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Optimization of the location of a multilateral well in a thin oil rim, complicated by the presence of an extensive gas cap

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Abstract. The specific share of the reserves of hard-to-recover hydrocarbon raw materials is steadily growing. The search for technologies to increase the hydrocarbon recovery factor is one of the most urgent tasks facing the oil and gas industry. One of the methods to expand the coverage of oil reserves and increase oil recovery is to use the technology of drilling multilateral wells with a fishbone trajectory. In the Russian Federation, the most branched well was drilled in the Republic of Sakha (Yakutia) at the Srednebotuobinskoye oil and gas condensate field. The main object of development is the Botuobinsky horizon (Bt reservoir). About 75 % of the geological reserves of the reservoir are concentrated in a thin oil rim with an average oil-saturated layer thickness of 10 m with an extensive gas cap. This circumstance is one of the main complicating factors in the development of the Srednebotuobinskoye oil and gas condensate field. For such complex wells, one of the most important design stages is to determine the optimal location of the fishbone well in an oil-saturated reservoir. The article shows the results of sector modeling in the conditions of the Srednebotuobinskoye field to determine the optimal location of multilateral wells using Tempest simulator.

***Keywords*:** Srednebotuobinskoye oil and gas condensate field; multilateral well; cumulative oil production; oil flow rate; gas cap; gas factor; bottom water; thin oil rim; inclined oil-water contact

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Introduction. The Srednebotuobinskoye oil and gas condensate field (SBNGKM) in the Republic of Sakha (Yakutia) was discovered in 1971 and put into commercial operation in 2013 as a result of the expansion of Rosneft's activities and the development of the region [1-3].

The main development target is the Bt reservoir of the Botuobinsky horizon, which contains 77 % of the initial recoverable oil reserves and provides 99 % of its production. The main design solution for the Botuobinsky horizon provides for the use of a system of horizontal wells 1250 m long with a distance between well rows of 300 and 100 m [4-6].

The Botuobinsky horizon is represented by terrigenous sandstones deposited in coastal-marine conditions. The bar-like body, the axial part of which strikes northeast, was formed during the slow transgression of the marine basin. To the northwest of the deposit, a vast lower beach zone extended along the gently sloping coast. The bar-like body itself is probably formed by tidal and alongshore (northeastward) currents [7-9].

Taking into account the complex geological structure of the field, one of the main directions of development of the SBNGKM is the construction of multilateral fishbone wells [10-12]. Multilateral fishbone wells got their name because of the external similarity of the structure with a fish bone (Fig.1). Due to their design features, they cover a much larger field area compared to a single horizontal well, thereby increasing well productivity and reducing drilling costs [13]. A multilateral well with several branches from the main horizontal wellbore makes it possible to replace several single horizontal wells, increasing the profitability of the entire project [14, 15]. In addition, this technology

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is practically the only way to effectively develop thin under-gas oil rims, since other common technologies for increasing productivity, such as hydraulic fracturing, cannot be applied with similar complications that are typical for SBNGKM [16-18].

The technical characteristics of the fishbone well, which were used in the simulation, are as follows: the total horizontal part in the reservoir is 6052 m; main shaft length 1406.6 m; number of sidetracks 9 m; sidetrack length 334-1006 m; depression on the reservoir 5 atm; oil-saturated capacity 14.4 m.

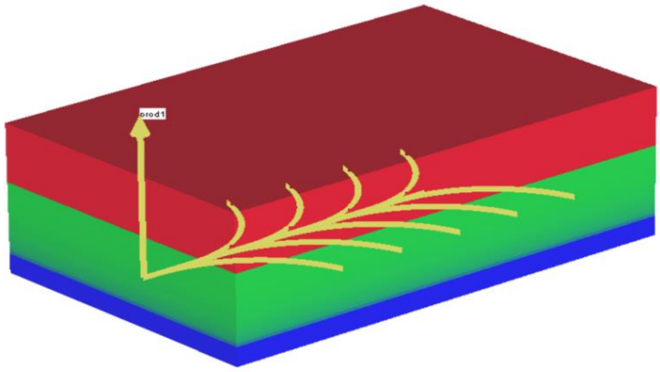

Fig.1. Sector model used in calculations

The problem of choosing the optimal well placement in the gas-oil-water zone of the reservoir is primarily due to the presence of an extensive gas cap, which can break through to the wells, thereby stopping the production process from the well [19-21].

