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Assessing the impact made by the geological features of a coalfield on producing well's operation

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Abstract

Introduction. *Coalbed methane extraction increases the economic efficiency of coal mining being a main measure mitigating coal mining risks. Research aim was to assess the impact made by host rocks with different reservoir properties on coalbed methane production dynamics before and after hydraulic fracturing.*
Methodology. *A coal seam model has been constructed using software systems; the coal seam has been represented as an integrated deposit of two minerals, coal and gas. Gas production scenarios with and without impact on the seam have been calculated as well. A model of a coal bed with a hydraulic fracture was constructed in application program package Petrel (Shlumberger).*
Results. *The calculation results showed the development of gas migration from the coal matrix to the surrounding rock through the fracture system during gas production. The use of hydraulic fracturing has positive impact on the dynamics of gas production from coal seams. Hydraulic fracturing revealed the growth of desorbed gas migration into the host interlayers. Analysis of coal methane migration to the surrounding rock has shown that the host rock can be considered as a transportation route for coalbed methane production.*

Key words: *coal seam; adsorption; hydraulic fracturing; host rock; double porosity; coal gas migration.*

Introduction. The unfavorable factors, coal and gas outbursts and mines' deformations, become greater as the depth of coal mining becomes deeper.

The solution to gas and rock outbursts problem is complicated by the fact that a coal seam with adsorbed methane is a fractured-porous medium that includes a genetically and spatially linked system of organic matter of coal, absorbed gas, gas-saturated water, and natural fractures in coal (cleavage) [1–3].

Coalbed methane extraction increases the economic efficiency of coal mining being a main measure mitigating coal mining risks.

Methane production is particularly difficult at the preparation stage, when the coal bed is not much affected by the development and there is no developed network of degassing channels. Insufficient degree of degassing at this stage contributes to further increase of risk of catastrophic results of gas-dynamic phenomena and decrease of productivity of coal mining [4–5].

Efficient and cost-effective recovery of methane out of coal seams by wells drilled from the surface is achieved by applying advanced technologies of hydraulic fracturing, pneumatic and hydrodynamic impact on beds with caverns formation (cavitation), and carbon dioxide injection.

The fracture volume in the bed is negligibly small compared to the total volume of solid skeleton and voids. Coalbed hydraulic fracturing promotes to making links between the natural fracture network and the well [6–10].

Most problems during coal bed hydraulic fracturing are related to coal mass heterogeneous properties, including geomechanical properties and the length of the natural fracture network in the coal. As a result, induced fractures are highly dependent on strata stress curves and their changes during drilling and hydraulic fracturing. The cleavage system affects the fracture trajectory and may result in complex fractures, which increases the injection pressure. Bottomhole rock parts or coal dust from hydraulic fracturing also increase the injection pressure. Cross-linked gels, water, and foams are used as fracturing fluids. The organic surface of coal can adsorb fracturing fluid (or drilling fluid) components in contrast to the inorganic surface of conventional reservoirs. Adsorption and physical capture of fracturing fluid molecules limit the permeability of main and secondary cleavages, tertiary fractures, methane desorption, gas diffusion and further gas filtration to wells [11–14].

A significant volume of a deposit by thickness in multi-layer basins with thin layers of coal (e. g., Black Warrior, Canada) is occupied by the host rock. Some characteristic properties of coal and host rock obtained from minifrac tests are presented in table 1 [4, 15–16].

Table 1. Input data for the model
Таблица 1. Исходные данные модели

Depth	850 m
Reservoir pressure	8,5 MPa
Coal methane capacity	20 m^3/t
Grid size	1250×1250×10 m
Number of cells	100×100×10 pcs
Fracture height	13 m
Fracture half-length	68 m

The table shows the values of Young's module (Erock, MPa) and Poisson's coefficient of coal and host rock for different coal basins.

High Young’s modulus of other rocks with low modulus for coal, as well as strata stresses, affect fracture growth and propagation [9].

Research aim was to assess the impact made by host rocks with different reservoir properties on coalbed methane (CBM) production dynamics before and after hydraulic fracturing.

Table 2. Input data of interlayers in the double porosity model
Таблица 2. Исходные данные прослоек в модели двойной пористости

Number of layer	Rock	*h*, m	*m* matrix/fracture, portions	*k* matrix/fracture, 10^{-12} m^2
1	Sand	2	0 / 0.2000	0 / 0.1020
2	Coal	1	0.2 / 0.0010	0.00001 / 1.0200
3	Siltstone	2	0.2 / 0.0001	0.00001 / 0.0001
4	Coal	3	0.2 / 0.0010	0.00001 / 1.0200
5	Siltstone	5	0.3 / 0.0001	0.00001 / 0.0001

The Narysko-Ostashkinskoye deposit’s coal bed reservoir properties, its methane content research results, and the results of fracture geometry (half-length and height) after coal bed hydraulic fracturing at a depth of 850 meters were taken as initial data (tables 2, 3).

