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Prospects for industrial methane production in the mine n.a. V.M.Bazhanov using vertical surface wells

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The estimated methane resources in the coal stratum of Donbass are 798.5 billion m^3, including 119.5 billion m^3 in the Donetsk-Makeevsky area. Such significant potential implies that methane can be used not only for industrial production and energy purposes but also as a commodity for the chemical industry. However, in practice, commercial production of methane from coal seams, as is done in the fields of the USA, Canada, India, and China, is not carried out, and methane, obtained as a by-product, is utilized for ensuring the safety of the main technological processes for coal mining. The main reasons for this are the difficult mining and geological conditions of bedding, low thickness and permeability, which does not allow to separate methane production into an independent type of activity due to its low profitability, especially with the use of new technologies based on hydraulic fracturing of coal seams.

The assessment of the possibility of industrial methane production in the mine n.a. V.M.Bazhanov in the Donetsk-Makeevsky area of Donbass, which reserves equal to 23.7 billion m^3, showed that a significant part of the methane reserves is concentrated in coal seams and interlayers with a gas content of 18.5-20.7 m^3/m^3. Moreover, in the host rocks, methane is practically in a liberated state. This circumstance makes possible the commercial production of methane for its utilization from the unloaded rock mass by wells drilled from the surface, without the use of hydraulic fracturing technology.

The paper discusses the technology of methane extraction by a degassing well drilled from the surface into a coal-bearing stratum unloaded from rock pressure in a mining field of the 4th eastern face of the m_3 seam of the mine n.a. V.M.Bazhanov and its subsequent use as the fuel of an electric generator. It is shown that over the entire period of operation of the pilot well, the volume of actually produced methane exceeded the design value by 23 %, and the cost of the gas produced amounted to 1535 rubles per 1000 m^3, which is more than 3 times lower than the market price for natural gas for consumers in the Russian Federation. This made it possible to make a conclusion about the possibility of industrial extraction of mine methane using vertical surface wells for its subsequent utilization in power plants, which does not imply the usage of hydraulic fracturing technology.

***Key words*:** coal seams; methane; carbonaceous stratum; gas content; degassing; surface well; mining technology; electric generator; cost price

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Introduction. The Donbas coal-mining industry is mainly represented by coal mines. Many of them are highly gas-bearing (50-100 m^3 or more gas per ton of mined coal) and primarily contain methane, which is heavily occluded in coal seams ("Coalbed Methane" according to international terminology [16]) and dispersed in rocks with inclusions of coal substances. The calorific value of 1000 m^3 of methane is equivalent to burning 1.3-1.5 tons of coal. As a result, with the right approach to the degassing of coal seams and gas processing, methane can become a very significant source of unconventional fuel.

The idea of coalmine methane utilization is not new. It first appeared in the second half of the 20th century, and its implementation was aimed at solving two overriding priorities: to secure the coal mining and to get an additional source of energy. According to research results, the estimated methane resources in the coal stratum of Donbass are 798.5 billion m^3, including 119.5 billion m^3 in the Donetsk-Makeevsky area [4, 8]. The methane captured in the mines of the Donbass is mainly used to supply the energy needs – the generation of electricity and heat, as well as refueling cylinders for vehicles. At some mines, they use captured methane as a fuel for gas power generators for heating the ventilation shafts of coal mines [1, 13]. Recently methane has become the object of the sales agreements dealing with the greenhouse gas emissions, as shows the proven experience in the utilization of mine methane at the mine n.a. A.F.Zasyadko (Donetsk) [2]. In addition, methane can

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also be sold as raw material to produce methylene chloride and its derivatives: chloroform, carbon tetrachloride, ammonia, acetylene, hydrogen, methanol, nitric acid, formalin, etc. [10]. Expanding the use of methane, i.e. potential for utilization, contributes to the achievement of the strategic goal – reduction of global greenhouse gas emissions to mitigate the effects of climate change, recognized by the world community as one of the priority tasks [12]. We should also consider the global trends of structural changes of energy consumption and strengthening of ecological requirements in energy industry [19], which makes the task of expanding the methane application even more relevant.

The widespread implementation of coalmine methane utilization technology in the mines of Donbass, especially for generating electric energy, is hindered by the high cost of imported equipment, as well as the significant maintenance costs of degassing wells and computer systems for controlling gas flows of underground coal seam degassing systems [11]. Another significant reason is the difficult geological conditions of the Donbass, which does not allow to separate methane production from coal seams into an independent activity due to its unprofitability. In this regard, only a small proportion of methane (as a by-product) is utilized as a part of the safety measures of the main technological processes of coal mining.

