DOI: 10.18454/PMI.2017.1.125

UDC 622.88:502.65

JUSTIFIED SELECTION OF A SEAM DEGASSING TECHNOLOGY TO ENSURE SAFETY OF INTENSIVE COAL MINING

Sergei V. SLASTUNOV[1], **Evgenii P.YUTYAEV**[2]
[1] *National University of Science and Technology «MISIS»*, Moscow, *Russia*
[2] «*SUEK-Kuzbass*», *Leninsk-Kuznetsky*, *Russia*

The paper contains main aspects of methodological approach to objective analytic assessment of maximum permissible output of the mine faces from the viewpoint of gas factor. Analytic forecast is centered around the assessment of methane inflow into the face area from all possible sources, based on fundamental physical laws, modern tools of mathematical modeling and in-situ tests of main properties and state parameters of the gas-bearing coal formation. Objective and reliable estimation of permissible outputs is a starting point for justified selection of a seam degassing technology, that has to be based on time factor and predicted value of gas recovery from a coal seam to a degassing well. Recommendations have been formulated on the selection of degassing technology for the coal seam «Boldyrevsky» of the Kirov mine, based on the use of cutting-edge technological schemes (hydraulic fracture, carried out from development workings, etc.), successfully implemented on the mentioned site.

Key words: gas factor, permissible output, forecast methodology, selection of seam degassing technology, hydraulic fracture, practical recommendations

How to cite this article: Slastunov S.V., Yutyaev E.P. Justifies Selection of a Seam Gegassing Technology to Ensure Safety of Intensive Coal Mining. Zapiski Gornogo instituta. 2017, Vol. 223, p. 125-130. DOI: 10.18454/PMI.2017.1.130

Introduction. Development strategy of Russia's coal mining until 2030 calls for an increase in coal production up to 430 Mt/year. The tendency of production intensification is characteristic of many mines, particularly the mines of «SUEK-Kuzbass» have constantly growing face outputs that in some cases amount to 20÷30 kt/day. In Russia there is a significant number of mines with a gas hazard. Absolute methane inflow sometimes exceeds 150 m^3/min. For many mines the problem of methane safety is a central one. It includes many important aspects, one of which is a demand to develop and implement an effective technology of seam degassing. It is seam degassing that often serves as a constraint for providing safe mining conditions at high face output.

In Russia a wide and productive use has been found for methods of operational degassing, which imply that methane is recovered from depressurized coal mass and mined-out spaces in the process of coal extraction. Their efficiency is 70-80 % or even more. High efficiency of these degassing methods is due to the fact that most gas recovered from the coal mass is non-associated. Separate issues arising in this field have no fundamental scientific value, the efficiency of degassing process is provided mostly by adequate engineering support.

One of the key objectives in the field of providing methane safety in the context of rising face outputs is development of effective technologies of seam degassing, as under current geologic, mining and technical conditions its actual efficiency of 10-20 % [1, 3] is not always able to remove significant restrictions on the faces outputs from the viewpoint of gas factor and to provide high-efficiency development of gas-bearing coal seams.

Aforementioned field contains following research and practical issues waiting to be resolved:

• to develop methodic foundations of adequate and objective estimation of maximum permissible output of the production faces from the viewpoint of gas factor;

• to develop and implement reliable and efficient methods of assessment for main properties and state parameters of coal seams that can be used to justify maximum permissible outputs of production faces;

DOI: 10.18454/PMI.2017.1.125

• to justify selection methodology of degassing preparation technology for mine fields and extraction areas;

• to formulate practical recommendations on intensification of seam degassing for specific geologic, mining and technical conditions.

Forecasting methodology. Researchers and experts from National University of Science and Technology «MISIS» and «SUEK-Kuzbass» have suggested and justified objective forecasting methodology for permissible face outputs from the viewpoint of gas factor, which comprises estimation of methane inflow into production face area from all possible sources basing on fundamental physical laws, modern tools of mathematical modeling and results of in-situ tests of the main properties and state parameters of gas-bearing coal formation [2, 4].

