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Methane Problem of Coal Beds.

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ABSTRACT

The article analyzes current state and potentials of coal mining industry. The performed analysis revealed that the main restricting factor to increase application efficiency of up-to-date high-intensive equipment is the concern of gas. Main up-to-date approaches to solution of the gas problem of coal beds are discussed in details. The experience in the field of up-to-date degassing methods of high gas-containing seams in coal mines is analyzed. Efficiency increase in gas recovery of coal beds by means of gas permeability increase is considered: various methods of hydrodynamic impact on coal bed. Comparative analysis is carried out covering preliminary degassing of coal beds from surface and direct bed degassing from site coal pits, as well as increase in gas permeability of coal bed by pulse hydrodynamic impact upon degassing of coal bed. In order to achieve high efficiency of coal bed degassing via branch degassing holes the test procedures are described in the course of increase in efficiency of coal bed degassing in high gas-containing seams of coal mines. The article describes experimental results, analysis of these results and efficiency estimation of improvement of gas recovery of coal bed upon branch coal bed degassing. On the basis of performed experiments under actual conditions of operating coal mine the conclusions are obtained in the scope of approaches to optimization of the applied methods of degassing and determination of the most reasonable parameters of hydropulse impact on degassed coal bed.

Keywords: coal mining, gas permeability, methane safety, gas bearing capacity, degassing efficiency, pulse hydrodynamic impact, methane of coal beds, degassing holes.

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INTRODUCTION

Starting in the early 2000-s there is steady increase in global coal mining. This production growth amounted to 2.5 billion tons and achieved 7.1 billion tons in 2010. In the twentieth century the achievement of such level of coal production required seventy seven years. Increasing role of coal in global fuel and energy balance should be mentioned (in 2009 it again reached 30%). The growth of coal production and consumption in 2001÷2011 (Fig. 1) was provided by the countries of Asia-Pacific Region: in China – by 2138 mln. tpy; in India – by 246 mln. tpy; in Indonesia – by 233 mln. tpy; in Australia – by 82 mln. tpy (Berezikov and Bor, 2011; Burchakov, 2012; Magomet and Bor, 2014).

At present more than 62% of all global explored coal reserves are located in China, Russia and US.

While characterizing coal reserves in Russia it should be mentioned that they are presented by various coal types: lignites, bituminous coals, anthracites. Overall geological reserves are 6421 billion tons, including 5334 billion tons of standard quality coals. Bituminous coals amount to two thirds of overall reserves. The reserves of process fuel, coking coals, amounts to one tenth of total reserves of bituminous coals.

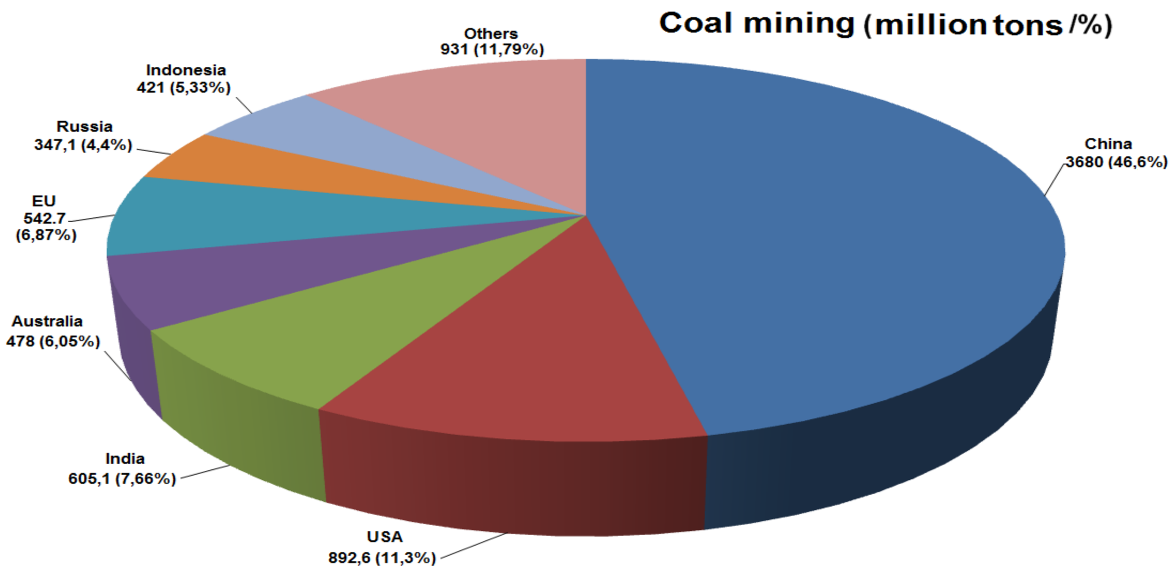

Figure 1: Coal production by major coal mining countries.

