into volume elements. Using the developed model enabled to get distributions by moving velocity of air flows and methane concentration within the studied area.

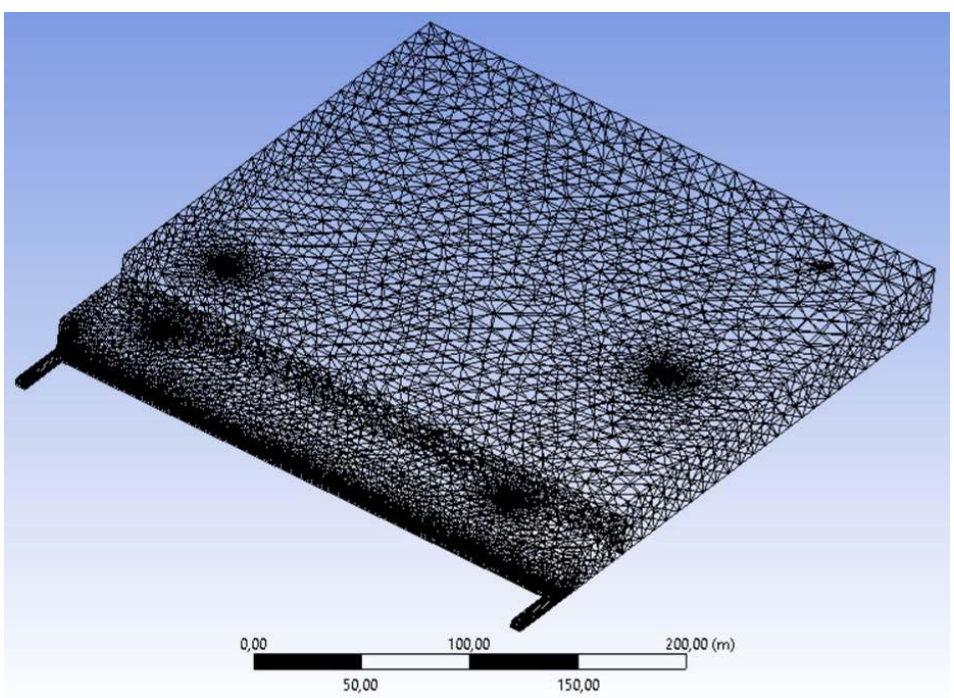

Figure-4. Model of extraction area with degassing holes.

Using the developed model, ventilation scheme reliability was assessed for Kotinskaya mine and the effects of parameters of the scheme to control gas release on methane drainage efficiency from working area of the stall and road heads were studied.

3. RESULTS

Mine observations in Kotinskaya mine identified the dependencies of gas release into workings of extraction area on the basic parameters of technological schemes and methods used to control gas release. Figure-5 shows that average total absolute methane release in extraction area 5210 is directly proportional to load on the face. Also, gas balance of extraction areas was found. In average, the portion of gas release in the face from the seam in gas balance of area 5210 within the stope since April to September 2015 was 18.9%. Increasing portion of gas release from the face in area 5210 compared to areas 5207 and 5209 was caused by high portion of gas release from the face in the initial period of works and small time lapse. Upon the results of working of reserves in area 5210, the forecast average level of methane release into the face will be about 13-15% in general gas balance of extraction area.

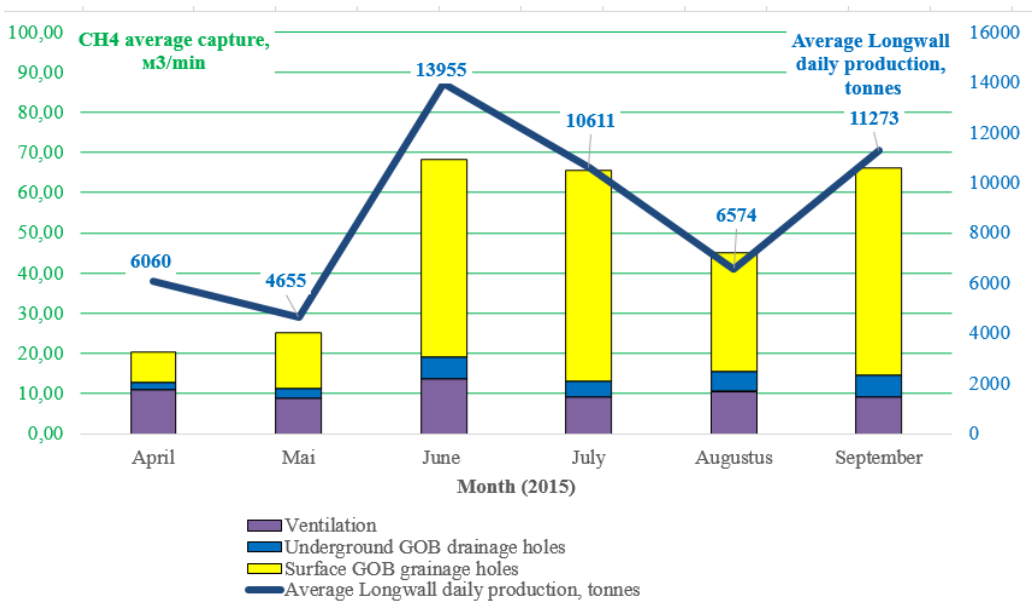

Figure-5. Interdependency of average monthly load on the face and absolute volume of gas of extraction area 5210.