It was presumed that at extraction depths less than 500÷600 m for practical calculations it is reasonable to describe the process of methane sorption – desorption using Langmuir equation, which accounts for methane transformation in filter pores and fractures of the coal seam from near-liquid state to a gas.

To estimate main parameters of gas transfer in the coal seam it is acceptable to use partial differential equations for single-phase methane movement in the porous media, reflecting the properties of a gas-bearing coal seam:

$$\operatorname{div}\left(\frac{C}{\mu}\rho \operatorname{grad} P\right) = \frac{\partial}{\partial t}\left[\Pi\rho + \frac{abP}{(1+aP)}\right],$$

where C –coal permeability, m^2; μ – methane dynamic viscosity, Pa·s; ρ – methane density, kg/m^3; t – time, s; Π – coal porosity; a, b – sorption constants in Langmuir equation; P – pressure of free methane in the porous media, Pa.

Mathematical modeling using modern software permits to carry out analysis of factors, defining maximum permissible output of the production face from the viewpoint of gas factor. Methane inflow into production workings is estimated depending on coal cutting speed, longwall length, coal seam permeability. The method has been implemented using programming language «MathCad-14».

Calculations have been carried out for the conditions of longwall 24-55 (coal seam «Boldyrevsky», Kirov mine, «SUEK-Kuzbass»), and they demonstrate that for set properties and main state parameters of the gas-bearing coal formation and high face outputs the major contribution to the methane inflow into the mined-out spaces of the production area comes from two sources – production face and loose coal. Methane inflow from the floor and ceiling of the mine does not exceed 5 %. The value of methane inflow permitted by safety rules (up to 13.1 m^3/min) for set conditions without efficient seam degassing is reached at face output above 8100 t/day.

To meet the target value of 10 000 t/day in the production area 24-55, preparatory seam degassing from development workings has been carried out.

Presented methodic approach and based on it analytical method of calculating maximum permissible outputs of production faces from the viewpoint of gas factor are aimed at practical implementation in operating coal mines by relevant units, having technical facilities to evaluate main properties and state parameters of the coal seam under development.

The most reliable way to estimate constants of Langmuir's sorption isotherm is laboratory tests. In case those are impossible, the constants can be calculated indirectly: judging by the rate of pressure increase in the well, using means of computer modeling and considering differential equations of mass transfer, Langmuir's constants can be obtained by solving an inverse problem. Obtained values can also be estimated using classifier of a specific basin or coal deposit as a source of advisory (supporting) information.

DOI: 10.18454/PMI.2017.1.125

Methane seam pressure can only be calculated in-situ by drilling wells, sealing their heads and measuring the rate of pressure increase in a closed well until it reaches the highest peak. In limited time maximal value of well pressure is decided using the method of approximation.

Permeability of the coal seam in the production face is assessed relying on the results of gas survey in the longwall during maintenance shift. It is also reasonable to specify natural volumes of gas in the coal seam due to significant errors at the stage of geological exploration (up to 30 %).

To analyze adequacy and efficiency of the developed method to define maximum permissible output of production faces from the viewpoint of gas factor, actual data has been used, including data on faces outputs and materials from the document «Schedule of production faces put into and out of operation», reflecting design values of monthly outputs for production faces «Boldyrevsky» and «Polenovsky» of the Kirov mine.

Input data for the analysis of adequacy and efficiency of the analytical method:

Longwall	2457	2592	2593	2594
Basic forecast (traditional for SUEK) of maximum permissible output, t	7840	3310	3480	6890
Forecast based on the analytical method of maximum permissible output calculation, t/day	8665	7063	6731	7409
Actual maximum permissible output on the production face, t/day	8667	5700	7452	7200
Amount of coal extracted, kt	560	1547	2386	3184

As an objective assessment criterion serves the indicator of volume weighted deviation from the actual value. The smaller the criterion, the more reliable the forecast is. Carried out analysis allows to state that the reliability of the developed analytical method is by 20 % higher than the basic method applied in «SUEK-Kuzbass».

It should be noted that such comparative assessment demonstrates only methodical correctness of the developed analytical method (forecast precision increases by 15-20 %) and its fundamental effectiveness; nevertheless, currently obtained numerical values cannot be considered reliable and representative due to great uncertainty in the input data. First and foremost, it relates to natural amounts of gas in the formation, seam pressure and sorption properties of the coal seams.

