Exploration drilling for pre-mining gas drainage in coal mines

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Abstract. High natural gas content in coal seams and low gas drainage efficiency are the basic issues to be addressed in order to ensure coal mining safety. A great number of wells being drilled within various gas drainage techniques significantly increase the costs of coal mining and do not reduce the gas content levels within the coal beds up to the required parameters in a short period of time. The integrated approach toward exploration well spacing applied at the stage of project development could make it possible to consider coal seam data to provide more effective gas drainage not only ahead of mining but also during further gas content reduction and commercial production of methane. The comparative analysis of a closely spaced grid of exploration program compiled in accordance with the recommendations on applying mineral reserves classification and inferred resources of coal and shale coal deposits and currently effective stimulation radius proves the necessity and possibility to consider exploration well data for gas drainage. Pre-mining gas drainage could ensure the safety of mining operations.

1. Introduction
Due to the fast growth of coal mining industry, there is an increase in mining depth which in its turn means gas content increase, as well. This fact significantly influences the safety of mining operations, volumes of coal output and associated gas production, as well as the extent of environmental pollution.

Only 20 % of total coal reserves in Kuzbass can be produced by the most cost-effective method, i.e. open-pit mining. Therefore, the rest coal reserves can only be extracted by underground mining. However, increase in mining depth and gas content inevitably results in coal production costs.

Due to high methane level, such techniques as in-seam gas drainage (shortly before mining) and gas drainage while mining are widely applied in coal mines. Usually, to reduce gas content in a coal mine, it is required to drill from 10 to 150 m and stop all mining operations within the proven territory.
2. Materials and methods
In practice, a combination of various methods is used to degasify coal seams characterized by high gas content as much as possible before they are mined, and to decrease the amount of emissions during mining.

Techniques that reduce coal seam gas content before mining include: barrier degassing and in-seam drainage, shortly before mining. Pre-mining drainage that is of rare use in Russia is also classified as a technique applied to reduce coal seam gas content.

Due to low efficiency factor of in-seam drainage (shortly before mining – 0.2 – 1.4 %), the basic portion of methane is released during gas drainage while mining, particularly, by means of ventilation systems (10-40%) and powerful fans (60-90%) placed at the coal face.

Therefore, all the actions taken to reduce coal seam gas content result in significant production costs and do not allow increasing coal production rate. Challenges in methane extraction from coal seams are caused by low permeability of reservoir coal seam, with methane being occluded. To increase permeability of reservoir coal seam, a great number of stimulation technologies have been developed.

Pre-mining drainage is carried out by drilling vertical, directional and horizontal wells from the surface. Most wells do not release gas until the permeability of the reservoir coal seams is enhanced by stimulation treatment aimed at creating various fractures for further methane extraction from coal seam before mining operations themselves.

Depending on coal geology of a mine and stimulation technology to be used, gas can be released within a radius of 200-300 m from the vertical well.

Based on the results of hydraulic fracturing implementation in the Karaganda and Donetsk coal basins, the parameters of this technology are defined.

Pre-mining drainage involving reservoir coal seam fracturing is more suitable for use in coal seam confined by impervious rocks of not lower than mean stability [1-5], with gas content being 8 m³/tonne when reported on a dry, ash-free basis.

The efficiency of drainage wells depends on various factors; therefore, methane production period is more than 3 years.

Based on the research carried out by Inter-industry scientific center VNIMI, it has been revealed that the most effective way to prevent coal mine burst in deep mining is to apply stimulation technologies which are widely used in petroleum industry as they may significantly increase the effective drainage radius.

One of the solutions to control strain-stress characteristics of large coal seams is to apply acoustic simulation of production wells which has been already tested in coal deposits and gas condensate fields of the Russian Federation. This method makes it possible to control strain-stress characteristics of a coal mass by means of the wells drilled directly into the coal seam from the mine workings, or drilled down from the surface. Local acoustic excitation is one of the types of acoustic simulation method.

When applying the method of acoustic excitation, it is possible to influence strain-stress characteristics of the coal seam as the system “well-formation/well-rock stratum” is considered resonance.

