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Geological Aspects of Producing Reserves from Complex Gas Deposits

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Abstract

The main problems encountered in the operation of Cenomanian gas deposits at the late stages of development are considered in the article. On the base of the analysis of primary data, the dependence of the gas saturation coefficient on the height location of the reservoir from the gas-water contact was determined. An analysis of the porosity coefficient in the zone of limit gas saturation revealed an increase in the porosity down the section to the gas-water contact. The change in porosity in the poorly gas-saturated zone (zone of gas-water contact2) occurs according to the opposite law - an increase in the porosity of the rocks as moving up. This fact confirms the presence of reservoir heterogeneity, depending on the geological peculiarities of the structure and the formation conditions of the deposit. Experience of operation of the main reservoir has proved the necessity of operating the zone of limit gas saturation and the poorly gas-saturated zone of the productive reservoir of the Cenomanian deposit as an independent development object.

Keywords: gas deposits development, gas water contact, gas saturation coefficient, porosity coefficient, reservoir heterogeneity, porosity and permeability properties.

INTRODUCTION

The West Siberian oil and gas province is the largest oil and gas region in Russia, the main mineral resource base of the country. For further development of the oil and gas production industry, the incremental increase in recoverable hydrocarbon reserves of commercial categories is important rather than their production.

Within the territory under consideration, oil and gas accumulations are established from the Paleozoic deposits to the Upper Cretaceous combined into the five largest regional oil and gas complexes, with the overwhelming majority of the deposits (up to 98%) in the Aptian-Cenomanian, Neocomian and Jurassic. Moreover, more than 85% of the explored gas reserves are contained in purely gas deposits confined to the Aptian-Cenomanian gas-bearing complex of the northern regions [1].

The development of Cenomanian gas deposits was based on the phased commissioning of separate sections due to the geological structure and the simultaneous commissioning of gas processing units (GPU), which in turn caused an uneven rise in the gas-water contact (GWC), as well as an uneven distribution of reservoir pressure in general across the deposits. At the same time, the development of giant Cenomanian gas deposits in the north of West Siberia has passed to its final stage, where the main negative factor affecting the gas recovery coefficient is well watering due to the rise of the GWC, as well as the lateral introduction of aquifer formation waters. Increased watering of well production leads to the formation of a sand-liquid bottom plug, hydrate formation, sand abrasion on wellhead pipelines and process equipment, which leads to irrational losses of reservoir energy. However, the main negative aspect of the introduction of formation water into the reservoir is "jamming" (the formation of water barriers) of gas reserves. For the Vyngapurovskoye deposit alone, the amount of jammed reserves according to model calculations is 7.8 billion m^3, or 2% of the initial reserves (Cenomanian deposit) [2]. On the other hand, after completion of the development of the field using traditional technologies of increased gas recovery, at least 1.5 trillion cubic meters of gas will remain in the deposits, of which more than 500 billion m^3 will be low-pressure gas in the free state. All this leads to a decrease in the ultimate gas recovery of the reservoir, an increase in the development time and, ultimately, to a large financial cost of extracting gas. This causes a thorough study of the processes of plantar water movement, the features and regularities of watering reservoirs and wells, the joint inflow of fluids to the bottom of wells and the study of natural factors that contribute to an increase in the water-free period of operation and improvement of the technological conditions of reservoir development in order to maximize gas recovery from the formation [3].

In natural reservoir rocks there is firmly bound (adsorbed), loosely bound (water of diffuse layers) and free water. This division is valid for artesian basins in the presence of a homogeneous liquid in the reservoir - formation water. At the same time, there are no clear boundaries between reservoir fluids in nature, free gas and free water are separated in deposits according to the gravitational-capillary principle: water saturation naturally increases as it approaches fully water-saturated rocks, aquiferous formation system (to the “free water mirror”). And the higher the contrast of the porous characteristics of the contacting layers in the deposits and the higher the heterogeneity of its structure, the more complex the nature of the change in the residual water saturation along the height of the deposit. The nature of the water saturation distribution along the height of a real deposit is determined by changing the value of the water saturation ($k_в$) or gas saturation ($k_г$) coefficient depending on the absolute depth of bedding (or distance from the GWC along the height of the formation).

