THE PROSPECTS AND OPPORTUNITIES TO USE COAL BED METHANE AS UNCONVENTIONAL ENERGY SOURCE

M.P. Yurova
Oil and Gas Research Institute of the Russian Academy of Sciences, Moscow, Russia

Abstract. The article shows that the gas from coal beds (as unconventional source) in the near future may become one of the most important suppliers of energy, not only in the coal regions of the country, but because of its demand, in the market conjuncture. The emphasis is put on materials of Russian researchers who seriously study the problem of methane production from coal beds in Russian regions. The urgency of this problem is not only that gas is not sufficient in remote coal areas of our country, but above all in the fact that the risk of methane explosions in mines and loss of life is reduced. At this, a large amount of pollutants is ejected into the atmosphere, worsening environment and increasing the greenhouse effect. The article shows the specifics of finding methane in coal beds. More than 85 % of the gas is in the adsorbed in state (linked to the rock matrix). The article show the basic differences of gas production from coal beds from the development of the conventional gas deposits. Coal beds can be of different brands. The most valuable are strongly metamorphosed coals (vitrinite reflectance of 80 % or more). Being a rock of organic origin, coal is a fractured porous media. Cracks are formed either during coalification of rock or by tectonic motions, so the layers are divided into blocks. The block has sorbed gas, stripping in a diffusion form. The cracks and micropores have free gas, moving in them in the filtration mode. Coal permeability depends not only on the number of cracks, but also on their disclosure. Efficiency of methane extraction is time, reservoir pressure, permeability, wellhead pressure, etc. There are several stages of methane extraction, corresponding to different stress-strain states of the formation. The paper gives a value (83.7 billion m^3) of gas resources in coal basins of Russia. Pilot commercial production of gas from coal beds has been carried out in Russia from 2010 on the Taldinsky field of Kuzbass, where it is simultaneously utilized for local needs.

Keywords: unconventional gas, specifics of gas-bearing coal, development methods, resources of the country, prospects
DOI: 10.18599/grs.18.4.10

For citation: Yurova M.P. The Prospects and Opportunities to Use Coal Bed Methane as Unconventional Energy Source. *Georesursy = Georesources*. 2016. V. 18. No. 4. Part 2. Pp. 319-324. DOI: 10.18599/grs.18.4.10

In recent years, the growth of energy consumption is constantly growing. According to the forecast of the International Energy Agency, demand for energy and electricity will grow by 50-70 %, respectively, in 2020 (Agapov et al., 2002). The specific amount of natural gas in the energy balance of the world in 2030 could reach about 30 % (Khryukin et al., 2009). In this regard, the recent interest in alternative energy sources is growing. One such source is a coal bed gas, total resources of which on the territory of Russia are up 83.7 trillion m^3 (Koshelets, 2012). Saving the trend for the production of the most affordable and cheap gas will lead to a transformation of the existing schemes to that shown in Figure 1. After several decades unconventional gas resources will become cost-effective and feasible (Figure 1) (Koshelets, 2012).

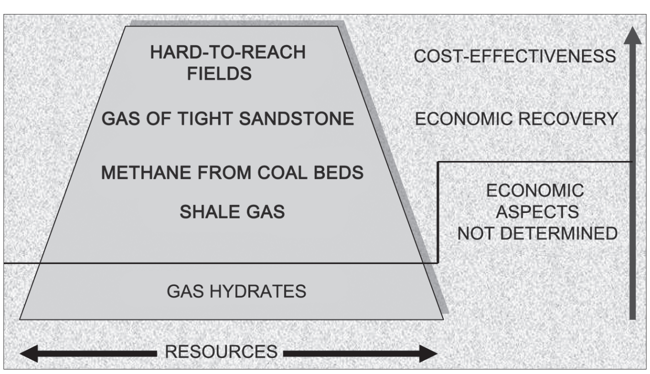

Figure 1. Forecast of the future structure of the global gas production.

The major developed sources are fossil fuels (solid, liquid and gaseous). Among them, coals and shales are the most proven in the commercial and exploratory stages. Advances of gas US companies allowed declaring the formation of the gas sub-sector in the extraction of methane from coal beds. The combination of the interests of the gas and coal industries can provide and significantly improve technical and economic, environmental and social conditions of the population of industrial areas.

