THE EFFECT OF BARITE DRILLING MUD ON THE PERMEABILITY OF TIGHT GAS IN CRACKED SHALES OF DEEP WELLS

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ABSTRACT

In the conditions of depletion of traditional energy resources, the development of hard-to-recover hydrocarbon resources is becoming increasingly important in the world economy. One of these potential sources of tight gas can be in carbonate-clay fractured reservoirs of the Cambrian deposits of Kazakhstan, located at the depth of about 6 km. The reservoir rocks consist of quartz, muscovite, albite, calcite, mixed layered clays, and chlorite. It is assumed that, the deposited particles from barite mud, which are used in deep drilling, can clog the cracks, thereby blocking the gas outlet. The X-ray computed microtomography of mud-saturated shale sample has showed that the cracks width in these compacted rocks varies up to 20-25 µm, which corresponds to the size of the particles of the weighted drilling mud, as a result of significant penetration of the mud particles is not observed. Cracks, acting as a filter, pass water, but block the particles from getting inside, causing a thick crust to form up to 5 mm of drilling fluid on the surface of the reservoir in the well, which makes it difficult to escape the gas. Experimental upbuilding of 5-mm mud crust on the shale sample has led to decreasing of gas permeability from 3.182 mD to 0.418 mD. In this case, the porosity of the sample increases from 0.669% to 4.688% due to the porosity of the crust. The action on the barite mud crust of an aqueous solution of the Atren B-Solv complexing agents at a temperature of 100° C and background pressure of 20 MPa for 24 hours, almost completely dissolves the crust, partially leaving a clay fraction on the surface. As a result, the gas permeability increases to 1.166 mD, the porosity of the sample decreases to 0.331%.

Keywords: Tight gas, shale, deep well, drilling mud, microCT

INTRODUCTION

With a view to energy security of the world, unconventional energy resources - coalbed methane (CBM), methane gas hydrate, shale gas, basin centred gas, tight gas, oil shale and heavy oil-exploration and exploitation is a pertinent task before geoscientists. Shale gas production in commercial quantities requires fractures to provide permeability. For a given matrix permeability and pressure, the gas production is determined by the

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number and complexity of created fractures, their effective conductivity, and an ability to effectively reduce the pressure throughout the fracture network to initiate gas production. Understanding the relationship between fracture complexity [1], fracture conductivity, matrix permeability, and gas recovery are a fundamental challenge of shale-gas development [2].

One of potential source of tight gas located at the depth of about 6 km in Cambrian carbonate-shale deposits of Caspian depression in Kazakhstan. The tight gas permeation associates with sub-horizontal fractures, but deep well exploration led troubles with gas production [3]. It is assumed that, the deposited particles from barite mud, which are used in deep drilling, can clog the cracks, thereby blocking the gas outlet. This problem and its solution are considered in this article.

METHODS

Studies of the material composition and mineral composition of the shale sample included X-ray fluorescence analysis applying the Bruker Ranger S2 instrument and X-ray diffraction analysis applying the Shimadzu XRD-7000S X-ray diffractometer.

For microtomographic studies, a cube with a rib size of 5 mm is cut from the inside of the core, which is then dried in an oven at a temperature of 60 ° C for 3 hours. After that, the microtomography of these cubes is performed using a micro- and nanofocus research X-ray system for computed tomography General Electric V | tome | X S 240 (Germany). The survey resolution for the samples is 8 μm. According to the obtained digital model, a hollow-porous rock system is allocated in the Avizo Fire software package based on the distribution of shades of gray, reflection of the x-ray density of various sections of the sample, the porosity and pore size distribution are calculated [4-7]. Then, the sample is saturated with a barite-based drilling mud under vacuum for 4 hours and then dried for 12 hours in an oven at a temperature of 60 ° C. The surface of the samples is cleaned from the mud crust and microtomography is repeated, similarly to the procedure described above.