The coals are distributed highly heterogeneously over the country. The main portion of total geological coal reserves is concentrated in Tunguska and Lena coalfields. Commercial coal reserves are located in Kansk-Achinsk and Kuznetsk Basins (Berezikov and Bor, 2011; Burchakov, 2012).

In terms of coal production Russia occupies the fifth position in the World (after China, US, India and Australia), three fourths of the mined coal are use for power and heat generation, one fourth is consumed in metallurgy and chemical industry. Only minor portion is exported, mainly to Japan and Republic of Korea.

Modern trends of development of coal underground mining in Russia are mainly the same as in the rest of the World: high-efficient stoping and excavating equipment, which provides maximum concentration of mining operations in the scope of one bed and conversion to the structure "mine--longwall"; multi-entry development of working areas, promoting maximum use of capabilities of up-to-date high-efficient equipment; refuse to maintain entries behind longwall at the boundary with waste area.

Despite the obvious advantages of existing coal reserves, in the comparative analysis it is possible to mention that at present the total mining productivity of solid minerals in Russia is by 1.5÷4 times lower than in US, labor efficiency of miners is by 5÷10 times lower than in US, labor efficiency of miners at production sites is by 1.2÷2.5 times lower than in US (Burchakov, 2012; Magomet and Bor, 2014).

Modern conditions of underground coal mining determine the concern of gas as the main obstacle for increase in load on working face: high rates of advancing of working faces escalate the problem of management of gas recovery upon preliminary development. Occurring disproportion between preliminary and actual mining lead to significant decrease in mining technical and economical performances.

Increase in the mining depth (average annual increase in the depth of mines is 10÷12 m) is accompanied by concentration and intensification of mining operations (Burchakov, 2012). In its turn, the increase in the operation depth is accompanied by increase in gas bearing capacity of coal beds. Explosion hazard of methane-air mixture is one of the main hazards of coal field development. Ignitions and explosions of methane initiate explosions of coal dust with subsequent damages and numerous human fatalities. (In Russia the number of fatalities is about 0.5÷1.0 persons/mln. t of coal, which is more than by an order of magnitude higher than that in leading coal mining countries). This situation os mainly defined by the extent of solution of methane safety (Slastunov, 2011; Slastunov et al., 2012; Shmat, 2011; Lu T. et al., 2015; Hou B. Et al., 2013; Chen Y. et al., 2015; Zhao J. Et al., 2015).

In addition to the concern of methane safety, their outburst hazard significantly encumbers the development of coal beds, which increases with the development depth. This dictates the necessity to perform preliminary development with application of local anti-outburst measures. This circumstance leads to significant impairment of technical and economical performances operations: the rates decrease by 1.5÷2 times, the labor efficiency of mines is by 1.2÷1.4 times lower than under similar conditions but upon operations without hazards of unexpected outbursts of coal and gas (Mazanik, 2010; Puchkov et al., 2002; Puchkov et al., 2009).

The peculiar features of coal fields are as follows:

- existence of numerous coal sublayers, intermediate layers of fine vegetative detritus in embedding rocks (methane exists in all vegetative debris);
- low gas permeability of coals;
- existence of methane in coal in free form (filling of pores and cracks), adsorbed form and in the form of coal gas solid solution.

In generalized form the current problems of coal methane can be classified as three interrelated constituents: safety, environment and energy. The problem of safety, related with concern of methane, is determined by the level of management of gas release. At present the degassing system of coal mine is an inherent element of mining company. The use of efficient degassing methods of coal beds enables extraction of air-methane mixture with the parameters providing recovery of coalmine methane, which in its turn promotes development of energy concern (especially in the regions with severe climates) and environment concern (annual increase in amount of methane is about 1%, carbon dioxide 0.4÷0.5%, nitrogen oxides 0.2%) (Voloshinovskiy, 2012; Karmanskiy, 2009), Lu T. et al., 2015; Chen Y. et al., 2015).