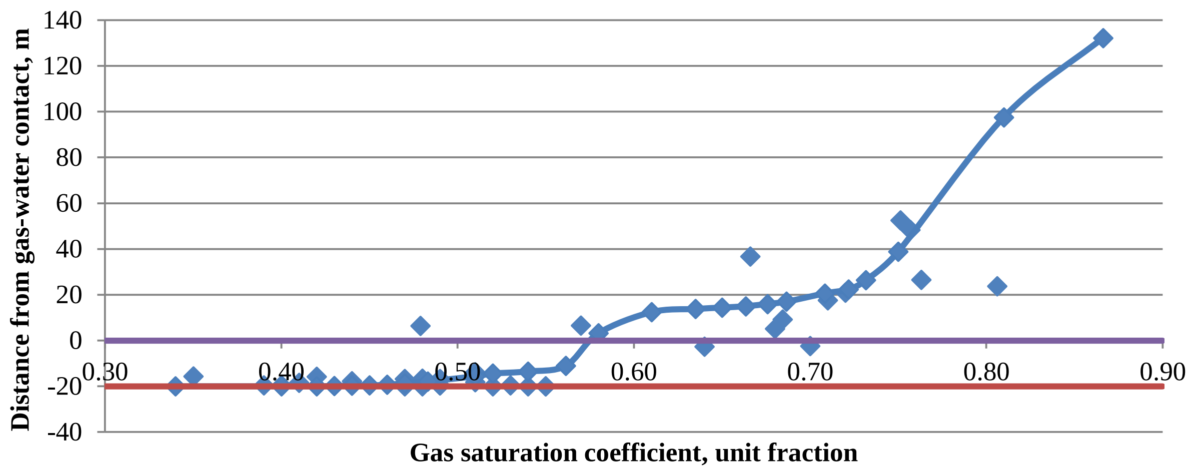
At the same time, for a number of fields in West Siberia, the presence of a plantar or marginal aquifer saturated with occluded gas was found to be below the gas-liquid contact of gas deposits.

Occlusion or adsorption is the absorption of gases not by the surface layer but by the entire volume of the liquid, and in this sense the fluid containing the occluded gas is a microfluidheterogeneous system where the dispersion phase is liquid and the dispersed medium is gas represented as microinclusions (microbubbles) of free gas, the adsorption film being formed at the interface between phases. A significant difference between the viscosity of the phase and the medium and the constancy of the tangential stress component in the adsorption film keeps the gas bubble in a state of equilibrium, and they move together, which identifies the system as liquid [4].

MATERIALS AND METHODS

In order to determine the nature of water saturation changes along the height of the Cenomanian reservoir, the results of testing the first exploratory wells of the Yamburgskoye field were analyzed; the results of the analysis showed that the structure of this deposit is complicated by the presence of an extensive transition zone characterized by the inflow of formation water with a large gas factor (Fig.1). The thickness of this zone is approximately determined by the graphic method at a level of 20 m. In Figure 1, this zone is limited in the roof - by the position of the accepted GWC (GWC1), which is the boundary between the zones of ultimate gas saturation and the poorly gas-saturated ones.

The height of the transition zone depends on the geological features of the structure and conditions of the deposit formation, as well as the porosity and permeability properties of reservoir rocks and the inclination angle of the wings of the structure. At some fields in West Siberia, the height of the saturated zone is much less than the height of the undersaturated and transition zone accounting for more than 70% of the volume of the deposit [5]. The transition zone is characterized by the fact that in the base of this zone the gas phase permeability tends to zero (see Fig. 1), and the free water above this zone passes completely into the bound one. In this case, the content of the residual (low-pressure) gas corresponds to its maximum value. When calculating the reserves of the Yamburgskoye field, this zone was identified as an independent object of calculation, but not as an independent development object, therefore the reserves of the transition zone were not taken into account as commercial ones, the size of which was 1010.8 billion m^3 [6]. It was believed that as the main deposit was being developed, the gas saturation in the transition zone would decrease to the minimum values due to the pressure difference between the zones and the piston displacement of the gas from the transition zone to the gas saturation zone. However, as experience shows in the development of the main reservoir, this effect could not be achieved, possibly due to the uneven rise of the GWC and the complications associated with this process.