It is also worth mentioning that a reliable calculation method for maximum permissible output of production faces from the viewpoint of gas factor is an essential element in the selection of a seam degassing technology, as it permits to find the value of required seam degassing efficiency, which will secure the achievement of planned coal extraction rates.

As it was stated earlier [7], a justified selection of a seam degassing technology is fundamentally important. Formulated methodic recommendations on the selection of means of seam degassing under conditions of degassing preparation of coal reserves suggest a two-step solution:

First step:

• according to the company's strategic plan on face outputs (planned output), for each extraction block the feasibility of seam degassing is defined. The key moment here is constraints on the production face outputs from the viewpoint of gas factor, which are estimated basing on current regulatory documents and the developed analytical method. Practical output of this point is the calculation of required efficiency of seam degassing technology or required decrease in the amount of gas in the working seam planned for degassing and subsequent development;

• a time reserve for seam degassing is defined. This parameter permits to make a decision whether advance (in 3 years or more), preparatory (over 6 months) or operational degassing of the seam is most feasible in current situation. Efficiency of degassing schemes depends on the time left for methane extraction from the source of its inflow into the mine workings. Time factor predetermines limited efficiency of operational degassing technologies, that are coordinated with the main coal extraction processes, and potentially higher efficiency of advance degassing;

DOI: 10.18454/PMI.2017.1.125

• possible methane output from degassing wells is predicted, which allows to estimate the efficiency of existing degassing technology taking into account time reserve for degassing. Forecast of attainable methane output is made basing on fundamental laws of gas transfer (particularly, using the abovementioned formula or any other available approach, e.g. [3]) and experimental estimations of main properties and state parameters of the coal seam under rock pressure directly at degassing sites. Additionally, parallels can be drawn with objective efficiency of certain schemes of seam degassing, implemented in similar mining conditions.

Second step: scientific justification is offered for general technological scheme of coal seam degassing, the elements of which can be represented by various options of advance, preparatory and other types of degassing, as well as ways of their coordination.

An example of formulated recommendations on selecting means of seam degassing for the extraction block 24-59 of the Kirov mine:

First step	Second step
Value of «gas barrier»	Underground seam degassing (basic scheme)
Time reserve for seam degassing	Hydraulic fracture of the seam from development workings (supplementary scheme)
Forecasted efficiency of seam degassing (based on estimations of methane output from the well)	Auto-pneumo-stimulation: recommended method to intensify degassing

As a basic scheme it is recommended to use standard technology of underground seam degassing, carried out from development workings the same way it has been done for previous extraction blocks of this mine field. Implementation parameters of the standard technology are documented in operating Guidelines on coal mine degassing (2012) and in the design of mine degassing.

Justification of recommendations on the technology of underground hydraulic fracture (UndHF), carried out from development workings as a part of supplementary scheme, is based on positive results of experiments carried out under the supervision of the authors of this paper in Kirov mine (coal seam «Boldyrevsky», wells UndHF № 1-12) in 2015-2016 [5], where the efficiency of underground seam degassing preceded by hydraulic fracture amounted to 30÷40 %.

For some wells of underground seam degassing it is impossible to reach required efficiency of methane recovery, in such cases developed method of technology selection recommends to apply means that intensify gas emissions from degassing wells. For the extraction block 24-59 it was suggested to apply technology of auto-pneumo-stimulation (APS). To justify the recommendation to implement APS for intensification purposes, preliminary experiments testing and evaluating this technology [7] have been carried out in the extraction block 24-55. The idea behind APS is in periodical closing of degassing well in the course of its exploitation while it is securely sealed. When the well is closed, its pressure can rise up from 0.5 MPa or higher to the value of seam pressure (e.g., for the extraction block 24-58 estimated by the authors seam pressure amounted to 3.2 MPa), which promotes increasing permeability of the coal seam near well area. After APS eight experimental wells have been subject to a large increase in methane output (from 3÷8 to 22÷27 l/min), and these heightened levels were stable for several months afterwards, which had a positive impact on final efficiency of seam degassing.