The gained experience of preliminary extraction of coal methane demonstrates that gas recovery is influenced by high amount of natural and technogenic factors, among which it is possible to highlight the following major ones: natural gas permeability of coal bed; pore pressure of gas in coal bed; structure and properties of gas saturated coal beds and substance; stress-strain state of coal bed; temperature of coal and embedding rocks; tectonics of coal field and existence of specific areas in coal beds (increased fractures, decreased strains, and so on); water content of coal embedding mass and coal moisture content.

The portion of mines of the third category and lower exceeded 65%. Herewith, the existing experience evidences, that in gaseous mines capital investments per one ton of mined coal are by 25÷30% higher, and production costs are by 1.5÷2.5 times higher than in non-gaseous mines. In its turn, the load on working face and labor intensity of miner in gaseous mines are lower by 40÷60% and 25÷30%, respectively, than in non-gaseous mines (Burchakov, 2012; Magomet and Bor, 2014). Analysis of the existing experience of coal mining companies applying preliminary degassing of coal beds demonstrated that decrease in restriction to the concern of gas results in increase in coal production by 20÷50%. For instance, in US methane extraction from coal beds is considered as independent branch of gas industry, and in 2011 total amount of methane extracted from coal beds exceeded 55 billion m^3 (Magomet and Bor, 2014).

The Russian energetic strategy for the period up to 2020 includes development and implementation of innovative efficient environmentally safe technologies of utilization of non-conventional (gas hydrates, methane of coal beds and other) resources of carbon stock; engineering support of commercial utilization of coalmine methane; development of innovative technologies and equipment for efficient degassing of coal beds.

At present about thirty methods and engineering flowcharts of degassing have been developed and implemented, among which the following are the most popular: preliminary degassing of coal bed; degassing of waste space via surface holes; degassing of waste space and adjacent mines via holes bored from preliminary pits; barrier degassing.

The existing methods of preliminary and current degassing at modern rates of advancing of working faces and low permeability of developed coal beds become low efficient since there is no sufficient time for methane extraction from developed coal bed. As a consequence, frequent ignitions and explosions of methane in coal mines (four hundred and sixty five fatalities, including 85% after ignitions and explosions of methane).

The main approach to increase gas permeability of coal beds upon preliminary degassing is their hydraulic fracturing. This technology is based on opening of existing fractures in coal bed. In order to increase efficiency of hydraulic fracturing pulse impacts are used based on fuel-oxidizer mixtures and powder generators of pressure, which promotes colmatation of formed fractures in bottom hole area of coal bed (Aphanasiev et al., 2013; Belin et al., 2011). However, despite the fact that engineering procedures upon hydraulic fracturing are performed in several days, the development of holes requires for 5÷7 years.

Nevertheless, development and implementation of efficient coal bed degassing via surface holes in combination with extraction of coal methane in amount of at least 50÷60% for stress-relieved rock massif and 35÷40% for unrelieved rock massif with subsequent utilization of methane-air mixture in mine power facilities can be considered as one of the prioritized trends of the industry development. Efficient use of coalmine methane for energy production can provide increase in available power for mining companies by 20÷25% and, simultaneously, decrease in environmental damage resulting from hydrocarbon atmospheric releases by 40÷50% (Voloshinovskiy, 2012).

Despite obvious advantages, currently in Russia the preliminary degassing of stress-unrelieved coal beds is not widely applied, mainly due to prolonged periods of methane extraction and high costs of intensification and maintaining of methane influx into holes. While becoming more and more urgent, the aspect of intensification of commercial methane extraction from coal beds cannot be solved without increase in gas permeability of unrelieved rock massif.

The experience of Russian companies evidences that the current degassing with methane extraction from stress-relieved rock massifs is the most widely applied approach. Preliminary degassing of stress-unrelieved coal beds is not used due to low efficiency of this methods not exceeding 10÷15% (Slastunov et al., 2011).

While estimating the performances of modern applied methods and means of degassing, it is possible to highlight peculiar features: increase in gas evo0lution and more complicated conditions of application -- decrease in degassing efficiency due to increased economical constituent of this method of management of methane extraction.