Much attention and intensive development of this trend has been in the US for the last 10-15 years, where the volume of gas production from coal beds was up to 55 billion m^3 in 2010, in Canada – more than 9 billion m^3 in the same year. Australia has produced 5.5 billion m^3, China – 1.2 billion m^3, Russia – 6 million m^3 (Slastunov et al., 2012.).

Natural gas from coal beds for 90 % or more consists of methane. Methane is the cleanest of hydrocarbon energy sources; it does not contain harmful impurities such as nitrogen and sulfur compounds. Currently, commercial production of methane from coal beds is carried out only in the United States. More than 8 thousand wells are in operation, of which over 40 % are concentrated in the San Juan Basin. 10% of wells in this basin provide 75% of its production and 60% of the total annual production of coal bed methane in the United States (Khryukin et al., 2009).

The aim of such an approach in the United States is a degassing coal bed preparation rather than commercial production of methane. In some countries (China, India, Australia, Great Britain, Poland, Russia and Ukraine) there are pilot projects for development of gas resources from coal deposits (Ermolaev, Khaydina, 2008).

Materials of all kinds of coals (especially brown and others) contain various impurities, mineral components, sulfur, nitrogen, heavy metals, etc. During coal processing gaseous and aerosol products of oxidation of the carbon impurities fall to the atmosphere. Only during the energy coal combustion, each year about 90 million tons of sulfur oxide and 30 million tons of nitrogen oxide are ejected into the atmosphere. Together with ash, 60 thousand tons of lead, 50 thousand tons of nickel, 30 thousand tons of arsenic, and others pollute the atmosphere. The release of a relatively high proportion of CO_2 is a serious problem that causes the greenhouse effect and pollutes the atmosphere (Kreynin, 2008).

Methane is a negative factor in developing coal rocks, which leads to tragic consequences – loss of life, and its emissions pollute the environment, so the degassing of coal deposits with its subsequent disposal will help to reduce emissions of methane into the atmosphere and reduce the number of accidents in coal mines. In this case, the coal beds act as gas fields.

Conventional methods of production and consumption of coal turn coal regions into the ecological disaster zones. However, it should be understood that the flow rates of gas in coal beds are much lower than flow rates of gas fields, and the duration of operation of production wells will be determined by extraction rate of coal. In Russia only 10-12 % of methane is utilized that is released during coal mining and industrial extraction of methane from coal beds is not available.

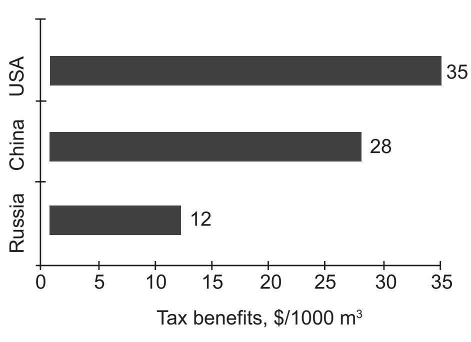

Figure 2. Comparison of tax benefits in the US, China and Russia.

The potential of coal beds in the Russian Federation is of limited use:

- Methane-air mixtures of vent streams are not used;
- The proportion of the methane-air mixtures use of degasification systems at the Vorkuta field does not exceed 40 % (boiler rooms use gas with a methane content of at least 25 %) in the Kuzbass – isolated cases of producing heat and power (mine named after S.M. Kirov, SUESK – Kuzbass) (Slastunov et al., 2012).

Despite strong interest in the development of coal bed methane in our country, the government support of this trend, as seen in Figure 2, is significantly (2 to 3 times) lower than in the United States and China. However, the results of gas production modeling from coal beds in the Kuzbass region have shown the importance of the legislative incentives for effective and rapid development of a new branch of the Russian fuel and energy complex (Khaidina, 2010).

The use of coal bed methane is greatly inferior to the conventional solid fuel (coal) production technologies. Technological solutions for the extraction of methane from coal beds are mainly based on the experience of the oil and gas industry. However, for efficient production of gas from coal beds it is necessary to take into account both natural and man-made factors. The specifics of the development of coal deposits is determined by the following factors (Slastunov et al., 2009):

- Geological conditions (deposit shape, the depth, temperature, gas pressure, etc.);
- Specificity of gas system – gas-bearing rocks;
- The possibility of further mining of coal beds.