The analysis shows that the main factor to undermine production growth of extraction areas by "gas factor" is gas release from goafs formed by superimposed coal seams due to growing permeability of interseam space upon discharge from rock pressure in underworking and overworking zones, first, seams "53" and "51" respectively.

Figures 6 and 7 show the dependencies of maximal methane concentrations in gobbed part of the conveyor gate and on the stream from the face respectively on the load on the working face when mining reserves of area 5210. As seen from Figure-6, increasing load on the working face till 11 thousand t/day and over causes sharp increase of methane concentration in the niche reaching in some cases up to 90% of maximal allowable value. Meantime, most of such cases are typical for the range of load on the working face from 11,000 to 14,000 t/day.

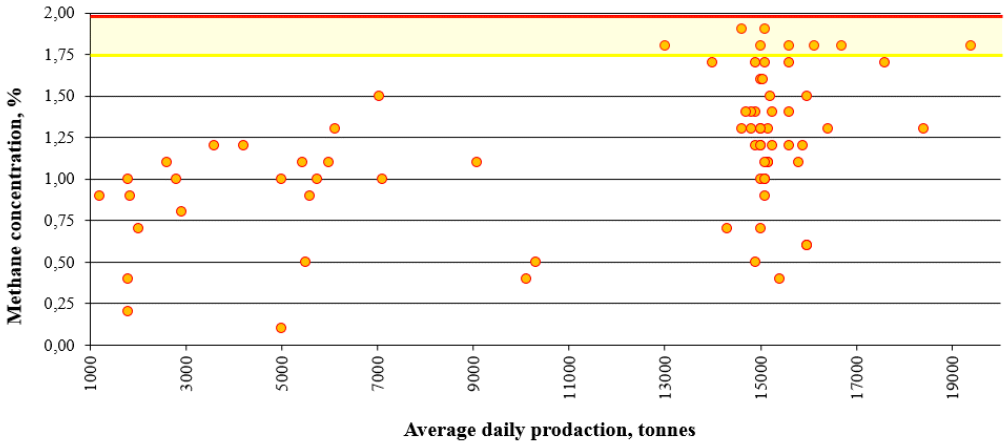

Figure-6. Interdependency of maximal methane concentration in gobbed part of the conveyor gate and load on the working face.

As seen from Figure-7, in case of load on the working face about 15 thousand t/day maximal allowable concentration of methane under safety rules was repeatedly observed in the stream from the face in the conveyor gate.

Figure-7. Interdependency of maximal methane concentration in the stream from the face in the conveyor gateand load on the working face.

The mine observations allowed identifying possible variation ranges of methane release from a mined seam and goaf which were given as initial conditions to do the calculations. Using the model in Figure-4, methane distribution was obtained within the modeled part of the extraction area (Figure-8).

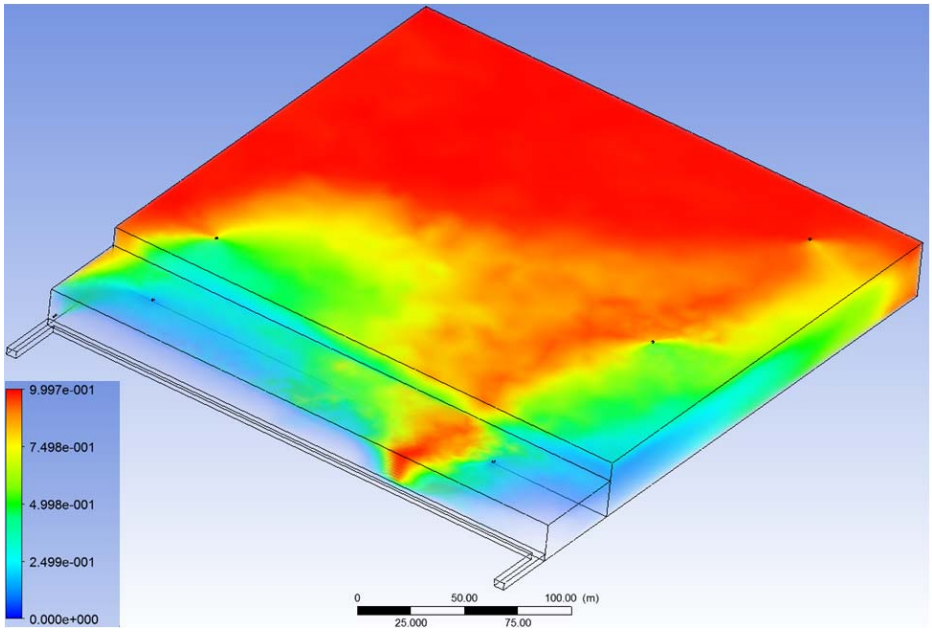

Figure-8. Methane concentration in extraction area using degassing holes from the surface (3D).