To investigate the effect of the crust from the weighting mud on the gas permeability, as well as the possibility of neutralizing it with an aqueous solution of complexing agents under thermobaric conditions close to the formation, a filtration experiment is carried out. A cylindrical specimen with a diameter of 30 mm and a height of 30 mm (fig.1A) is drilled from the sample of the shale across the core. Thus, the lithogenetic microcracks described in the previous chapter are located along the axis of the cylinder. This sample is dried at a temperature of 60 ° C for 3 hours. We note that a higher temperature leads to cracking of the sample by lithogenetic microcracks. Then we have made measurements of the porosity and permeability of the sample over the gas using a gas porosimeter and a permeameter PLAST-215 ATM. Then, on one end of the sample, a crust from a barite-based drilling mud used for drilling a deep well (fig. 1B) is built up by successive evaporation at a temperature of 60 ° C. After the sample is dried, the porosity and permeability measurements on the gas are again measured. Next, the sample is placed in an experimental filtering installation of Willie Geotechnik (Germany), a compression pressure of 20 MPa is set at a temperature of 100 ° C, and at a pressure of 10 MPa (a pressure difference of 15 MPa-5MPa is set in the pumps), then filtration of the reagent Atren B-Solv, including diethylenetriaminepentaacetic acid pentacalide, ethylenediaminetetraacetic acid, dipotassium salt, methylglycinediacetic acid, disodium salt and water is performed (fig.1C). After that, the third measurements of porosity and gas permeability are made.

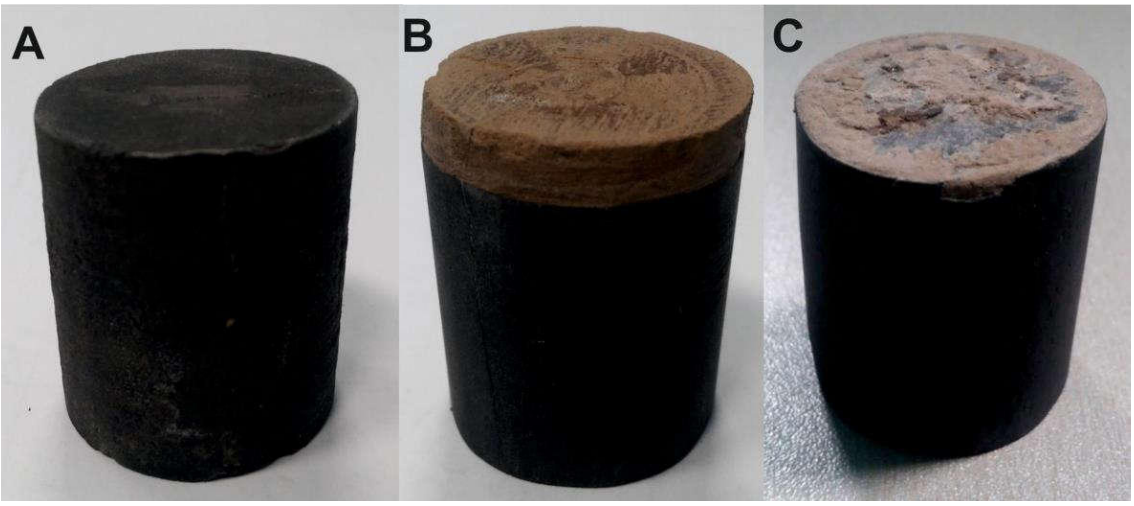

Fig. 1. Cambrian carbonate shale sample of deep well from Kazakhstan: A – before experiment, B – with 5-mm barite mud crust upbuilding, C – after Atren B-Solv filtration.

RESULTS AND DISCUSSIONS

According to the results of the X-ray fluorescence analysis (table 1), it is found that the main components of oil shale are silicon, aluminum, calcium, iron, sulfur, potassium, magnesium and sodium. The remaining elements play the role of impurities or have a trace value.

Table 1

Results of X-ray fluorescence analysis

Elements	Content, %	Elements	Content, %	Elements	Content, %
SiO2	52.07386	Cl	0.214935	NiO	0.00828
Al2O3	14.91384	P2O5	0.103015	CuO	0.006951
CaO	5.956475	BaO	0.095994	PbO	0.003294
Fe2O3	3.724053	MnO	0.065708	Y2O3	0.00235
SO3	2.999075	SrO	0.021263	Ga2O3	0.001372
K2O	2.743878	ZnO	0.01627	Nb2O5	0.000868
MgO	1.996953	ZrO2	0.012498	As2O3	0.000632
Na2O	1.698778	Rb2O	0.011924	LOI	12.85982
TiO2	0.456317	Cr2O3	0.011609		

According to the results of the X-ray phase analysis (fig.2), the main minerals of the sample are quartz, muscovite, albite, calcite, mixed layered clays, chlorite. There are smaller quantities of pyrite and gypsum.