The reverse situation with methane extracted from coal seams is true for the USA, Canada, India, China, and other countries. In Alabama, for example, since the late 60s of the last century, methane is mined for providing households with energy resources on a commercial basis after preliminary cleaning and applying required safety measures [17, 18]. Moreover, methane production technology is fundamentally different from that adopted in the Donbass, where methane is mainly captured using underground degassing systems [5, 14]. So, to create a permeable zone the coal mass is subjected to hydraulic treatment through horizontal wells drilled from the surface. Through the resulting network of microcracks, gas is drained to vertical production wells, then reaches the surface, goes through the processing stage and is supplied to the consumer (Fig.1). The degree of methane extraction of this production technology is up to 80 %. The fact that coal seams, in contrast to the coal seams of the Donbass mines, reaches a thickness of 20 m and has high permeability also contributes to a high degree of methane recoverability.

The methane extraction technology described above, based on hydraulic fracturing of a coal seam, is not applicable for the mines of Donbass due to the above-mentioned reasons and environmental issues. However, in addition to underground degassing systems, in Donbass methane is also produced through wells drilled from the surface. Capturing is carried out from unloaded coal seams and coal-bearing rock mass unloaded from rock pressure. Pilot testing of these methods was successfully performed at the mine n.a. A.F.Zasyadko of SE "Donetskugol", where they use the system of underground degassing and wells drilled from the surface up to 1300 m long [7]. It is noted that methane with a concentration of 90-95 % is extracted by wells drilled from the surface, while wells drilled from underground workings are used to extract methane with a concentration of not more than 25-60 % [3].

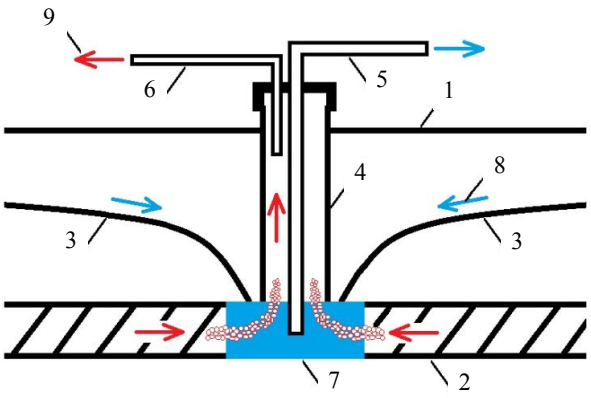


Fig.1. Methane production using surface wells and hydraulic fracturing technology

1 – surface level; 2 – coal seam; 3 – well creating hydrostatic pressure of water; 4 – production well; 5 – water supply pipe; 6 – methane supply pipe; 7 – fracture area of a coal seam; 8 – water flow direction; 9 – methane drainage direction

According to the results of geological research, the estimated amount of coal-bearing methane reserves at the mine n.a. V.M.Bazhanov in the Donetsk-Makeevsky district of Donbass is 23.7 billion m^3, 83.8 % of which are coal seams and sheds, the gas content of which ranges from

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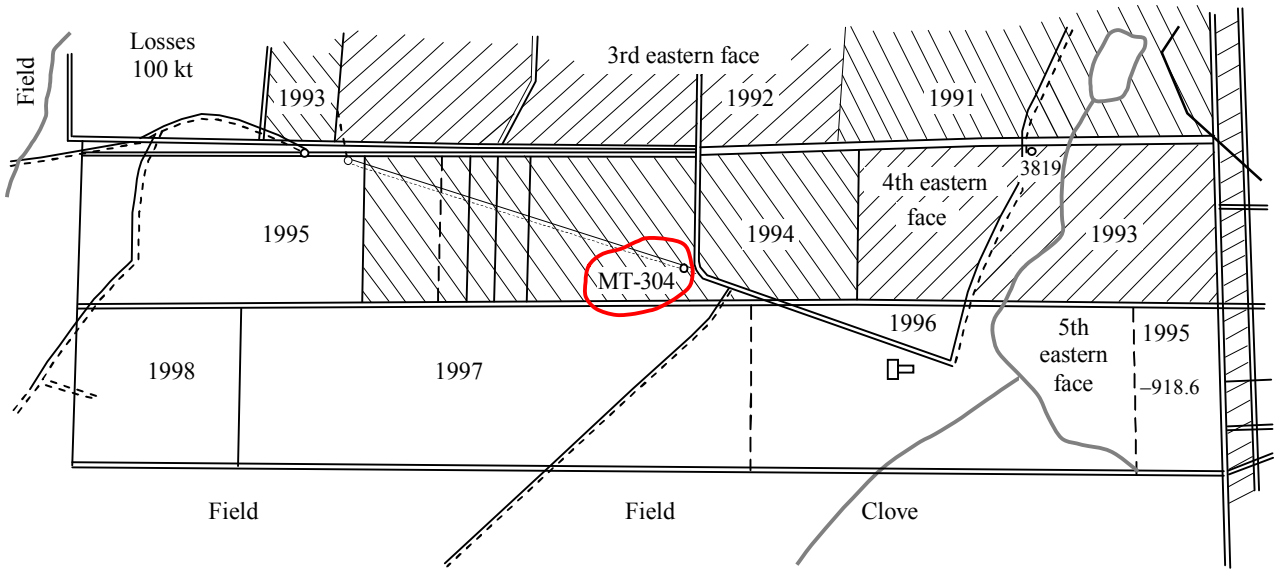