While characterizing the efficiency of coal bed degassing, it should be mentioned that it directly depends on seam pressure and natural permeability of coal. Low natural permeability determines the depth of draining of coal field by pits and holes tens meters in depth, hence, degassing of stress-unrelieved seams requires for significant scope of preliminary operations and, this, prolonged time periods (10÷20 months). Increase in draining depth of coal field requires for a set of operations which can provide increase in its gas permeability (Korshunov et al., 2012).

The efficiency of preliminary degassing is determined by gas permeability of seam, hole spacing and total duration of their efficient operation. Increase in the depth of developed seams in combination with decrease in their gas permeability requires for increase in the density of hole boring. Capacity of degassing holes is maintained not by expansion of degassing application but, instead, by development of coal reserves with appropriate methane bearing capacity. Herewith, the fraction of thus extracted methane constantly decreases and at present does not exceed 6% (Slastunov et al., 2012).

Numerous variants of intensification of gas recovery from coal seams are known, based on various methods of impact on coal seam (hydraulic, mechanical,. physico-mechanical, microbiological and others). Most of them are not commercially applied due to low efficiency, complexity, high labor consumption and costs of operations (increase in development depth from 300÷400 m to 600÷800 m decreased the efficiency of preliminary degassing in Karaganda and Donetsk coal basins by 1.5÷2 times) (Berezikov and Bor, 2011; Burchakov, 2012; Magomet and Bor, 2014).

Increased load on stoping face promotes sharp increase in contribution of methane evolved from developed seam. Efficiency of up-to-date degassing of seam at the level of 10÷20% cannot eliminate significant restrictions on loads of stoping faces in terms of gas and provide methane safety (Korshunov et al., 2012).

In general, current challenges of monitoring and management of gas evolution can be formulated as follows: approach to monitoring and management of ventilation and degassing systems in methane-hazardous mines radically differs from those in safe mines; application of automated (permanent) air and gas monitoring; application of degassing systems with methane extraction efficiency from 40% to 75% with casual inspection of their efficiency; no automated monitoring systems of methane extraction, which prevents impartial assessment of gaseous environment; the applied calculation procedures of degassing systems and determination of gas amounts of rock developments are not perfect.

Taking into account all generated conditions in mining industry, further improvement of degassing efficiency under conditions of constantly increasing loads on stoping faces is possible only by means of methane extraction directly from developed coal seam.

However, low radius of hole influence, limited time of operation of seam holes significantly restrict efficiency of coal seam degassing upon underground mining (Voloshinovskiy, 2012; Korshunov et al., 2012; Puchkov et al., 2002). Aiming at increase in efficiency degassing of extraction site via site holes experiments were performed in an operating coal mine.

EXPERIMENTAL

The experiment was performed in June, 2014. It was planned to test possibility to increase gas recovery from seam degassing holes of Boldyrevsky coal bed in Kirov coal mine, Leninsk-Kuznetsky, Russia. The tested holes were bored from site preliminary pit, two holes per each twelve meters: one hole is bored in parallel to stoping face, the other hole -- with turning to stoping face at 60° to pit axis. The pit was partially affected by bearing pressure from previously developed pit and separated from waste space by a protective coal pillar, 50 m in width.

In the course of testing the holes were considered as inactive and switched off degassing system. Location and numbers of testing holes are illustrated in the map fragment (Fig. 2).

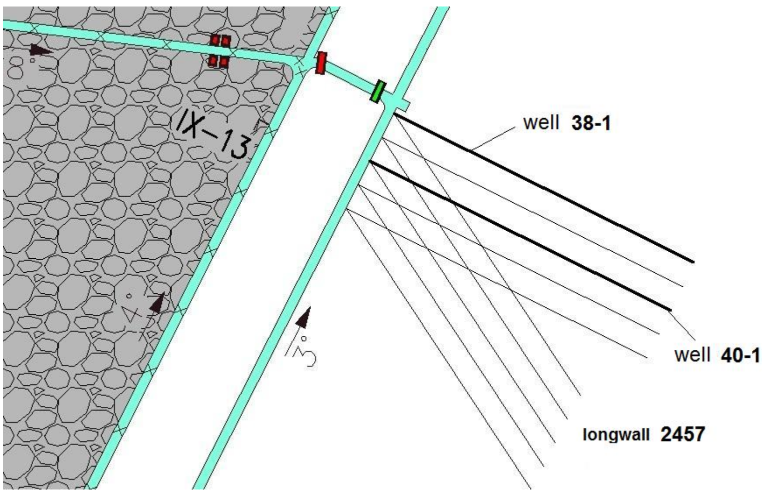

Figure 2: Map fragment of mining operations at testing site.