A model of a coal bed with a hydraulic fracture was constructed in application program package Petrel (Shlumberger). The coal bed model is implemented using the double porosity model consisting of two interrelated systems representing a coal matrix and a system of highly permeable fractures. Physical processes are described by modified Warren and Ruth model involving sorption and diffusion processes [8]. Fluid flows mainly through fractures and major reserves are in porous blocks. There are also local filtration flows from blocks to fractures. Design grid parameters, modifiable interval, fracture half-length, and fracture's height and direction were introduced to model the hydraulic fracture.

Table 3. The results of observing changes in the coal bed gas saturation without affecting the formation

Таблица 3. Результаты наблюдения за изменением газонасыщенности угольного пласта без воздействия на пласт

Rock	Gas saturation (fractures)				
	1 well (3 mos)	1 well (5 mos)	1 well (8 mos)	2 wells (3 mos)	2 wells (5 mos)
Sand	–	–	–	–	–
Coal	–	–	–	–	–
Siltstone	–	0.5	0.7	0.5	0.6
Coal	–	0.6	0.8	0.5	0.7
Siltstone	–	–	0.4	–	0.5

Methodology. The work consisted of two parts. The first part included the study of the impact made by the host rock when recovering gas from the coalbed in models with one and two wells without hydraulic fracturing.

In both cases, the well uncovered the entire coal patch as shown in figure 1. The fractures were initially occupied by water. So, the first step was to dry the coal patch and observe the subsequent release of the adsorbed methane from coal layers 2 and 4.

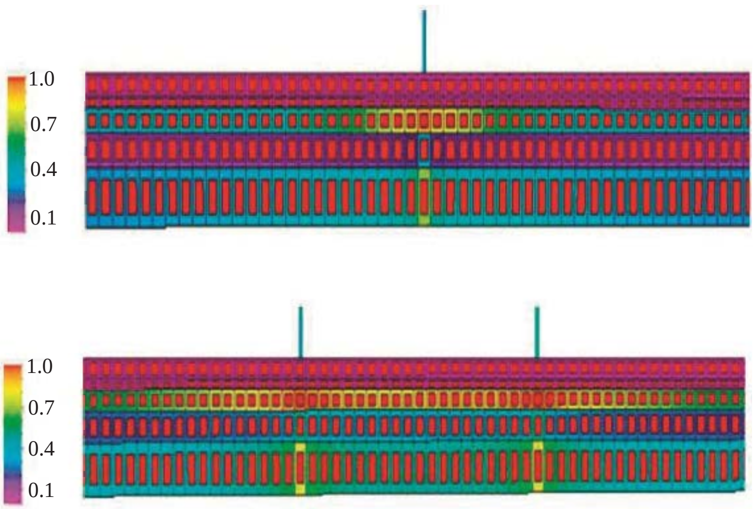

Fig. 1. Gas saturation distribution one year after production starts (1 and 2 wells)
Рис. 1. Распределение газонасыщенности через год после начала добычи (1 и 2 скважины)

Calculations in models with one well and two wells were made with pressure and gas saturation measurements after 1 day; 3, 5, 8, 12 months from the start of production (figures 1, 2).

In a single well model, after 5 months gas saturation changed from 0 to 0.5 in layers 3 and 4 (clay siltstone and coal) (table 4). One year after the start of water pumping, free gas filled layer 3 (clay siltstone), layer 4 (coal bedrock), and layer 5 (fissured clay siltstone) (figure 1).

In a two wells model, the distance between the wells is 250 m, which is typical for the development of coalfields. The same mode was set to simulate wells. Three months

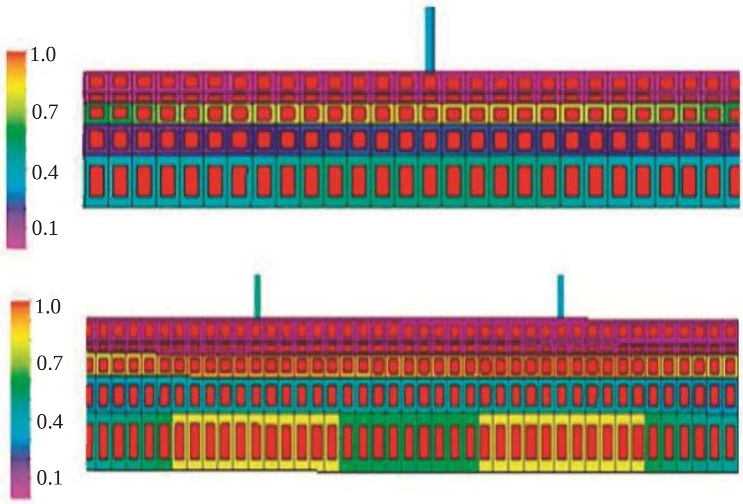

Fig. 2. Gas saturation distribution one year after production starts (1 and 2 simulated wells)
Рис. 2. Распределение газонасыщенности через год после начала добычи (1 и 2 моделируемые скважины)

after the start of water pumping, layers 3 and 4 (clay siltstone and coal) became saturated (table 4). Figure 2 shows the state of gas saturation in the reservoir one year after the start of development. It can be seen that two wells development is more intense in terms of gas saturation compared to a single well model.