Change in the gas saturation coefficient for the height of the deposit, depending on the distance from the gas-water contact

Location of "water mirror"

Location of accepted "gas water contact"

Figure 1. Change in the gas saturation coefficient as a function of the formation distance from the "free water mirror"

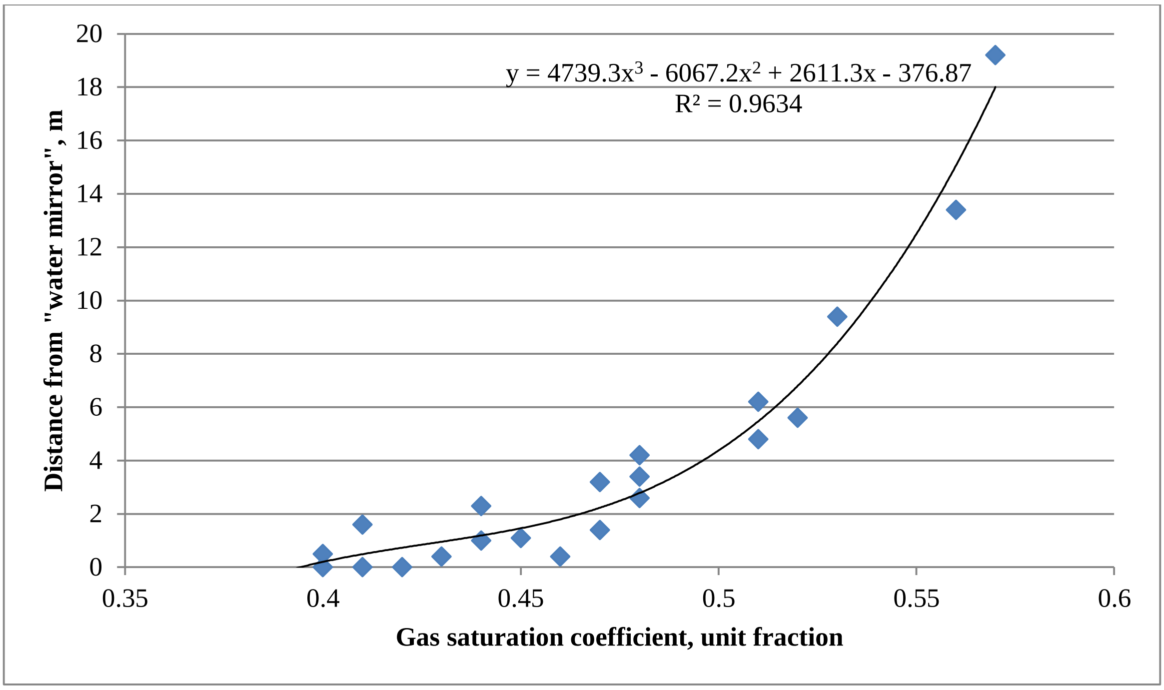


Figure 2. Change in the gas saturation coefficient as a function of the height of the reservoir from the position of the “water mirror” (GWC2)