Let us consider in more detail these features.

1. The basic form of the gas reservoir – reservoir arch, which is characterized by gas and the water displacement modes. In coal deposits marginal water is not available, the gas lies in shallow formations. Gas flow in the reservoir is determined only by its reservoir energy, which ranges from 2 to 6 MPa. Temperature of beds is 15-40 ° C at a depth of up to 100-1100 meters.

2. Coal deposits – coal of various grades. The porosity of coal beds does not exceed 5-8 %; at depths of 600-700 m coal beds are virtually impenetrable. Another feature is the interaction of gas with the gas-bearing rocks: 80-90 % of the gas is in a bound state, with different bound types (Table 1) (Slastunov et al., 2009).

Being a rock of organic origin, coal is a fractured porous media. Cracks are of different origin: either formed during carbonization, or by tectonic movements, due to which the coal beds are divided into blocks. The blocks contain mainly adsorbed gas, which is desorbed in the form of diffusion. The cracks and macropores contain free gas, moving along them in the filtration mode.

Fracturing, formed in the process of genesis, depends on the degree of metamorphism (vitrinite reflectance). Analysis of experimental data on methane adsorption on

Group	Form of gas saturation	Relative amount, %	Bound type	Energy of degradation, MJ/m^3
1	Free gas	5-6	Adhesive	0,09
2	Sorbed gas at surface and in macropores	8-10	Physical sorption	0,76-0,94
3	Sorbed gas in micropores Dissolved Gas crystalline	20-25 40-50 3-5	Volumetric filling Interstitial solution Chemical interaction	1,88-2,37 7,6-8,9 13,4-17,8

Table 1. The form and the energy of methane relation with coal.

Volatile yield	A (m^3/(t·K)) at p, MPa							
V, %	1	2	3	4	5	6	8	10
5	0,44	0,50	0,50	0,50	0,49	0,48	0,46	0,43
25	0,23	0,35	0,39	0,40	0,39	0,39	0,38	0,35
50	0,20	0,28	0,32	0,34	0,35	0,35	0,35	0,34

Table 2. The values of thermal methane adsorption coefficient.

coals shows the dependence of the sorption capacity of the temperature and is characterized by a coefficient A for coals of different metamorphic stages and at different pressures (Table 2) (Slastunov et al., 2009).

Analysis of coal degasification results shows that the maximum extraction of methane is observed in the mines, which produce mature coal (vitrinite reflectance of more than 80 %). Such coals emit methane during cracking on microcracks. Kinetics and gas-bearing of coal gas recovery are determined by factors such as the degree of metamorphism, depth, petrographic composition, mining and geological conditions of occurrence.

Coal structure comprises pores of 100 to 0.8 nm, with most of the porosity due to pore size, accordingly to methane molecules. Several classes of coal are identified by the nature of methane movement in different coal pores (Slastunov et al., 2009):

- Molecular pores (0.4-0.7 nm) are commensurate with the size of methane molecules (0.416 nm).

- Volmer pores (1-10 nm). The mean free path is less than the pore diameter of methane; therefore collisions of gas molecules with pore walls in such pores are greater than that between molecules.

- Knudsen pores (10-100 nm). In these pores the mean free path of the molecules is less than the pore size and the nature of the gas movement is molecular.

- Macropores (greater than 100 nm). These pores carry gas diffusion determined by the concentration gradient.

Cavitattion of coal related to fracturing is estimated at 3-12 %. The share of endogenous cracks is not more than 3 % of coal micro-cavitation (Slastunov et al., 2009).

Different parameters of coals fracturing (fracture density, fracture conductivity, etc.) correlate its permeability, which is directly connected with the degassing and methane recovery problems. The most important parameters of fracturing are: mean value of opening and density of cracks (or the average distance between cracks) (Table 3). (Slastunov et al., 2009).

The cracks and macropores contain free gas moving in the filtration process. 50-100 m^3/ton of gas can be released during the sudden release.