The closer the well is located to the gas-oil contact (GOC), the earlier we observe gas breakthrough, respectively, the shutdown of the well occurs in a relatively short time, which leads to a significant decrease in cumulative oil production. On the other hand, if the well is located in the immediate vicinity of the oil-water contact (OWC), thereby moving it as far as possible from the GOC level, there is a breakthrough of bottom water, rapid watering of the produced product, which in turn also leads to a decrease in cumulative production oil.

Due to the high salinity of reservoir waters of the SBNGKM, the problem of reservoir water breakthrough in wells is not as acute as gas breakthroughs from the gas cap [22].

It can be concluded that for a certain sector of the field there is an optimal location of the well, in which we can get the maximum cumulative oil production, and, accordingly, the maximum economic benefit. An effective solution to the problem can be obtained solely with the help of hydrodynamic modeling, considering different options for the location of the well in the oil-saturated thickness, analyzing the main technological indicators of field development at each location and focusing on such an indicator as cumulative oil production [23, 24].

The novelty of the project is to substantiate, using hydrodynamic modeling, the optimal location of a multilateral fishbone well with nine branches with a total length of a horizontal wellbore of 5050 m in an oil rim with a thickness of 11 m in difficult geological conditions of the SBNGKM.

Methods. The calculations were carried out on the Tempest MORE hydrodynamic simulator manufactured by Roxar (Emerson Group Company). The simulator is a tool for numerically solving the problems of fluid movement in a reservoir and allows performing the following basic operations: numerical solution of the equations of conservation and filtration of phases and components, analysis of filtration flows and calculated technological indicators, modeling of measures to control the development process.

The calculations were carried out on a sector model consisting of 112746 cells with dimensions of 1425×901×23 m (Fig.1). The absolute depth of the gas-oil contact is 1562 m, the depth of the water-oil contact is 1573 m. The calculations were carried out for a multilateral well (MGZS) fishbone, consisting of the main horizontal wellbore 1050 m long and nine branches 500 m long. The total length of the horizontal wellbore is 5050 m. The main goal work is to determine the optimal location of the MSGS in the oil-saturated part of the reservoir. Calculations were carried out according to the following main technological indicators: cumulative production of oil, gas, liquids; flow rate of oil, gas, liquid; gas factor.

The calculations were carried out for 50 years for different options for the location of the MGZS along the oil-saturated thickness in the range of 1563-1572 m (the options for the location of the fishbone well varied from 1 to 10 m from the gas-oil contact zone).