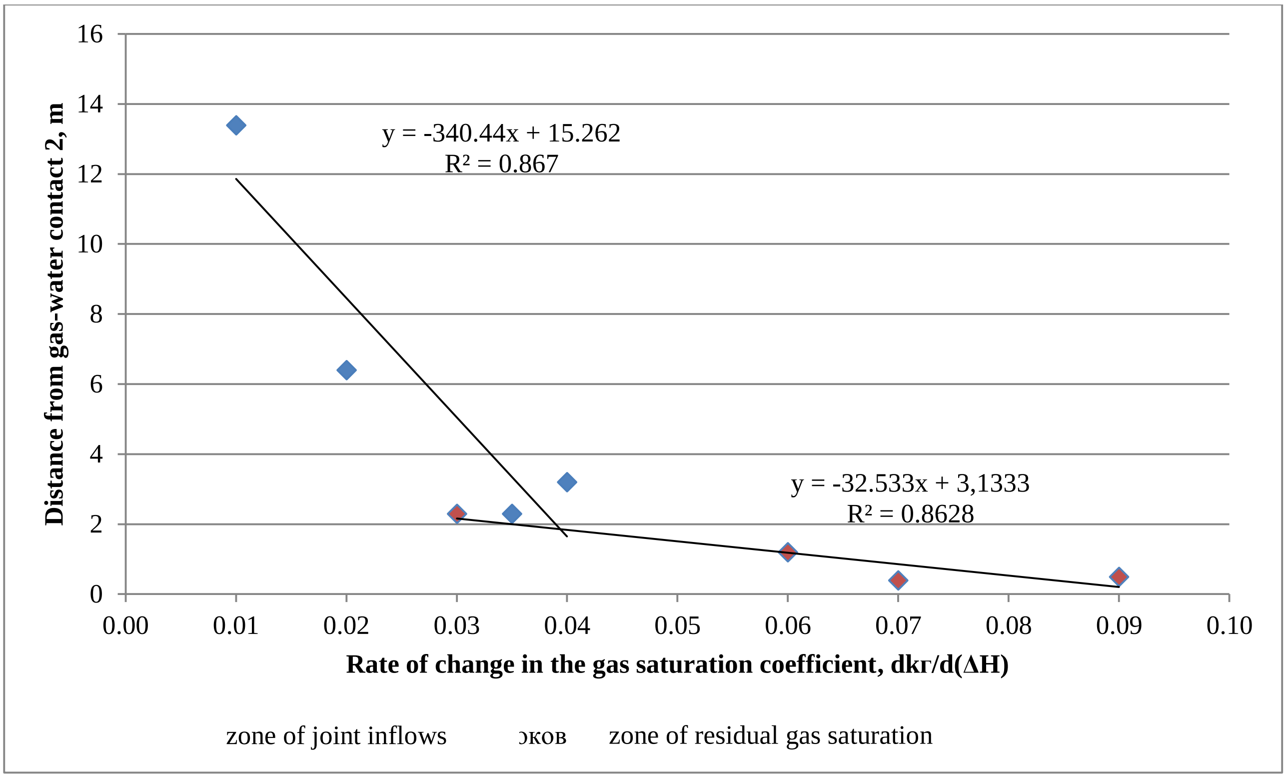


Figure 3. Change in the gas saturation gradient along the height of the deposit depending on the position of the “water mirror” (GWC2)

The zone of the ultimate gas saturation is characterized by the maximum and approximately the same gas saturation along the height for equal-permeable reservoirs. When tested, it produces pure gas inflows, which is confirmed by field tests of exploratory wells at the Yamburgskoye field. The gas saturation coefficient in 1983 was adopted at the level of 0.75 cu, and the reserves amounted to 5.479,8 billion m^3, without taking into account the reserves of the transition zone.

Of the two presented zones, the transition zone presents the most interest. It should be noted that reserves concentrated in it and not included in the development account for more than

20% of all balance reserves of the Yamburgskoye field. Also, if the nature of the inflow from the zone of ultimate gas saturation and the zone below the "water mirror" (zone GWC2) is unquestionable, when the inflow from the transition zone is initiated, the results may be inconsistent. In this case, the gas saturation coefficient is graphically determined in the range from 0.4 to 0.57 cu upward along the section of the deposit (Figure 2).

Further analysis of the curve k = f (H) for the transition zone of the Cenomanian deposit in the Yamburgskoye field using the method of static differentiation revealed that the transition zone, in turn, is divided into two independent zones (Fig. 3). The first zone is the zone of residual gas saturation located directly above the "water mirror". It is distinguished by a sharp decrease in the gradient dkg/d (ΔH) up the section of the deposit.

The thickness of this zone is 2 m, the residual gas saturation of this zone can vary, and generally increases to the top of the "water mirror", and according to Figures 2 and 3 the gas saturation coefficient varies from 0.44 to 0.47 cu. This zone on a commercial scale is not interesting, since at the lowest hypsometric levels there are completely water-saturated rocks, and the permeability for gas is always zero.

The second zone up the section of the deposit is clearly shown in Figure 3 and is a zone of joint inflows of gas and water (microfluidheterogeneous zone of the poorly gas-saturated part of the deposit). When testing this zone, inflows are obtained due to free water and mobile gas, which is confirmed by field tests when inflows of formation water with a gas factor are obtained. The relative permeability for water within the entire zone tends to zero, whereas at the upper boundary gas saturation reaches its maximum value. The thickness of this zone is 18 m, and the gas saturation coefficient varies from 0.47 to 0.58 cu, and corresponds to the accepted coefficient in [5], which is close to the critical gas saturation of reservoirs, when water at low pressure gradients has only capillary mobility, respectively, the main gas reserves are concentrated in this zone. Given the known formulas for calculating gas reserves, it is possible to determine the share of reserves directly for this zone, which will be 19% of all balance reserves of the deposit and in quantitative terms equal to 0.9 trillion m^3, which makes it necessary to consider this zone as an independent object of prospecting and exploration.

From the point of view of rational development and creation of conditions for efficient displacement of gas by water, it is necessary to select gas from interlayers in proportion to their porosity and permeability properties [1]. To this end, an analysis of the porosity coefficient in the zone of ultimate gas saturation was made, on the basis of which an increase in the porosity down the section and the maximum parameters to the accepted position of the GWC were revealed (Fig. 4), which is confirmed by the peculiarities of formation of the Cenomanian deposit [7].