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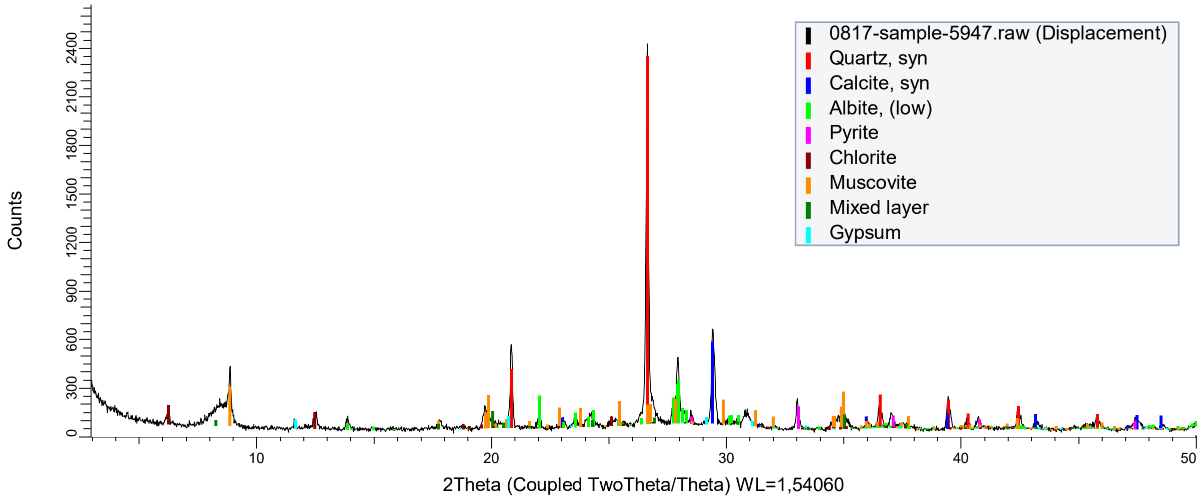

Fig. 2. Semi-quantitative composition based on the results of X-ray phase analysis: Muscovite 26,2%, Calcite 10,8%, Gypsum 1,9%, Pyrite 3,7%, Mixed layer 6,2%, Chlorite 4,3%, Albite 18%, Quartz 28,5%.

Thus, judging the mineral composition of the rock, it can be characterized as an alevrite carbonate clay shale [8]. We also note the high content of albite and calcite in the sample.

As a result of microtomographic studies, the nature of the change in the porous space is established before and after saturation of the rock. In the sample of the shale, cracks developed mainly subhorizontal, along the bedding of the rock, are noted (fig.3, 4). Its porosity before saturation is 1.57%, after saturation with a weighting solution and drying it has become 1.53% (table 2). There is a redistribution of the pore volume of the void space: the total volume occupied by the smallest pores is reduced, but the volume occupied by the largest pores increases (fig. 5). The increase in volumes that occupy the largest pores and the reduction in the volumes occupied by small pores, with a general reduction in porosity, may indicate the processes of erosion and redeposition of particles of clay minerals [9].

The saturation of the studied samples with a weighting solution based on barite does not significantly affect the change in the volume of the hollow-porous space. Despite the fracture of the shale sample, significant penetration of the mud particles is not observed (see fig. 3, 4). This may be due to the fact that the maximum crack width in the studied sample is 20-25 μm, while the average size of the fine particles of barite, that is most often used to weight the drilling mud, is 15-20 μm [10]. Thus, barite particles accumulate on the surface of the rock, and only water and colloidal components of smaller dimensions penetrate inside the cracks under the action of capillary forces.