In order to increase the permeability hydrodissection-crack opening is conducted without a sharp drop in pressure. Closure of cracks is prevented by injection of the fixing material. In the near-well zone cracks re formed of 2-10 mm, the maximum crack opening is marked at a distance of 30-60 meters from the well (Slastunov et al., 2009). Hydrodissection differs from hydrofracturing with the fact that proppant is pumped into the pre-existing crack, unlike in made cracks in hydrofracturing. Development of a system of cracks in the coal bed exposed to the fluid pumping has several features.

The permeability of coal is determined not so much by the frequency of fractures, as the value of their opening. In this case the gas permeability of strong and tectonically undisturbed coals exceeds permeability of low-strength, highly tectonically disturbed coals for about 50 times (Slastunov et al., 2009).

Methane recovery efficiency depends on the time, formation pressure, permeability, pressure at the wellhead and other parameters. The high sorption capacity of coal and its low permeability determine the need for active exposure for effective methane recovery.

External factors influencing the sorption capacity, are pressure and temperature. The lower pressure and higher temperature, the lower the sorption activity of coal, so the efficiency of degassing binds with pneumatic force, thermal effects, and others.

Type	Degree of disturbance	Coal strength	Average distance between fractures in polished section, mm
I	Undisturbed	Strong	4,0
II	Low-disturbed	Quite strong	1,9
III	Highly disturbed	Incompetent	1,20
IV	Crushed	Soft	0,88
V	Abraded	Soft	0,56

Table 3. Classification of coal according to the degree of disturbance.

Indicators	Advance degassing	Production
Load increment on stope, mln un.fr.	3,3	-
Constriction of entries, mln un.fr.	under 0,4	-
Methane realization (at 100 y.e. /1000 м^3 CH_4) mln un.fr.	0,15	1,5
Greenhouse gas emission reduction, mln un.fr. / (thous. t CO_2)	0,18/(18)	under 0,23/(23)
Total:	4,03	1,82

Table 4. Economic indicators of advance degassing and methane production from coal beds (per well).

During the operation of the mine it makes sense to use complex methods of extraction of methane that combine ground wells drilled on the surface for reservoirs degassing, and underground wells, combined into a single system.

The basic principle of the concept of CBM mining – is a simultaneous extraction of methane at all stages of the development of coal deposits, taking into account changes in the filtration properties of coal bed under the influence of mining. It is proposed to allocate three stages of methane extraction, principally related to various stress-strain state of the reservoir (Puchkov et al., 2010):

1st period – production of methane from unbalanced array (mine design and construction);

2nd period – mine operation to the full development of reserves;

3rd period – complete gas depletion of the coal strata (extraction of methane from the old abandoned mine).

Since these periods are not clearly separated in time, it is the most efficient technology of using the same wells at all stages of the deposit development. This technology reduces gassing in a mine environment, also significantly increases the level of performance and safety of the miners, as well as reduces the cost of operations.

When closing the mines in the mine working a significant amount of methane is remained, 2-3 times greater than the selected volume. Gassing of them lasts many years to come. The solution is to use a stepwise approach to methane extraction during the entire period of development of the CBM field, which increases the efficiency of coal production by reducing gassing in the mine atmosphere, which raises the level of safety and performance, as well as reduces the cost of operations.

This technology should provide safe working conditions of miners, the economic benefits of coal mining and methane, beneficial use of methane produced, reducing the emission of methane into the atmosphere, which will significantly improve the ecological situation in the region. Table 4 shows the economic indicators of advance degassing and production of methane from coal beds (per well). According to these figures we can see the advantage of advance degassing (Slastunov et al., 2012).

Assessment and forecast of the main geological-field characteristics of coal beds is a non-standard task because of the complexity of the structure and form of methane being in the pore space (Desyatkin, Strelchenko, 2010).

In the first stage regional seismic survey is carried out and promising areas for coalbed methane production are identified. It is usually, 2D- or 3D-seismic survey. At the same time the results of regional and detailed seismic survey are interrelated. At the stage of the detailed work, detailed seismic profiling is carried out (when exploration wells are drilled in the CBM section) in order to build geological and geophysical models of the studied area. Geological and technological studies of wells include the study of mechanical speed, weight on bit, the dominant frequency of the drill string vibration, etc.