In the method of selecting a seam degassing technology, as it was mentioned earlier, the first step starts from detecting and estimating «gas barrier», which is carried out using a developed analytical model of calculating maximum permissible output of production faces from the viewpoint of gas factor. Maximum permissible outputs of production faces, depending on residual gas flow of «Boldyrevsky» seam after degassing, longwall 24-58, have been calculated us-

DOI: 10.18454/PMI.2017.1.125

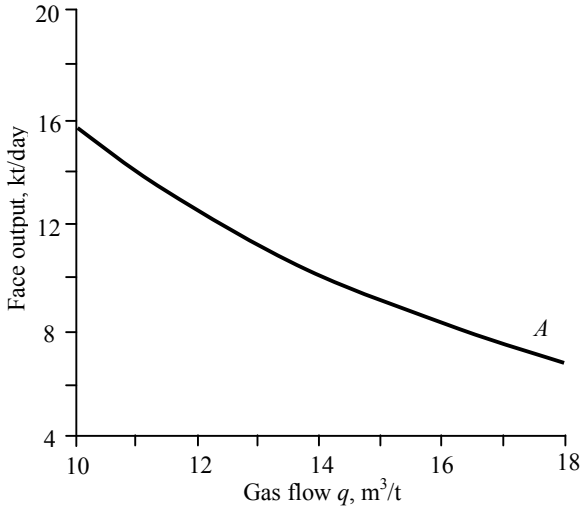


Fig.1. Face output depending on gas flow of «Boldyrevsky» seam, longwall 24-58

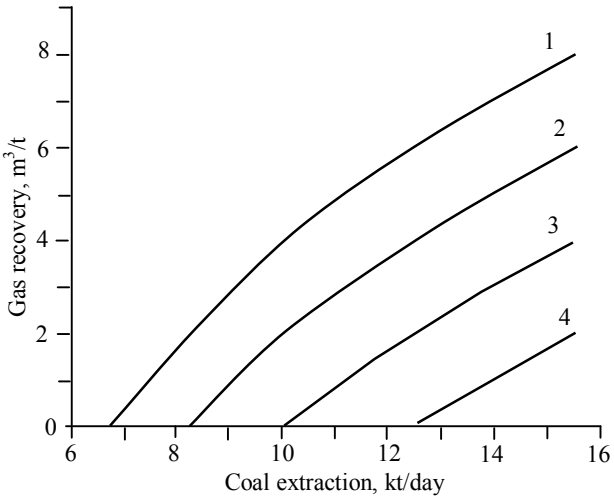


Fig.2. Methane recovery required to increase production face capacity
Initial gas flow of the coal seam:
1 – 18 m^3/t; 2 – 16 m^3/t; 3 – 14 m^3/t; 4 – 12 m^3/t

ing the developed method and are presented in Fig.1. It is easy to notice that, when seam gas flow is reduced to 11 m^3/t by suggested complex degassing, permissible output of the production face in longwall 24-58 rises to the mark of 14 kt/day.

A nomogram to estimate required methane recovery in the process of seam degasing (Fig.2) permits to make a reliable choice of seam degassing technology premised on required face output.

E.g., if it is reliably known that actual gas flow of «Boldyrevsky» coal seam in the extraction block is 14 m^3/t and the output is planned in the order of 11 000 t/day, then required intensity of degassing (required methane recovery in the process of seam degassing) will amount to 1 m^3/t. Such problem can be solved using standard technology of underground seam degassing by single or tandem wells drilled from development workings.

In case actual gas flow rate of «Boldyrevsky» seam in the extraction block reaches 16 m^3/t and planned output is 14 000 t/day, then required intensity of degassing (required methane recovery in the process of seam degassing) will be 5 m^3/t. According to available [1, 3, 6, 8] data on actual efficiency of different schemes of seam degassing, in this case as a basic scheme it would be most rational to recommend advance degassing of the coal seam (ADS) with wells drilled from the surface and hydraulic seam fracturing. The efficiency of this method can reach 40÷50 % and it can provide methane recovery at the level of 5 m^3/t and higher. As a supplementary scheme one can also recommend technology of underground seam degassing from development workings in zones of fracturing with an extended well grid, if required efficiency of the process is not to be achieved at the first basic stage of degassing.