The research showed the possibility to ensure explosion safety parameters of the atmosphere in working area of the face using five degassing holes drilled from the surface.

At the next stage of research, failure of one of degassing holes was modeled enabling to conclude that in the event of failure of even a single hole, excess of allowable methane concentration (1%) in the conveyor gate and local methane accumulations (2%) in the face are observed.

4. DISCUSSIONS

The analysis of the costs of preparation and development of extraction areas in Kotinskaya mine in 2014-2015 has shown that the costs of gas release control are 16% of the total costs of extraction area development, but the efficiency of degassing holes much depends on geomechanical processes flowing in underworked formation under various mining and geological conditions which may cause holes to fail. The costs of drilling holes from the surface are 75% of the total costs of gas release control which, alongside their decreasing efficiency and growing costs as the depth of works increases, makes it imperative to seek alternative solutions to control gas release, ensuring cost cut maintaining the required safety level (Kazanin*et al.*, 2015).

Total methane release in an extraction area may exceed 100 m^3/min, while 9-15% of methane goes from the working face and 85-91% from the goaf. The observations have shown that as the load on the working faces grows, the portion of methane release from the mined seam in the gas balance of an area falls down. Meantime, the methane release from the seam in the working face varies insignificantly and is about 9 m^3/min. If the costs of drilling and maintaining holes and mobile steam dewaxing unit are high, one of directions to cut the total costs of mining may be seeking variants to control gas release without drilling holes from the surface.

5. CONCLUSIONS

The calculations and mine observations of Kotinskaya mine allowed concluding that the current way to de-gas the goaf using holes from the surface while mining the reserves of thick gaseous coal seams having natural gas content about 10 m^3/t at load on the working face under 25,000 t/day ensures safe gas release control in extraction areas subject that at least two degassing holes (one on each side of the face) at the distance from the preceding one not exceeding a caving increment of the main roof of the seam. Meantime, a failure of a single hole under the conditions studied causes high danger of exceeding allowable methane concentrations in workings of the extraction area. One of the ways to eliminate emergencies in case of a failure of the hole is decreasing load on the working face or its stoppage.

Degassing of the goaf using holes may be recommended as the main tool to control gas release in extraction areas while mining superimposed gaseous seams when the portion of methane release in the gas balance of extraction area exceeds 50 m^3/min. Taking into account that gaseous beds position in formations is a typical feature of Kuzbass deposits, the gas balance of extraction areas with dominating gas release from the goaf is the most probable in mining gaseous seams, which predetermines wide use of that way of degassing in mines. However, as the mining depth grows over 300 m, the costs of such a way of degassing of the goaf reach 15% of the total costs in extraction area (75% of costs of gas release control) and keep growing as the depth of mining grows. Also, as the mining depth grows, the number of failures of

degassing holes increases causing the reliability of gas release control to fall, resulting in grown probability that hazardous accumulations of methane will form in workings of extraction area which has been acknowledged by the numerical research.

One of the ways to ensure safe degassing of goaf under the conditions of unstable work of holes drilled from the surface and degassing schemes currently used in practice is to use a few (from 3 to 5-6) simultaneously operating holes in extraction area. Such a way really ensures high reliability of methane drainage not only from the goaf area adjacent to the face area, but from the area rather remote (200 m and over) from the working face; however, large length of the aired zone under the conditions of mining seams much exposed to ignitability is, as we opine, dangerous and causes high probability of endogenous fires. Moreover, some scientific works (Oparin, and Skritskiy, 2012) point that endogenous fires are the reason for most explosions of methane in Russian mines making such practice extremely dangerous. The hazard of using such schemes also increases sharply in case of long downtime of working faces.

To ensure efficient and safe mining of gaseous seams formations exposed to ignitability it may be recommended to use the scheme of three-gate preparations of extraction column (Kurta *et al.*, 2011), providing the conditions for isolated drainage of methane and gas mixture from the goaf at minimal length of its airing zone.

It should be noted that the analysis of the global experience of using vertical degassing holes from the surface (Moreby *et al.*, 2010) allows concluding on their possible rather successful use only under 600 m deep, as at great depths they, as a rule, are impossible to be used technologically because of frequent collapse and economically unfeasible because of high cost and limited (a few days') time of work during intensive mining of reserves.

The near-term outlook for development of mining in Kuzbass is linked with increasing mining depth in existing mines and gradual fall of engineering and economic efficiency of using vertical degassing holes from the surface. So, a prospective way to control gas release may be considered degassing goaf via holes from mine workings drilled into the zones of load discharge of rock masses and using extra gas drainage or air supply workings.

Also, the need should be noted to improve the regulations to determine the procedure of choosing and rationalizing the parameters of various degassing methods in coal mines, as the current instructions/guidelines need great review (Timoshenko *et al.*, 2010).

The directions of further research of gas dynamics of workings in extraction areas should be linked with the choice and rationalizing of the ways to control gas release, ensuring safe mining of seams exposed to ignitability. Doing such research for the conditions of prospective Russian mines is also possible using numerical methods and software package ANSYS CFD and approaches to modeling, described earlier in works by other authors (Gao *et al.*, 2014; Yuan, and Smith, 2014).

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