Fig.2. A copy of mining operations plan at the 4th eastern face (m_3 seam) combined with land layout

18.5-20.7 m^3/m^3. It should be noted that methane in coal seams is mainly in the occluded state (the amount of free methane in the pores and cracks of coal seams does not exceed 20-35 % of their total gas content), and in host rocks, on the contrary, almost all methane is in a liberated state. Thus, the methane extracted by surface wells from unloaded coal seams without the hydraulic fracturing technology has practical importance for using methane in power plants.

Formulation of the problem – the goal is to test the technology of producing methane from a carbonaceous rock unloaded from rock pressure through a surface well and the possibility of achieving design modes in geological and mining conditions of the mine n.a. V.M.Bazhanov.

Methodology – monitoring the operation of a pilot well for methane production and its subsequent use as a fuel of an electric generator (EG) operating on gaseous fuel during the entire life cycle of the well.

Discussion. The pilot testing of methane production technology from a coal-rock mass unloaded from rock pressure by a surface well was carried out in the conditions of the mine n.a. V.M.Bazhanov on the field of the 4th eastern face of the m_3 seam (Fig.2).

The coal seam m_3 was mined using an inward continuous development system. The length of the panel mine section is 1400 m, the length of the face is 250 m. The extraction of coal in the face was carried out by the 1GSh-68 heading machine, which is part of the mechanized complex 1KMT. The roof management is a cave-in system. The ventilation diagram is return-flow with freshing air-floor (type 2-B according to [6]). The average load on the face is 900 tons/day.

The mining area of the coal seam m_3 is not hazardous in terms of coal and gas emissions, prone to spontaneous combustion, and hazardous due to explosions of coal dust. The natural gas content of the m_3 coal seam in the face area is 20.7 m^3/t of dry ash-free matter. The coal has the following qualitative characteristics:

- thickness – 1.6-1.8 m;
- ash content – 10 %;
- humidity – 0.8 %;
- volatile content – 27.0 %;
- bulk density – 1.52 t/m^3.

The seam roof m_3 has 14 coal seams with a total thickness of 23.8 m (Table 1) and thick layers of gas-bearing sandstones (Table 2).

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Table 1

Description of layers undermined by the 4th eastern face

Seam	Stratification depth, m	Thickness, m	Distance from the seam, m	Seam	Stratification depth, m	Thickness, m	Distance from the seam, m
m_4	1085.6	0.3	23.0	m_6^0	873.6	0.2	261.4
m_4^0	1062.6	0.2	72.4	m_6^2	815.0	0.2	320.0
m_4^1	1023.4	0.2	81.6	m_4^3	789.2	0.5	345.8
m_4^3	984.8	0.2	120.2	m_7^0	771.6	0.7	363.4
m_4^5	951.6	0.2	153.4	m_8^0	753.0	0.2	382.0
m_5^1	930.4	0.6	204.6	m_9^0	693.4	0.2	451.6
m_5^2	902.0	0.2	233.0	–	–	–	–

Table 2

Description of gas-bearing rock

Symbol	Depth of occurrence, m	Thickness, m	Effective porosity, %	Gas bearing capacity, m^3/t
$m_4^0 \int m_4^1$	1061.4	23.0	1.73	4.0
$m_4^1 \int m_4^3$	1020.5	16.5	1.97	3.0
$m_4^3 \int m_4^5$	972.0	6..5	1.38	3.0