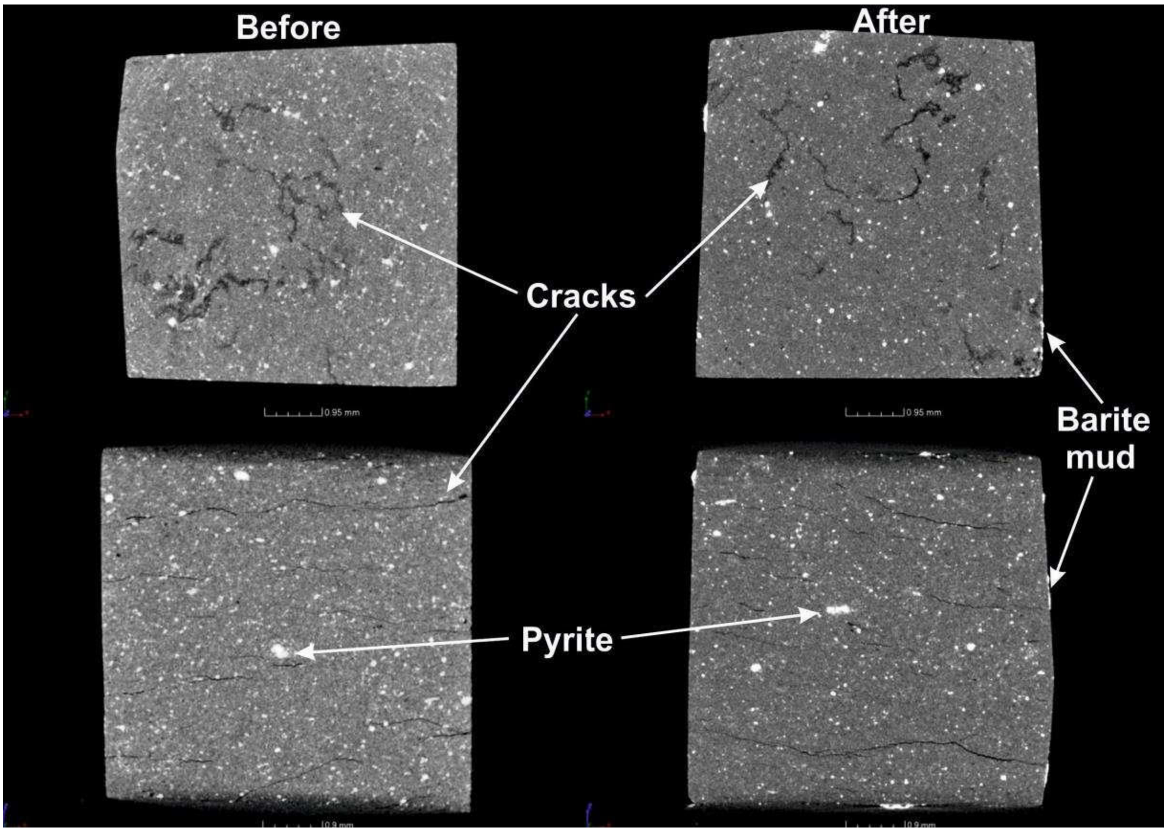

Fig. 3. Orthogonal sections of the shale sample before (left) and after (right) saturation of the rock with a drilling mud based on barite.

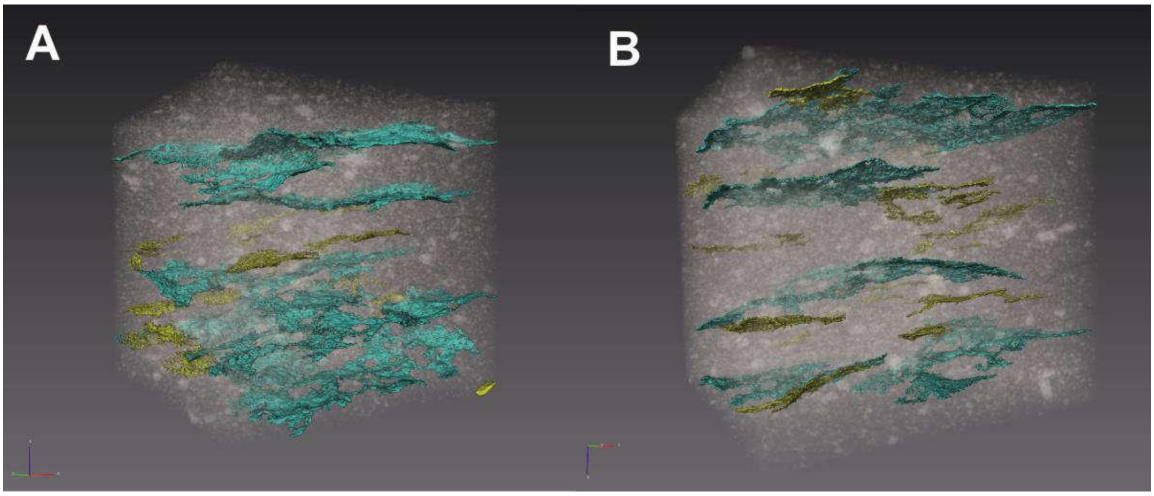

Fig. 4. 3D visualization horizontal cracks volume in the shale: A – before mud saturation, B – after mud saturation.