Geological-geophysical (including petrophysical) and technological research in the first stage of the study determine filtration-capacitive, mechanical properties, elemental and material composition of coal and coal-bearing rocks, as well as properties of such coals as volatile content, vitrinite reflection, humidity, gas saturation and others.

The gas permeability of coal beds is determined either by hydrodynamic methods, or on polished sections by the formula of Romm (Slastunov et al., 2009):

$$k_T = A\frac{b^3 l}{S} = Ab^3 L$$

where k_t – fracture permeability, 10^{-3} mm^2, A – numerical factor depending on the geometry of the fracture system, b – fracture opening width, mm, l – the total length of fractures, mm, S – area of the thin section, mm^2, L – specific length of fractures, mm.

Since the carbon core changes its characteristics when brought to the surface, the most common application received hydrodynamic methods.

In practice, the mining industry also uses a different parameter – the coefficient of gas or liquid filtration through the rocks. Filtration coefficient depends on coal grades (Table 5) (Desyatkin, Strelchenko, 2010).

Application of coal prospecting geophysics (V.V. Grichuhin) allows determining the material

Filtration coefficient, 10^{-5} m/min	Long-flame	Gas	Fat	Coking	Forge	Nonbaking	Anthracite
$K_{ф.max}$	4,24	3,50	13,70	3,50	3,27	3,40	9,70
$K_{ф.min}$	3,12	0,20	0,26	0,80	0,26	0,30	0,13
$K_{ф.ср.}$	3,68	1,45	2,45	1,54	1,30	1,63	1,74

Table 5. Limits of filtration coefficient change for various grades of coal.

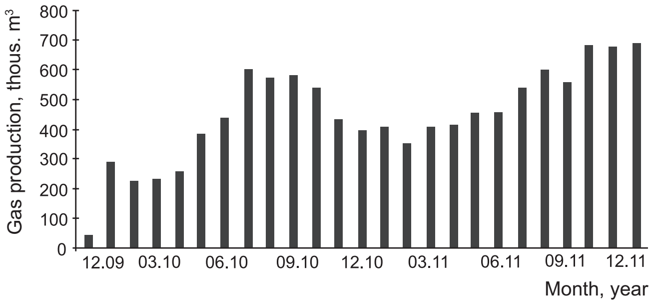

Figure 3. Extraction of coal bed methane in the Kemerovo region.

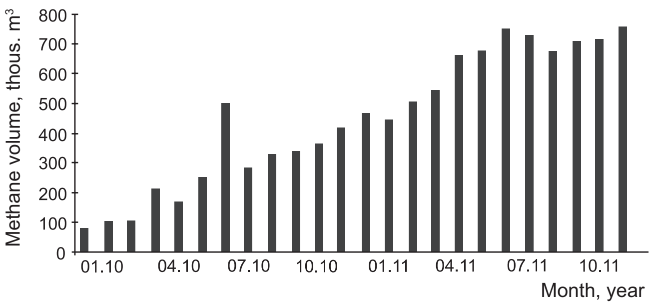

Figure 4. The use of coal bed methane in the gas-filling compressor truck station in the Kemerovo region.

and size distribution of the surrounding rocks, and stratificating the section. The results are used to construct geological and geophysical model – the basis for constructing hydrodynamic models, as well as for the calculation of reserves of coal and methane in the coalbed methane field.

Calculation of methane reserves in coal beds is a combination of the method of geological blocks normally used to calculate the reserves of coal and volumetric method of estimating reserves of gas (Puchkov et al., 2010).

Preparation of CBM fields to the industrial gas production involves three stages (Khryukin et al., 2009).

1st stage. Allocation of promising basins – large CBM fields. Preparation of feasibility study survey and assessment work on promising areas.

2nd stage. Selecting the most promising areas and places of laying exploration wells. Identification of the most promising permeable intervals.

Sampling of coal to assess their sorption and gas content. Selection of priority areas for exploration works.

3rd stage – Exploration: the trial mining, modeling to clarify the reserves, feasibility studies and field development process, flow diagram of pilot operation.

The main criteria to evaluate the high prospectivity of the basin are: the presence of large-scale resource base, high gas content and permeability, the presence of large gas consumers, efficient gas extraction technology from coal beds.