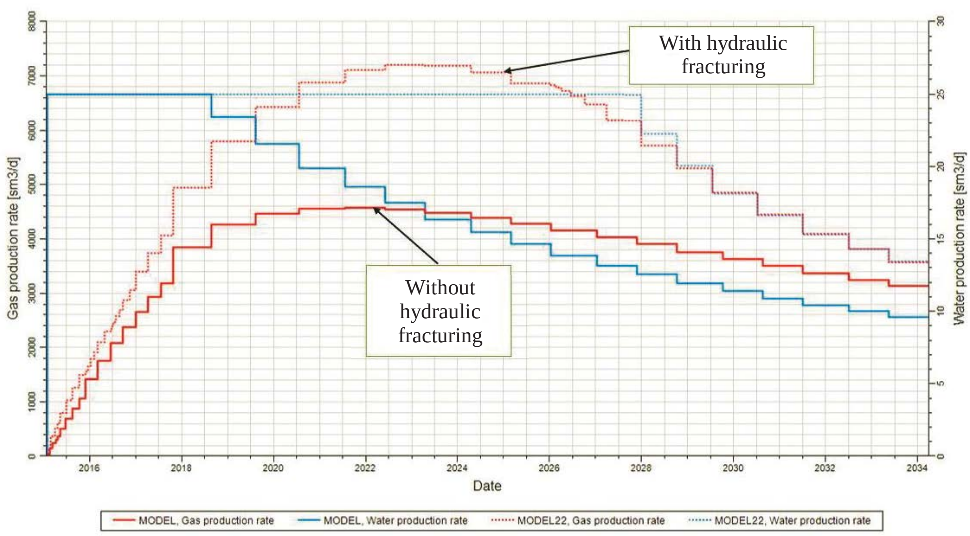

Fig. 3. Changes of gas and water rates (1 well)
Рис. 3. Изменения дебитов газа и воды (1 скважина)

The second part of the work included the study of the impact made by the hydraulic fracturing operation on CBM production, as well as the assessment of host rocks impact on methane production after hydraulic fracturing.

Fracture dimensions at one of Naryksko-Ostashkinskoye field wells were taken as initial data, namely, the fracture height (13 m) and its half-length (68 m). Input data for the model were used in accordance with tables 2, 3.

The efficiency of hydraulic fracturing is significantly affected by the mechanical properties of rocks and associated stresses. In the case of the Naryk-Ostashkinskoye deposit, coal seams are uncovered in patches that include coal and enclosing rock

Two development scenarios were considered with hydraulic fracturing at the start of production at one well in the center of the seam model and at two symmetrical wells.

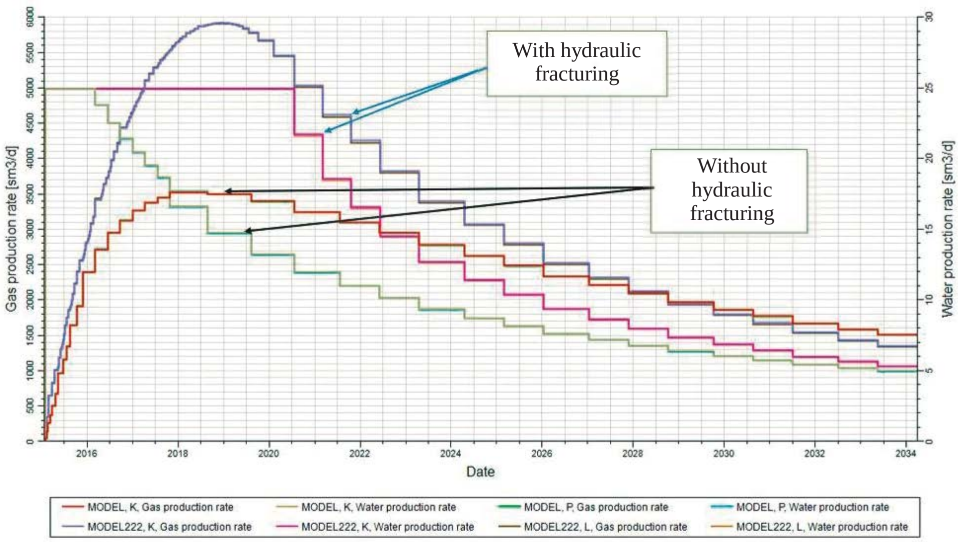

Fig. 4. Changes of gas and water rates (2 wells)
Рис. 4. Изменения расходов газа и воды (2 скв.)