Table 2

Volume parameters before and after mud saturation

Volume, mm^3	Before mud saturation	After mud saturation
Minimal pore	1.30E-06	1.30E-06
Maximal pore	0.2178	0.4375
Mean pore	6.67E-06	9.05E-06
Porous space	1.8353	1.8172
Sample	116.7908	118.4967
Porosity, %	1.5714	1.5335
Pores number	275094	200774

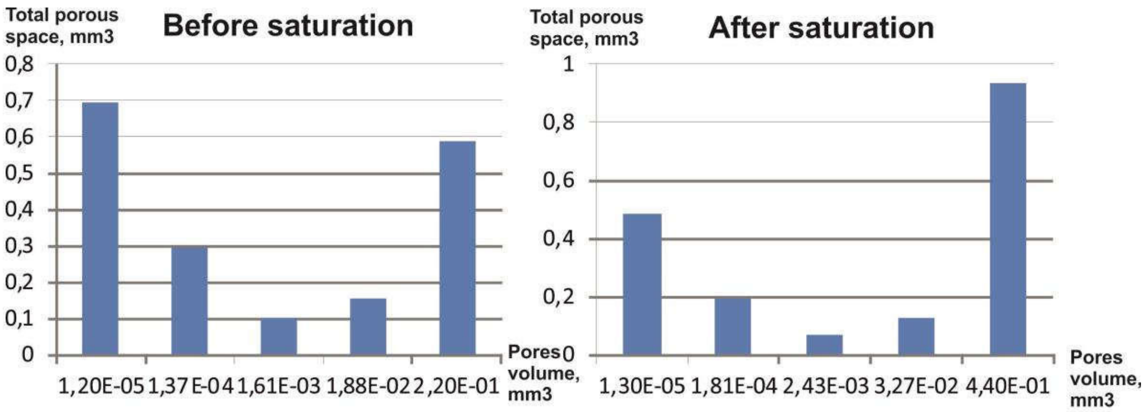

Fig. 5. Distribution of pores volumes before and after mud saturation

As a result of the filtration experiment, it is revealed that the increased crust of a weighting drilling mud of 5 mm thick is almost completely dissolved, only small remains of the clay fraction remain on the surface (see fig. 1C). After increasing the crust thickness of 5 mm from the weighting mud at the end of the sample, its gas permeability decreases from 3.182 mD to 0.418 mD (table 3). In this case, the porosity of the sample increases from 0.669% to 4.688% due to the porosity of the crust itself. The reagent provided by the Customer, being filtered at a temperature of 100 ° C and under the simulation of the rock pressure of 20 MPa for 24 hours, almost completely dissolves the crust, partially leaving a clay fraction on the surface of the sample. Thus the gas permeability increases to 1.166 mD, the porosity of the sample decreases to 0.331%.

Table 3

Gas permeability and porosity changing through the experiment

Sample	Gas permeability, mD	Porosity, %
Before experiment	3.182	0.669
After 5-mm mud crust upbilding	0.418	4.688
After mud crust dissolution	1.166	0.331

CONCLUSION

Studies of the material and mineral compositions of the sample from the deep well in Kazakhstan have shown that the main components of the rock are silicon, aluminum, calcium, iron, sulfur, potassium, magnesium and sodium. The main minerals of the sample are quartz, muscovite, albite, calcite, mixed layered clays, chlorite. The rock can be characterized as an aleurite carbonate clay shale.

In the course of the studies it is shown that the saturation of the studied samples with a weighting drilling mud based on barite does not significantly affect the change in the volume of the porous space. Despite the fracture of the sample, significant penetration of the mud particles is not observed. This may be due to the fact that the maximum crack width in the sample being studied is 20-25 µm, while the average size of the fine particles of barite most often used to weight the drilling mud is 15-20 µm. Thus, barite particles accumulate on the surface of the rock, and water only together with colloidal components of smaller dimensions penetrate inside the cracks under the action of capillary forces. Therefore, a thick drilling crust is formed on the surface of the rock, being observed on the surface of the core of the wells. The increase in volumes that occupies the largest pores and the reduction in the volumes being occupied by small pores, under the general reduction in porosity, may indicate the processes of erosion and redeposition of particles of clay minerals.

The filtration experiment has revealed that after being increased the crust thickness of 5 mm with the weighting mud at the end of the sample, its gas permeability decreases from 3.182 mD to 0.418 mD. In this case, the porosity of the sample increases from 0.669% to 4.688% due to the porosity of the crust itself. The action on the barite mud crust of an aqueous solution of the Atren B-Solv complexing agents at a temperature of 100° C and background pressure of 20 MPa for 24 hours, almost completely dissolve the crust, partially leaving a clay fraction on the surface. As a result, the gas permeability increases to 1.166 mD, the porosity of the sample decreases to 0.331%.

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