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The parameters of test holes are summarized below: length – 150 m; diameter – 93 mm; turning angle – 60°, 90°; angle of boring into the seam 1÷3°; inter-branch spacing – 12 m; inter-hole spacing in a branch – 0.3÷0.8 m; hole location depth – 397.8 m.

In the course of the tests the processed hole is cased to the depth of at least 10 m, borehole annulus is sealed by epoxy resin. Gate valve with pneumatic drive is mounted on the pipe casing.

Water is supplied to the hole by pumping unit. In order to increase pressure pulse amplitude upon cyclic hydrodynamic impact an additional hydraulic accumulator is used.

Hole filling is monitored by readings of injection pressure of liquid into the hole. The valve is equipped with pressure gauge before the gate. After filling of the hole the pneumatically driven gate is closed, the pump conitinues to inject water from fire tank into the hydraulic accumulator. Series of hydraulic pulses is repeated up to stoping of existing channels, which is confirmed by increase in the rate of pressure drop in hole and more rapid pressure drop after opening of the gate.

The test was performed on two horizontally bored holes #38-1 and #40-1. On June 28 the hole in branch #40 was tested, cased with drill rods and sealed by epoxy resin up to the depth of 10 m.

Before hydropulse processing of the hole methane concentration is measured, then the hole is filled with water and a series of hydropulse impacts is carried out. After that the methane concentration in the processed hole is measured and, subsequently, monitoring upon each shift during four days.

RESULTS AND DISCUSSION

Figure 3 illustrates the plot of variations of methane content in the test degassing hole #40-1 before and after hydropulse impact.

Measurement of concentration demonstrated that after hydropulse impact methane content in the considered hole decreased to 0%. However, further observations during the day revealed gradual increase in the gas concentration with achievement of the initial 0.2% in the third mining shift (0.15% in the second shift) and further increase in the fourth shift up to 0.34%, which exceeds the initial value by 70%.

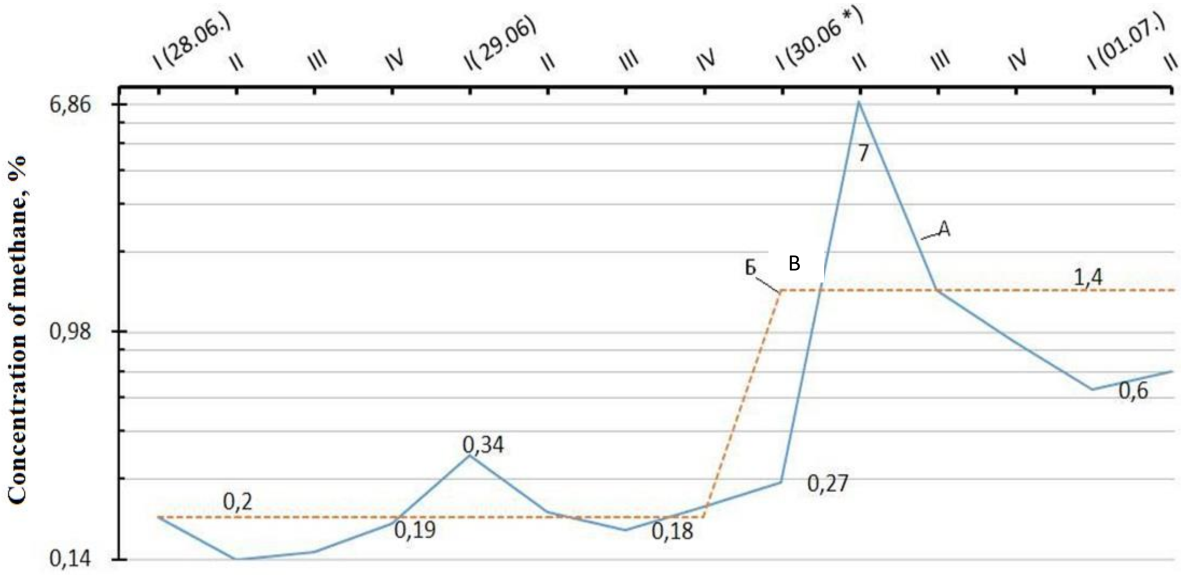

Figure 3: Variation of methane concentration in horizontal degassing hole #40-1 in time: A – variation of methane concentration in hole by shifts; B – background methane concentration in; I, II, III, IV – shift numbers; (28.06) – measurement dates; I (30.06*) – hydropulse impact on hole # 38-1.