Russia has a huge variety of industrial resources on the quality of coal – from brown to anthracite. Total resources in coal bed methane of the main Russian coal fields, as described above, are estimated

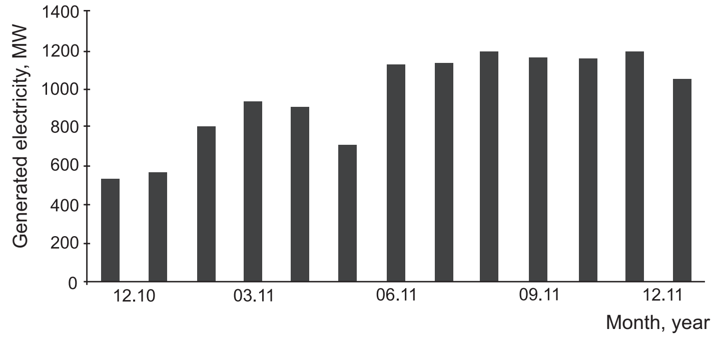

Figure 5. Electricity generation based on coal bed methane.

at 83.7 trillion m^3. Highly prospective basins include Kuznetsk (methane resources -13 trillion m^3), Pechora (1.3 trillion m^3) coal-bearing basins and Apsatsk mine with methane resources of about 55 billion m^3 (Khryukin et al., 2009).

The development of CBM basins such as the Tunguska, Lena, South Yakutia, Bureya, Zyriansky, will begin with a small-scale gas production to meet regional needs, although later to the development of technologies, extraction of methane will be produced and also be used as conventional gas deposits. In the case of the successful organization of gas fields in the highly prospective coal basins of Russia methane production level can reach 17-19 billion m^3 per year (Khryukin et al., 2009).

Industrial extraction of methane from coal beds is the science-intensive process and requires constant scientific support. From a scientific point of view, the problem of extraction of adsorbed methane in coal beds is not studied.

In Russia, production of coal bed methane on a commercial scale is at an early stage of its development (Surin, 2012). In the Kuzbass in 2009 JSC Gazprom has launched the first Russian field on methane production from coal beds on the Tallinn CBM field (Figure 3) (Surin, 2012).

On the first stage the task was worked out of trial operation of exploratory wells, equipment was selected that can be used in harsh conditions of Siberia, well modes were worked out, specialists were prepared, etc. Using the experience of the USA and Canada, own-patented designs were introduced that improve the performance of the wells.

On the field seven production wells are operated, new ones are drilled, technologies for using gas are developed. Sulfur components are completely absent in the composition of gas mixture. To meet the needs of the field and the population, gas-filling compressor truck stations are put into operation (Figure 4) (Surin, 2012).

The produced gas supplies not only to the gas-filling compressor truck stations, but also on the gas piston power plant for electricity generation for own needs of the local population and the field (Figure 5) (Surin, 2012).

In August 2010, exploration works started on Narykско-Ostashkinsky area of Kemerovo region.

The total capacity of 25 discovered deposits is 60-80 m, prospective resources of methane (Cat. C) – 153 billion m^3 (Surin, 2012).

Using the experience of drilling wells in Tallinn field, on Narykско-Ostashkinskaya multi well horizontal drilling is applied, which will allow improving the safety of miners due to the preliminary degassing of coal beds in mines under construction. Work is performed on the close cooperation of industrial organizations (JSC "Evraz", JSC "UK" YuzhKuzbassushl" and others) and design institutes (JSC "Gazpropromgaz", CJSC "Giprougol", etc.).

By 2025, it is planned to fully transform all Kuzbass consumers to the local gas (Surin, 2012).

Thus, in practice, it was able to demonstrate technological capabilities and the high demand for coal bed methane as an economical and environmentally friendly fuel. Pilot operation of Tallinn field continues.

Successful international experience, the availability of efficient technologies, a rich resource base, increase in the production cost of conventional gas, increasing demand for gas within the country and abroad – are the main factors of the necessity and feasibility of involving into commercial development of Russian CBM fields.

Technological solutions come to the foreground to optimize the cost, as well as an objective assessment of the prospects for production and sale of methane based on market conditions. And though it is premature to give an unambiguous assessment of coal bed methane prospects across the country, but it can be argued that Russia has all the necessary conditions to ensure that this new resource has become an important part of the future gas industry of the country (Koshelets, 2012).