However, the change in porosity in the poorly gas-saturated zone (zone GWC2) occurs according to the opposite law, as it moves upwards along the section from the "water mirror", and the porosity of the productive reservoir rocks increases (Fig. 4). This circumstance confirms the presence of heterogeneity in the porosity and permeability properties of the entire Cenomanian productive complex, and suggests that these zones (ultimate and poorly gas-saturated zones) should be considered as independent development objects.

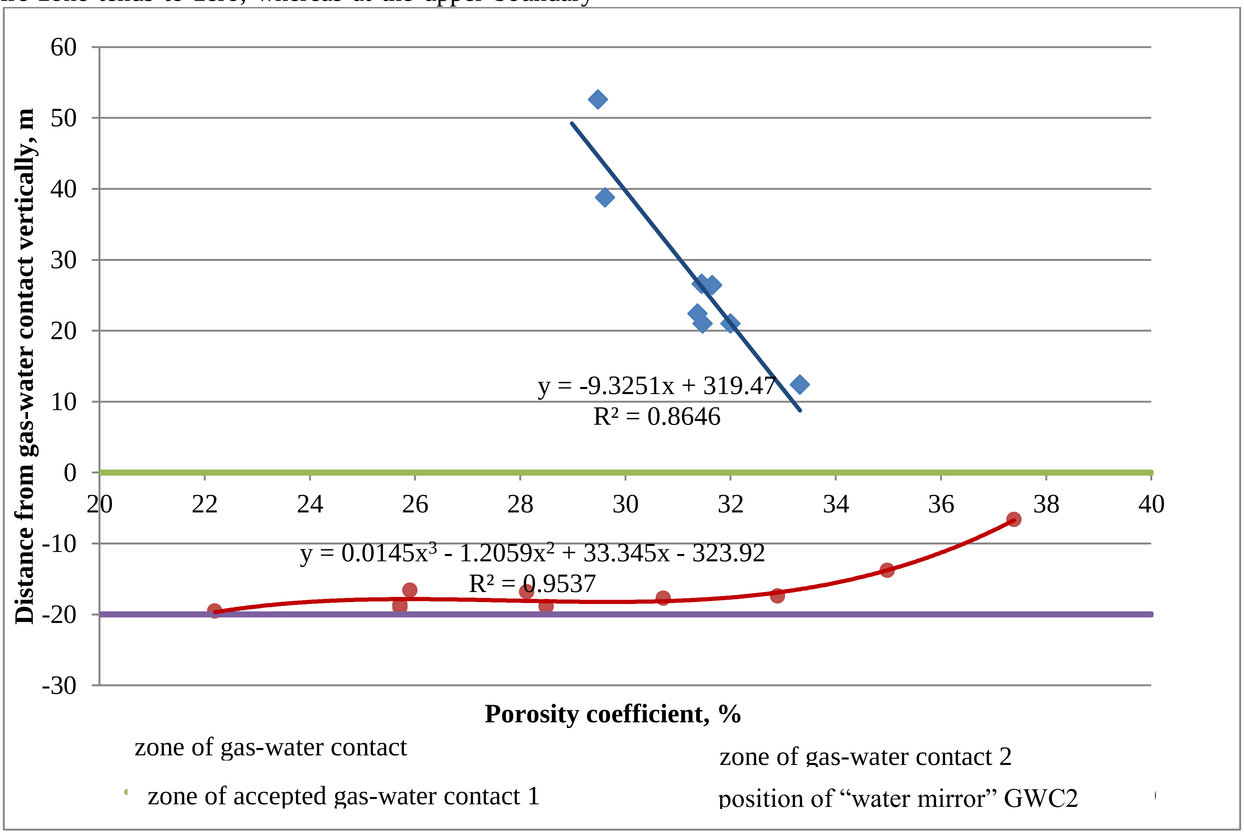


Figure 4. Change in the porosity coefficient in relation to the vertical distance of the reservoir from the "water mirror"