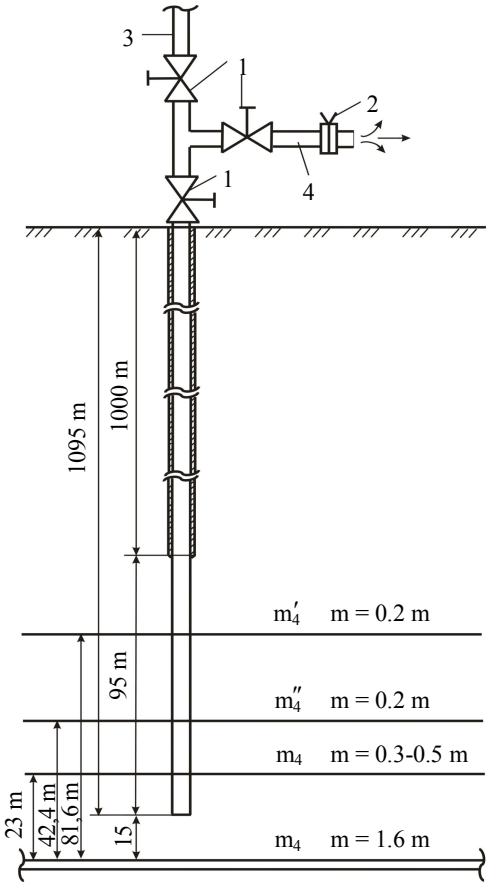


Fig.3. Technological scheme of degassing of undermined coal seam m_3 with pilot well MT-304

1 – valves; 2 – means of pressure and gas flow control; 3 – "flare"; 4 – pipe for supplying methane to consumers

For pilot testing of gas production technology at the mine n.a. V.M. Bazhanov there were developed the project and constructed the MT-304 well (Fig. 2). Technical characteristics of the well construction project technology are the following:

- well depth – 300-1200 m;
- diameter of operation well – 102-146 m;
- gas inlet length – 50-120 of developed seam thickness;
- bottom diameter of well – minimum 98 mm;
- distance from well face to developed seam roof – 15-50 m;
- distance between well and housing (production) premises – minimum 100 m;
- thickness of production string wall – minimum 6 mm;
- thickness of gas inlet section coupling wall – minimum 4 mm;
- expected average well production – 3.5 m^3/min;
- average well operation time – 250 days.

The gas production technology consisted of drilling specially designed wells in the currently mined panel section. The well location was chosen so that the projection of its bottom on the m_3 seam was not closer than 50 m and not further than half the length of the working face. The well construction was completed before the face was close to its bottom. During drilling geophysical studies were carried out to determine aquifers and gas pressure. Based on the results, the string casing depth and the grouting of the annulus were

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determined. The casing depth was taken from the conditions of all worked out spaces and aquifers crossed by the well. The lower part of the well, passing through aquifers and rocks, was secured with a perforated pipe. The depth of the well was taken so that the gas inlet section intersected all the produced seams, while the bottom of the well was located not closer than 30 thickness values of the developed coal seam. Drilling was carried out with light washing fluid. After drilling was completed, the well was washed up to clean water. When approaching the face, water was removed from the well. The wellhead was equipped with a valve tee and a means for monitoring pressure and gas flow (Fig.3). After the underworking of the well with the face and unloading the underworked mass from the rock pressure, the gas entered the well, so it was possible to determine its chemical composition and conditions of supplying to the consumer.

The decision to use gas as a fuel for EG was made immediately after well testing, which showed that the gas pressure and flow rate are sufficient to ensure the operation of the gas turbine. The gas turbine power station EG 1000 manufactured by Motor Sich Company (Ukraine) was adopted as an electric generator [15]. Characteristics of the gas turbine EG-1000 power plant are the following:

Power plant capacity with a daily supply of 14,000 m^3 of gas, kW·h	1000
Current type	three-phase alternating
Voltage, kW	6.3
Current, A	51
Power factor	0.8
Power consumed for needs of ventilation shaft substation, kW	30
Frequency, Hz	50
Minimal gas pressure at the inlet, kg/cm^2	7.0

Before the start of the EG, the flow rate of the gas leaving the well and its composition were controlled. The measurements were carried out at a methane flow rate of up to 1.5 m^3/min with an Orifice plate, the high flow rates were controlled with diaphragms with openings of 5 and 3 mm. The latter was installed in order to reduce the release of gas into the atmosphere and save it for the electric generator (complete closure of the well could lead to filling with water and then subsequent cessation of gas emission).