Figure 3 shows pressure distributions in the interbedded layers the next day after hydraulic fracturing at one well. Hydraulic fracturing was carried out on the first day of production. It can be seen that pressure in the fracturing zone has changed by 0.1 MPa in comparison with the initial strata pressure (8.5 MPa) in coal interlayers and sandstone, in fissured siltstones to a lesser extent (interlayer 3) and a little in the last formation 5. Such pressure distribution is due to different formation reservoir properties of the interlayers. Fissured siltstone has the lowest fracture permeability. In addition, figure 4 shows the effect of wells interaction caused by reservoir pressure decrease in the model and gas production intensification.

Analyzing the results of alternate designs with one and two fractured wells, significant quantitative changes in free gas distribution across the interbedded layers were recorded one year after the start of the calculation.

Peak gas rate at a single well development with hydraulic fracturing is reached after 10 years; in the case of two fractured wells, the peak rate is reached after 3 years. This can be explained by the depression cone created during the two wells development and by pressure reduction below the desorption pressure, which caused rapid release of gas from the matrix. The fracture, in turn, created a link between the well and natural fracture system and ensured fluid flow to the well.

Results. The comparison of CBM production with two wells in two scenarios, (a) hydraulic fracturing and (b) gas production without any impact on the formation, has made it possible to make the following conclusions:

1) Gas rates after hydraulic fracturing are 1.5 times higher than CBM production without any impact on the formation;

2) Water rates after hydraulic fracturing doubled and remained at the initial level for 10 years in comparison with the model without hydraulic fracturing. However, peak gas rate in both scenarios is reached after 3 years. The dynamics can be explained by the effect of the fracture connecting the well and the network of water-saturated fractures;

3) After hydraulic fracturing at two wells, methane from the coal interlayer migrates to the host rocks 2 months earlier than in the one well scenario;

Table 4. The results of observing changes in the coal bed gas saturation with hydraulic fracturing

Таблица 4. Результаты наблюдений за изменением газонасыщенности угольных пластов при ГРП

Number of layer	Rock	Gas saturation with and without fracturing			
		1 well (5 mos)	1 well (8 mos)	1 fractured well (3 mos)	1 fractured well (5 mos)
1	Sand	–	–	–	–
2	Coal	–	–	–	–
3	Siltstone	0.5	0.7	0.3	0.5
4	Coal	0.6	0.8	0.4	0.5
5	Siltstone	–	0.4	–	0.3

4) Migration to sandstone and upper coal occurs after 8 years in case two wells are operated without any impact on the formation. When calculating the model with hydraulic fracturing, it is observed that methane migrates from the upper coal to the overlying sandstone after 5 years.

The use of hydraulic fracturing has positive impact on the dynamics of gas production from coal seams [17]. Compared to the scenario of CBM production without hydraulic fracturing, gas flow rates after hydraulic fracturing increased by 1.5–2 times.

Calculations prove the occurrence of gas migration from the coal matrix to the surrounding host rocks through the system of fractures during reservoir development. Host rock can be considered as a transportation route for coalbed methane production.

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Оценка влияния геологических особенностей метаноугольного пласта на работу эксплуатационной скважины

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Реферат

Введение. *Извлечение метана из угольных пластов повышает экономическую эффективность добычи угля, а также является одной из главных мер по снижению рисков, возникающих при разработке угольных месторождений. Целью исследования являлась оценка влияния вмещающих пород с различными фильтрационно-емкостными свойствами на динамику добычи метана из угольных пластов до и после проведения ГРП (гидравлический разрыв пласта).*
Методология. *С использованием программных комплексов построена модель угольного пласта как комплексного месторождения двух ископаемых – угля и газа – и рассчитаны варианты добычи газа с воздействием на пласт и без воздействия на пласт. В пакете прикладной программы Petrel (Shlumberger) построена модель угольного пласта с трещиной ГРП.*
Результаты. *Установлено, что миграция газа из угольной матрицы во вмещающие близлежащие породы происходит по системе трещин в период добычи газа. Применение технологии ГРП положительно влияет на динамику добычи газа из угольных пластов. После проведения ГРП выявлен рост миграции десорбированного газа во вмещающие прослои. Результаты исследований миграции угольного метана в близлежащие породы показали, что вмещающие породы можно рассматривать как транспортные пути при добыче метана из угольных пластов.*

Ключевые слова: *угольный пласт; адсорбция; ГРП; вмещающая порода; двойная пористость; миграция угольного газа.*

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