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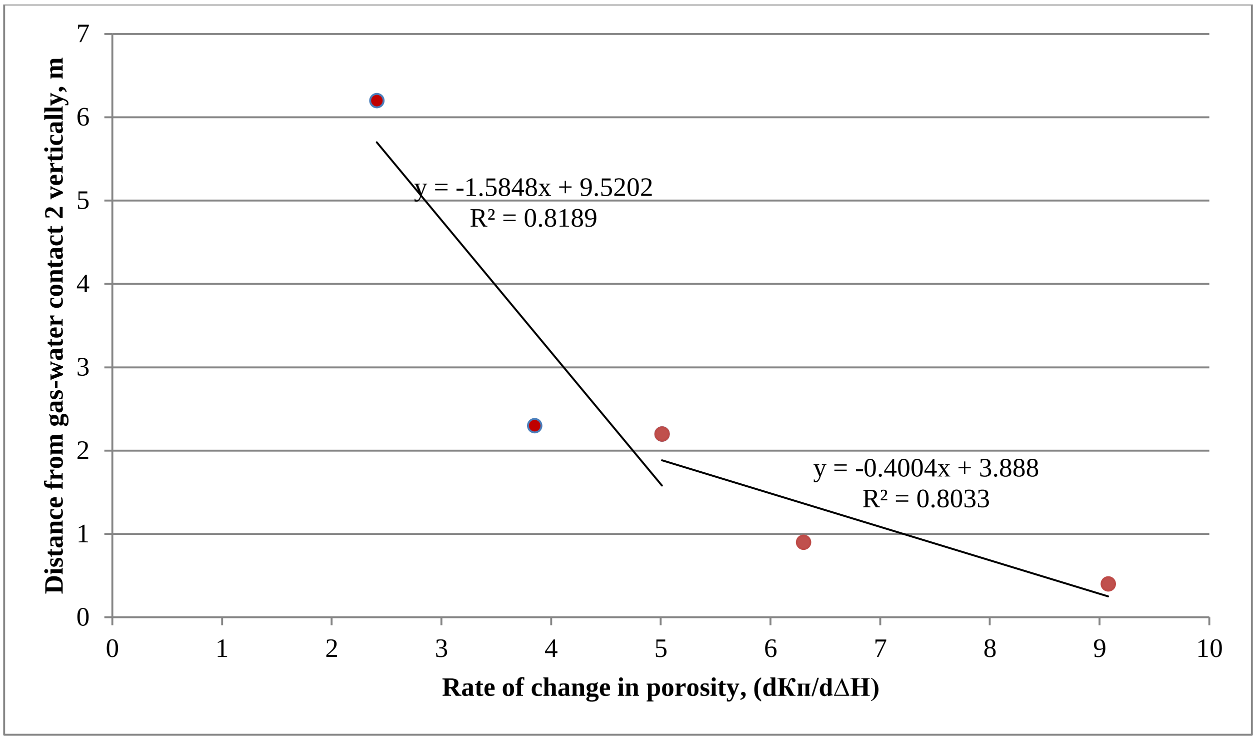

Figure 5. Change in the gradient of the porosity coefficient along the height of the deposit, depending on the established elevation of the GWC for the transition zone

The method of static differentiation of the curve kp = f (H) for the transition zone of the Cenomanian deposit of the Yamburgskoye field confirmed the results of the dkg/d (ΔH) gradient change and isolated the microfluidheteroheterogeneous zone of the poorly gas-saturated section of the reservoir with about the same height of the transition interval from water to occluded gas (Figure 5).

RESULTS AND DISCUSSION

Opening the zone of the ultimate gas saturation and the poorly gas-saturated zone of the productive reservoir of the Cenomanian deposit by a single filter in the conditions of a heterogeneous porosity and permeability properties section will not be a means of effective development of the deposit. This is confirmed by the experience of operating the main deposit (the zone of ultimate gas saturation). Extraction of gas from the transition zone due to piston water displacement caused by the pressure difference between the zones does not occur. This makes it necessary to operate each zone as an independent development object.

Obviously, if it is necessary to develop the transition zone as a separate object, isolation works must be conducted to create an impermeable bridge between free gas and a poorly gas-saturated aquifer. At the same time, in the process of operation, it is necessary to carry out work to destroy the microfluidheterogeneous system with the release of gas microinclusions into the free gas phase. On the other hand, in the process of operating this object, limiting the flow of formation water will be the decisive factor in justifying the technique and technology of impact on the near-wellbore zone. It is necessary to change the approach to carrying out waterproofing works, with the required preservation of the thickness of the microfluidheterogeneous zone of the poorly gas-saturated section of the deposit, which is explained by low formation energy for further transportation of gas to the surface and the gas gathering pipeline.

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