After the installation of the EG, the well worked periodically, the gas pressure at the mouth was 0.7-2.23 MPa. At the same time, gas flow rate, pressure drop, EG output power and the amount of generated electricity were controlled (Fig.4).

The graphic integration determined that 1.38 million m^3 of gas, mainly methane, was released through the well in 280 days after the start of gas production. The chemical composition and content of gas trapped in the MT-304 well is as follows, %: He – 0.1225; H_2 – 0.1164; CH_4 – 93.5; C_2H_4 – 3.09; C_3H_8 – 0.729; C_4H_{10} – 0.098; C_5H_{11} – 0.089; C_6H_{12} – 0.1; CO_2 – 0.1; O_2 – 0.3; N_2 – 0.8. The maximum gas flow rate was 10.2 m^3/min, the average flow rate for 280 days of continuous operation of the well was 3.42 m^3/min.

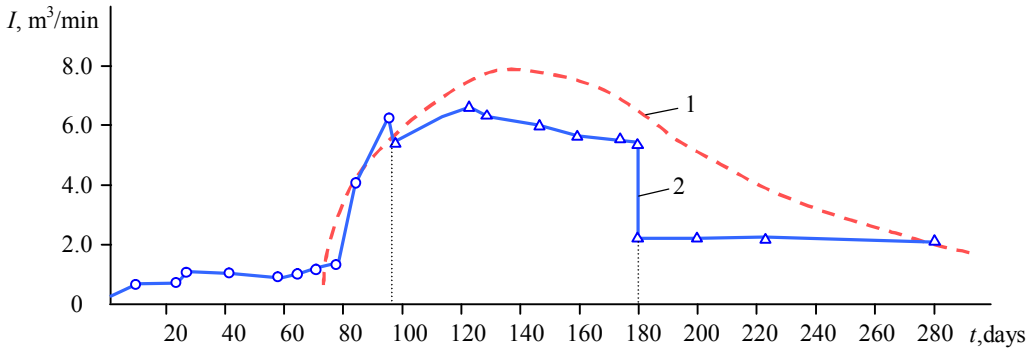


Fig.4. Gas flow rate at the MT-304 well
1 – estimated free flow rate; 2 – actual rate with controlled flow

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The amount of combustible substances in the composition of the gases is 97.5 %, the calorific value is 35659 kJ/m^3. During its periodic operation, the electric generator generated 196.2 kW·h of electricity and consumed 216 thousand m^3 of gas (Table 3).

Table 3

Electricity generation and gas production

EG operation time, days	Electricity generation, thousand kW·h		Average output, kW	EG operation time, h/day	Gas output, thousand m^3	
	Total	Daily			Total for the observation period	Daily
8	17.55	2.2	709	2.75	22.6	2.82
16	51.9	4.3	302.4	4.8	64.9	5.29
23	67.9	1.6	704.6	2.3	84.9	2.0
36	82.7	1.48	703.8	2.1	99.7	1.48
46	97.46	1.53	708.9	2.1	114.5	1.48
56	112.76	1.57	715.0	2.2	129.8	1.53
66	188.42	1.5	711.5	2.2	145.5	1.57
76	143.45	1.5	713.5	2.2	160.5	1.50
86	157.22	1.38	733.1	1.9	174.4	1.39
96	171.44	1.42	748.9	1.9	188.8	1.44
106	185.12	1.27	741.8	1.9	213.8	1.5
116	196.2	1.13	605	1.8	216.0	1.22

Totally in 400 days of well operation, 1.596 thousand m^3 of gas was produced. Well construction costs amounted to 2.45 million rubles. As a result, the cost of produced gas was determined as the ratio of the cost of the well construction to the volume of captured methane, which amounted to 1.535 rubles. per 1000 m^3. With an average price of natural gas for consumers of the Russian Federation about 4991 rubles per 1000 m^3 [9] the profit from the operation of the MT-304 well for 400 days amounted to 3.42 million rubles.

Conclusions. The pilot testing revealed a real possibility of industrial production of mine methane in the mine n.a. V.M.Bazhanov by vertical wells drilled from the surface, without the use of technology of hydraulic fracturing of the coal seams. The extracted methane was used as fuel for electric energy generators. During the operation of the electric generator, 216 thousand m^3 of gas was consumed, which made it possible to generate 196.2 thousand kW·h of electricity, which was used for domestic consumption of the coal mining enterprise. The volume of actually produced methane for the entire life of the well exceeded the design value by 23 %, and the cost of gas obtained was 36.2 % lower than the amount required by technical design specification.

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