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Analysis of the observation results demonstrates efficiency of hydropulse impact on horizontal hole bored horizontally in coal seam. This is manifested in steady increase in methane concentration in adjacent branch degassing holes bored in the coal seam horizontally and inclined. Moreover, the increased concentration remains during the day and, despite gradual decrease, it dies not reach initial values after 24 h..

Observations of methane concentration in inclined holes demonstrate gradual decrease in the gas concentration at the level above the initial after 24 h.

It should be mentioned that in the second day after hydropulse impact on hole #40 the average daily increase in methane concentration in the adjacent horizontal hole #41-1 with regard to the initial level (before hydropulse impact) was 11.88%.

The observed variations of gas concentration in holes #40-1 and #41-1 (and further in inclined hole #41-2) during the second shift can be considered as an evidence of generation and development of interlinked fractures in coal massif as a consequence of hydropulse impact, which promotes methane migration.

It should be also mentioned that, as in the first day of observations, the increase in methane concentration in the inclined degassing hole is more intensive than in horizontal one, and decrease in methane concentration is more gradual than in horizontal hole.

Variations in methane concentration in the considered holes, manifesting in plots for the second shift, evidence occurrence and influence of processes in coal embedding rocks, which can be activated as a consequence of mining operations, since no mining operations are carried out during the first shift.

After hydropulse impact the methane content in degassing hole gradually decreases (this is also peculiar for the adjacent holes), however, after 48 hours the methane concentration is not recovered to the initial level, that is, before hydropulse impact.

Measurement of methane concentration in the third day revealed excess of the performances in the first shift, that is, after 72 h the concentration in the hole is higher than the initial value by 2.1 times.

Step-by-step increase in рост methane concentration in degassing hole can evidence interaction of pores and fractures with newly generated fractures in coal as a consequence of hydropulse impact, which promotes methane migration in massif, additionally confirmed by variation of gas content in holes.

Methane content in the inclined degassing hole is higher than in horizontal one, since the methane content in inclined hole #41-2 after 48 h of hydropulse impact on hole #40-1 is by 56.7% higher than in horizontal hole #41-1.

Hydropulse impact on hole #38 resulted in increase in methane content in inclined hole # 41-2 by 17.4% higher than in horizontal hole #41-1.

CONCLUSIONS

On the basis of the performed work it is possible to conclude as follows:

- after hydropulse impact on hole the methane concentration in adjacent hole sharply increases, such increase is multifold in comparison with initial level (in the affected hole methane after hydraulic impact is not recorded, in adjacent holes the concentration increased by 75÷83%);
- after seventy two hours the methane concentration in degassed hole exceeds the initial values, and repeated hydropulse impact on adjacent hole leads to additional increase in the gas concentration in the hole with its subsequent decrease, though without recovery to the levels after forty eight hours;
- monitoring of methane concentration in the considered holes in three days demonstrated that in the first twenty four hours after termination of hydraulic impact on the hole there occurs gradual decrease in the methane concentration.

- taking into account sufficiently rapid decrease in methane concentration in adjacent holes (according to monthly monitoring of methane concentration in holes by Department of ventilation and mine safety), it is required to provide for certain periodicity of hydropulse impact on coal bed with consideration for mining and geological features of coal formation.

REFERENCES

[1] P. I. Afanasyev, E. P. Yutiaev, and A.S. Seregin, et al., "Justification of process variables of cyclic hydrodynamic impact upon preliminary degassing of coal beds," Mining Informational and Analytical Bulletin (scientific and technical journal) (Gornaya Kniga, Moscow, 2013. -#4).

[2] V. A. Belin, N. I. Gribanov, and A. A. Shilov, et al., Destroying Reservoir Beds by Combustion Energy of Condensed Systems. Guidebook (MGTU, Moscow, 2011).