The above-mentioned methods are unique as they allow carrying out pre-mining gas drainage and decreasing high strain energy up to safety parameters over great areas – up to 200 thousand m² (R~500 m) when the wells are drilled from the surface; for in-mine boreholes, the effective area is up to 30 thousand m² (R~200 m).

In order to control mechanical properties of rock effectively [6], the above-mentioned methods can be applied in the following way: with the amplitude being more than critical compressing strain or elastic strain, elastic waves are excited at a set distance from the well or acoustic waves are excited within elastic strain values.
70-90% of total methane volume is extracted by means of modern pre-mining gas drainage techniques based on drilling wells from the surface. There some cases when methane is produced in coal deposit, with gas content being 3-4 m$^3$/tonne when reported on a dry, ash-free basis [7].

In worldwide mining practice, there is a special term “methane control” which implies that 75% of the total volume of methane is extracted by means of pre-mining gas drainage, 15% - by the drainage shortly before mining, 10% - by ventilation systems during mining itself.

Unfortunately, the implementation of pre-mining gas drainage technique is a rather complicated process as it faces such challenges as high costs of well drilling and extended period of drilling and degassing works (minimum - 3 years).

The number of wells, its depth and spacing depend on many factors and these parameters including the direction of drilling are defined based on the specific features of a given mining site.

Unlike horizontal drilling, vertical well drilling is not so expensive. In most cases, vertical well drilling does not require any extra facilities. An alternative method of pre-mining drainage is to drill directional boreholes, i.e. deliberate inclination of the bore hole from the vertical, and horizontal wells within the coal seams characterized by great thickness or complicated geology when it is too expensive to drill vertical wells. A single horizontal well can replace the need to drill several vertical wells; however, horizontal well drilling is rather cost-intensive. Besides, it horizontal drilling is impossible without extra equipment and trained specialists. Well spacing is basically defined by time, i.e. the less field development period is, the more wells are required [7].

In some cases, a combined well spacing pattern including vertical, horizontal and directional wells is applied. All these types of wells have their own advantages and limitations. Since for exploration purposes vertical wells are basically drilled and only in some cases directional drilling is applied, the main focus of this article is the application of vertical wells in coal gas drainage.

In order to extract as much methane as possible from coal seam and surrounding strata, it is proposed to apply pre-mining gas drainage technique based on drilling exploration wells planned to be drilled at the exploration stage of coal mine development project.

3. Results and discussion

Gas content data obtained at different stages of prospecting and exploration present reasonable interpretations of the geology of the area, which is enough to decide upon whether to continue exploring the area or carry out the pre-mining gas drainage.

Based on the experience gained while exploring the mines within Kuznetsk coal basin, it is possible to predict the thickness of gas weathering zone and further increase in gas content with increasing depth.

On the average, the thickness of gas weathering zone in Kuzbass region varies from 200 m to 100 m, which corresponds to the horizons from ±200 to ± 0 m absolute. Today, mining is basically carried out within the horizon ± 0 m absolute and lower.

The dependence of gas content on the horizon is given in table 1.

As indicated in table 1, coal seam gas content within the mines currently developed by coal-producing companies is 10-30 m$^3$/tonne when reported on a dry, ash-free basis. It increases with increasing depth, which in its turn will result in significant gas drainage costs. A more vivid example of gas content increase with increasing depth is illustrated in figure 1.

### Table 1. Gas content data in Kuzbass basin

| Horizon, m abs. | Gas content, m$^3$/t on a dry, ash-free basis | Mining depth, m |
|-----------------|--------------------------------------------|-----------------|
| + 200           | 0-9                                        | 100-200         |
| ±100            | 10-15                                      | 200-300         |
| ±0              | 13-22                                      | 300-400         |
| -300            | 22-30                                      | 600-900         |
The application of exploration drilling for pre-mining drainage will certainly allow coal mine operators to manage the time more effectively which is usually spent on developing mine plan, evaluating mine plan stages, constructing the main facilities within the mine workings and conducting pre-mining gas drainage.

* when reported on a dry, ash-free basis

**Figure1.** Coal seam gas content cross-section

In accordance with the Decree of the Government of the Russian Federation № 315 of April 25, 2011, it is required to degasify coal seams, with gas content being more than 13 m³/tonne when reported on a dry, ash-free basis.