References

Agapov A.E., Kaplunov Yu.V., Shpirt M.Ya. Parnikovye vozdeystviya gazoobraznykh produktov dobychi (pererabotki) ugley i osnovnye vozmozhnye meropriyatiya po ego snizheniyu [Greenhouse effects of light-end products of coal production (processing) and main possible mitigation measures]. Shakhty: YuGO AGN. 2002. 110 p. (In Russ.)

Desyatkin A.S., Strel'chenko V.V. Otsenka i prognoz osnovnykh geologo-promyslovykh kharakteristik ugol'nykh plastov dlya dobychi metana [Assessment and forecast of the main geological field characteristics of coalbed for methane production]. *Gazovaya promyshlennost' = Gas industry*. 2010. No. 7. Pp. 18-21. (In Russ.)

Ermolaev A.I, Khaydina M.P. Issledovanie degazatsii uglya i dobychi metana iz ugol'nykh otlozheniy [Study of coal degassing and methane production from coal deposits]. *Gazovaya promyshlennost' = Gas industry*. 2008. No. 1. Pp. 45-47. (In Russ.)

Khaydina M.P. Sovremennye problemy dobychi metana iz ugol'nykh otlozheniy [Modern problems of methane production from coal deposits]. *Gazovaya promyshlennost' = Gas industry*. 2010. No. 7. Pp. 12-13. (In Russ.)

Khryukin V.T., Storonskiy N.M., Sizikov D.A., Kiril'chenko A.V., Shvachko E.V. Zapasy metana v ugol'nykh plastakh – real'nyy rezerv rasshireniya syr'evoy bazy OAO «Gazprom» [The reserves of methane in coal bed – a real reserve of expansion of raw materials base of «Gazprom» JSC . *Gazovaya promyshlennost' = Gas industry*. 2009. No. 13. Pp. 17. (In Russ.)

Koshelets A.V. Ekonomicheskiy potentsial promyshlennogo osvoeniya resursov metana ugol'nykh plastov v sovremennoy Rossii [The economic potential of industrial development of coalbed methane resources in modern Russia]. *Gazovaya promyshlennost' = Gas industry*. 2012. No. 9. Pp. 86-89. (In Russ.)

Kreynin E.V. Ekologicheski chistye tekhnologii zameny prirodnogo gaza uglem [Green technologies of natural gas replacing by coal]. *Gazovaya promyshlennost' = Gas industry*. 2008. Special issue No. 8 (621). Pp. 83-85. (In Russ.)

Puchkov L.A, Sastunov S.V. Osvoenie uglegazovykh mestorozhdeniy: osnovnye tekhnologicheskie resheniya [Development of Coal and Gas Deposits: the main technological solutions]. *Gazovaya promyshlennost' = Gas industry*. 2010. No. 7 (648). Pp. 26-29. (In Russ.)

Slastunov S.V., Kolikov K.S, Agarkov A.V. Struktura ugol'nogo plasta i osobennosti izvlecheniya ugol'nogo metana [The structure of the coal bed and features of extraction of coalbed methane]. *Gazovaya promyshlennost' = Gas industry*. 2009. Special Issue No. 13 (633). Pp. 18. (In Russ.)

Slastunov S.V., Kolikov K.S., Ermak G.P. Ugol'nyy metan: dobycha ili degazatsiya [Coal Bed Methane: degassing or production]. *Gazovaya promyshlennost' = Gas industry*. 2012. No. 10. Pp. 60-62. (In Russ.)

Surin E.V. Razvitie dobychi metana ugol'nykh plastov v Kuzbasse [The development of coal bed methane production in Kuzbass]. *Gazovaya promyshlennost' = Gas industry*. 2012. No. 10. Pp. 63-65. (In Russ.)

Information about author

Margarita P. Yurova – PhD in Geology and Mineralogy, Leading Researcher, Oil and Gas Research Institute of the Russian Academy of Sciences

Russia, 119333, Moscow, Gubkin str., 3

Phone: +7(499)135-71-81, e-mail: mpyurova@mail.ru

Manuscript received October 08, 2016