[3] S. A. Berezikov and V. A. Tsukerman, "Engineering development of economy of Northern regions oriented at raw mineral resources: state, problems, and potentials," Mining Informational and Analytical Bulletin (scientific and technical journal) (Gornaya Kniga, Moscow, 2011.- #8).

[4] V. A. Burchakov, "Methodological approach to estimation of utilization level of potentials of coal mining company," Mining Informational and Analytical Bulletin (scientific and technical journal) (Gornaya Kniga, Moscow, 2012.- #4).

[5] K. I. Voloshinovskii, "Instrumentation systems for measurements of volumetric flow rate and operation parameters of methane and natural gas," Mining Informational and Analytical Bulletin (scientific and technical journal) (Gornaya Kniga, Moscow, 2012.- #4).

[6] A. T. Karmanskii, "Study into methane desorption upon saturation of coal by carbon dioxide," Zap. Gorn. Inst., St. Petersburg, SPGGI (TU), 2009, Vol. 183, pp. 285-288.

[7] G. I. Korshunov, A. I. Pal`tsev, and A.S. Seregin, et al., "Development of block and fracture structure in coal bed upon pulse and wave hydrodynamic impact," Mining Informational and Analytical Bulletin (scientific and technical journal), 2012. #4. C.109-113.

[8] G. I. Korshunov, A. V. Shipulin, and A. S. Seregin, Increase in Gas Permeability of Coal by Pulse and Wave Impact via Holes (Gazovaya Promyshlennost', Moscow, 20120, Issue 672, pp. 46-47.

[9] R. D. Magomet and N. A. Mironenkova, Development Trends of Fuel and Energy Complex for the Case Study of Coal Industry. In: Proceedings of R&D Conference "Innovations in monitoring, control, protection and safety management in mining industry," #2(516), Katowice, Poland, EMAG, 2014, pp. 44-51.

[10] E. V Mazanik, Improvement of degassing of coal mines by means of preliminary step-by-step bore preparation of mine fields: Doctoral Thesis: 05.26.03, (Moscow, 2010).

[11] L. A. Puchkov, S. V. Slastunov, and K.S. Kolikov, Methane Recovery from Coal Beds (MGTU, Moscow, 2002).

[12] L. A. Puchkov, S. V. Slastunov, and K.S. Kolikov, Aspects of implementation of methane safety in coal mines of Russia," Coal, 2009, - #1, pp. 28-30.

[13] S. V. Slastunov, G. G. Karkashadze, and Yu. M. Ivanov, et al., "Development of engineering recommendation on preliminary degassing of Boldyrevsky coal bed via coal pits in Kirov coal mine, OAO SUEK-Kuzbass," Mining Informational and Analytical Bulletin. Environment, methane safety,.2011, Issue 8.

[14] S. V. Slastunov, K. S. Kolikov, and G. P. Ermak, "Coal methane: production or degassing," Gas Industry, 2012, # 10, pp. 60-62.

[15] S. V. Slastunov, "Methane safety of Russian coal mines - key problem of coal industry," Mining Informational and Analytical Bulletin, Miner's Week, 2011 (Gornaya Kniga, Moscow, 2011).

[16] V. N. Shmat, "Management of gas recovery upon high-intensive mining of coal beds," Mining Informational and Analytical Bulletin (scientific and technical journal) (Gornaya Kniga, Moscow, 2011. - #7).

[17] Lu T., Wang Z., Yang H., and Han Y., et al., "Improvement of coal seam gas drainage by under-panel cross-strata stimulation using highly pressurized gas," International Journal of Rock Mechanics and Mining Sciences. 2015, Vol. 77, pp. 300-312

[18] Hou B., Chen M., and Wang Z., et al., "Hydraulic fracture initiation theory for a horizontal hole in a coal seam," Petroleum Science. 2013, Vol. 10, Issue 2, pp. 219-225.

[19] Chen Y, Liu D, and Yao Y., et al., "Dynamic permeability change during coalbed methane production and its controlling factors," Journal of Natural Gas Science and Engineering, 2015, Vol. 25, pp. 335-346.

[20] Zhao J., Thang D., and Xu H., et al., "High production indexes and the key factors in coalbed methane production: A case in the Hancheng block, southeastern Ordos Basin, China," Journal of Petroleum Science and Engineering. 2015, Vol. 130, pp. 55-67.