In coal producing countries, to ensure the safety of mining operations this value is decreased up to 9 m³/tonne when reported on a dry, ash-free basis.

Due to devastating mine explosions in mine workings, the proposal to degasify coal seams, with gas content being 9 m³/tonne when reported on a dry, ash-free basis is currently under consideration in the Government of the Russian Federation. Therefore, it can be assumed that pre-mining gas drainage of coal seams with gas content being 13-30 m³/tonne when reported on a dry, ash-free basis will become an obligatory stage. Besides, depending on the relative methane-bearing capacity, mines are divided into categories. Thus, in accordance with the item № 267 “Coal mine safety rules”, a mine is classified as “very gassy mine” when relative methane-bearing capacity is 15 m³/tonne or more when reported on a dry, ash-free basis [8].

The analysis of relative methane-bearing capacity of Kuzbass coal mines (lower than horizon. ± 0 m absolute) has revealed that most mines can be classified as “very gassy mines” as relative methane-bearing capacity is 30-60 m³/tonne and more when reported on a dry, ash-free basis.
The above-mentioned data prove the relevance problem in question, i.e. high coal seam gas content. It is also proved by the fact that relative methane-bearing capacity is 2-4 times higher than the value set to such a category of mines as “very gassy mine”. Therefore, it is proposed to use exploration wells not only for information gathering but also for pre-mining gas drainage, which should be considered even at the stage of mine planning.

The application of well spacing pattern in accordance with “Recommended practice for application of the classification of reserve and possible resources of mineral deposits” [9] and the stage of mine-site exploration allows further pre-mining gas drainage by means of the exploration wells planned to be drilled at the exploration stage of mine development. The well data should be preserved for the duration of compiling geological record including coal seam methane reserves confirmation.

Table 2 illustrates the analysis results of gas drainage area when stimulation radius is 200 - 300 m and exploration wells are spaced with the above mentioned recommendations.

For example, based on the exploration well spacing pattern requirements, i.e. 200 m between wells and 400 m between exploratory lines, it is possible to degasify 100% of mine site (figure 2) and decrease gas content up to 13 m³/tonne when reported on a dry, ash-free basis, with the fracturing radius being 200 m.
The proposed well spacing pattern can also be applied to decrease the gas content during mining, which could prevent a sudden emanation of methane from the roof and floor during the pillar recovery process.

Therefore, a closely spaced well pattern applied at the exploration stage will provide more accurate reserves estimates, which in its turn will ensure 100% gas drainage and gas content reduction up to 70-90% [7]. This will ensure the safety of mining operations and reduce the urgency of gas drainage while mining.

Figure 2. Well spacing pattern: 1 – initial mining license area; 2 – cross-section; 3-planned borehole; 4 – drilled borehole; 5 – stimulation zone; 6 – license area boundary

The optimal well spacing pattern determined at the exploration stage, as well as a properly defined number of exploratory wells which can be further applied for pre-mining gas drainage make it possible to use effectively mine planning period so that gas content is reduced by the commencement of mining operations. Besides, while building coal mining facilities at the mine site, it is possible to degasify the territory carrying out pre-mining gas drainage of mine workings.

The volume of coal seam methane extracted by means of pre-mining drainage makes it possible to use it in various industries. In many drainage projects worldwide, the drained gas is basically used as an energy source for the mine itself or local region. Depending on produced gas quality and volumes, it can be commercially used as well.

4. Conclusion
The application of exploration drilling for pre-mining gas drainage can be effective not only in terms of gas content reduction but also because of the following reasons:
• reduction in drilling costs when it comes to barren spots and gas weathering zone (100-200 m) drilling that accounts for 50-70% of total exploration drilling costs;
• possibility to degasify surrounding strata from which methane also emanates as the overlying strata subside and the underlying strata have;
• possible application of exploration well to degasify the roof of pillar-caving;
• elimination of expensive machine downtime while mining;
• reduction in the amount of methane emissions contributing to greenhouse effect, which has been increased 8 times over the last decade because of higher mining productivity in Kuzbass basin;
• mining industry cost-efficiency increase due to the use of methane for industrial purposes at the mine site.

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