Conclusion. After a general analysis of the situation in «SUEK-Kuzbass» mines, the following notes can be made. The highest production face outputs have been registered in «Kotinskaya», «Taldynskaya – West» и Kirov mines. From the viewpoint of gas factor two of them are of practical interest – «Kotinskaya» and Kirov mines. Analysis of constraints posed on the output of production faces by a gas factor for several extraction blocks of «Kotinskaya» and Kirov mines demonstrates that for most production faces (up to 80 %) seam degassing technology is required with design efficiency in the range of 10÷35 %. Under favorable conditions, such technology efficiency can be attained using means of preparatory degassing from development workings: from standard seam degassing technology without any active stimulation to supplementary stimulation, e.g., hydraulic fracture of the coal seams.

DOI: *10.18454/PMI.2017.1.125*

Based on research presented, recommendations on technological schemes and parameters of seam degassing for promising extraction blocks of Kirov mine field have been formulated and accepted for implementation.

REFERENCES

1. Baimukhametov S.K. Issues of Mining Safety for Coal Seams with High Gas Flow. Karaganda: Poligrafiya, 2006, p.201 (in Russian).

2. Mazanik E.V. Improvement of Coal Mine Degassing Technology Based on Advance Step-wise Well Preparation of Mine Fields: Avtoref dis. … kand. tekhn. nauk. MGGU. Moscow, 2010, p.22 (in Russian).

3. Karkashadze G.G., Ermak G.P., Yutyaev E.P. Gas Factor-based Safety of Gaseous Coal Mining by Accounting for Coal Properties and Mining Method Parameters. *Gornyi informatsionno-analiticheskii byulleten'*. 2014. N 5, p. 152-156 (in Russian).

4. Karkashadze G.G., Slastunov S.V., Ermak G.P., Yutyaev E.P. Preliminary and Real-time Forecast of Permissible Loads on Working Face at the Intensive Development of Gas-bearing Coal Seams. *Ugol'*. 2015. N 3, p.30-35 (in Russian).

5. Slastunov S.V., Yutyaev E.P., Mazanik E.V., Sadov A.P. Increasing Efficiency of Seam Degassing Basing on Hydraulic Fracturing of Coal Seams. *Gornyi informatsionno-analiticheskii byulleten'*. Special issue N 60-2. 2015, p. 408-418 (in Russian).

6. Slastunov S.V Technology Selection of Gas Emission Management in the Extraction Block under Degassing Preparation of Coal Seams to Safe and Efficient Development. Energeticheskaya bezopasnost' Rossii. Novye podkhody k razvitiyu ugol'noi promyshlennosti: Sbornik trudov XV Mezhdunar. nauchno-prakticheskoi konferentsii. Kemerovskii tekhnicheskii universitet. Kemerovo, 2013, p. 316-318 (in Russian).

7. Slastunov S.V. Intensification of Methane Recovery from Coal Seams Basing on Increasing Their Permeability in the Process of Periodic Sorption Deformations. Mekhanika gornykh porod pri razrabotke mestorozhdenii uglevodorodnogo syr'ya: Sbornik Mezhdunar. nauchno-tekhnicheskoi konferentsii. Permskii natsional'nyi issledovatel'skii politekhnicheskii universitet, 2015, p. 41-42 (in Russian).

8. Rzhevskii V.V., Bratchenko B.F., Burchakov A.S., Nozhkin N.V. Controlling Properties and State Parameters of Coal Seams to Prevent Main Mining Hazards. Moscow: Nedra, 1984, p.327 (in Russian).

Authors: **Sergei V.Slastunov**, *Doctor of Engineering Sciences*, *Professor*, *slastunovsv@mail.ru* (*National University of Science and Technology* «*MISIS*», Moscow, *Russia*), **Evgenii P.Yutyaev**, *general Director*, *mazanikev@suek.ru* (*JSC* «*SUEK-Kuzbass*», *Leninsk-Kuznetsky*, *Russia*).

The paper was accepted for publication on 22 November, 2016.