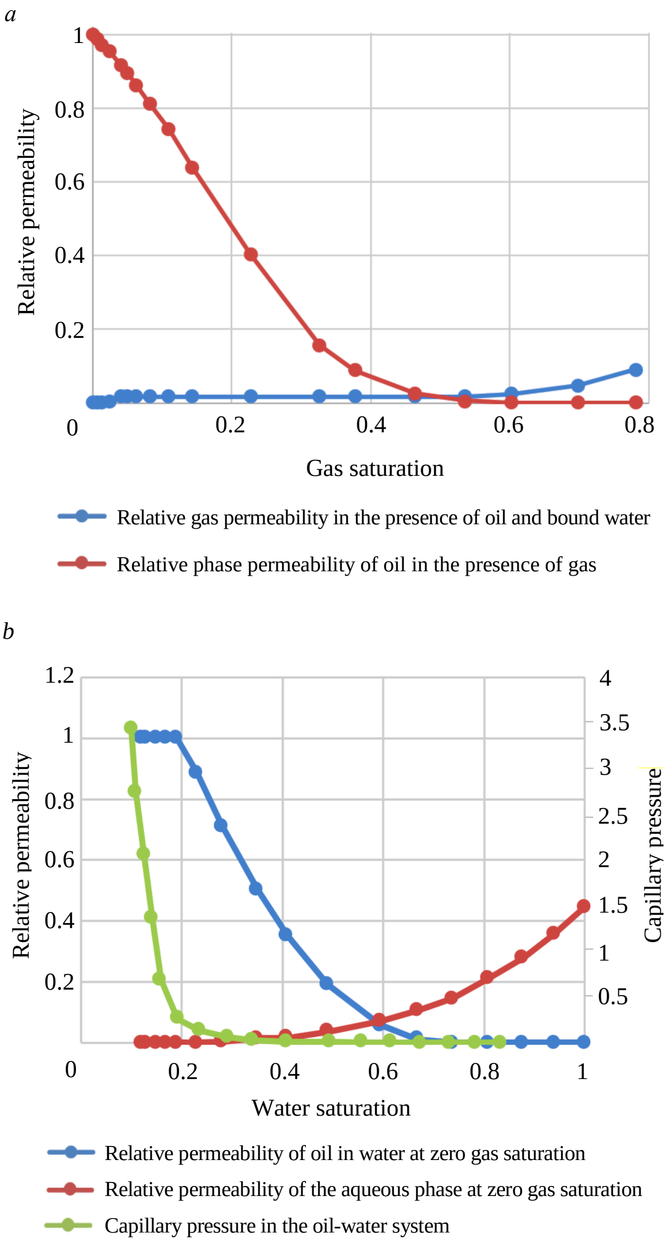

Fig.2. Relative gas-oil (*a*) and water-oil (*b*) phase permeabilities

Figure 2 shows the relative phase permeability of the fluids included in the model.

The main pressure-volume-temperature (*PVT*) properties of the fluid and the porosity and permeability properties of the reservoir, included in the model: oil density 864.2 kg/m^3; molecular weight 1000 kg/m^3; gas density 0.822 kg/m^3; reservoir water density at reservoir conditions 1236 kg/m^3; water compressibility 0.255 atm^{-1}; reduced pressure 140.1 atm; viscosity 8.0 cPs; critical water saturation 0.23; critical gas saturation 0.05; residual oil saturation in water 0.31; residual oil saturation for gas 0.43; residual water saturation 0.08; permeability 369.3 mD; porosity 0.16.

The discussion of the results. As a result of the simulation, the following results were obtained. Figure 3 shows the dynamics of oil production for different well locations. Well location depths ranging from 1563 m (the closest location t o the GOC) to 1572 m (the furthest location from the GOC) were used as designation of the well location options.

From the analysis of dependences in Fig.3, one can see how the well flow rate will change during the development period (50 years). When modeling in the Tempest software product, a limitation was set – the maximum liquid flow rate was 60 m^3/day. In addition, for this field, a GOR limit of 2400 m^3/m^3 was set (Fig.4) that corresponds to gas breakthrough. Figure 4 shows a stepwise decrease in the flow rate, which is typical for the estimated achievement of the gas factor and corresponds to a decrease in the flow rate in order to limit the gas inflow. From the analysis of the GOR data, one can clearly see how long it will take gas to break through from the gas cap into the well, which is equivalent to stopping the well for SBNGKM conditions. Due to inherent limitations in the Tempest simulator, when the maximum value of the GOR is reached, a decrease in the flow rate is observed. Gas breakthrough into the well for the case of the maximum distance from the GOC (1572 m) will occur by 2031, for a well with a depth of 1571 m – by 2030, and for a well with a depth of 1570 m – by 2029.

Analysis of the water cut calculation results (Fig.5) at different depths of the MGZS location shows that the water cut of the well production reaches 0.24 m^3/m^3 by the time of gas breakthrough for the case where the well is located at a distance of 1 m from the OWC. For depths up to 1567 m, there is a slight increase in water cut to 0.01, for depths of 1568; 1569; 1570; 1571 and 1572 m – increase in water cut up to the moment of gas breakthrough up to 0.02; 0.07; 0.13; 0.18 and 0.24 m^3/m^3, respectively.

Figure 6 shows the cumulative oil production at different depths of the fishbone well.

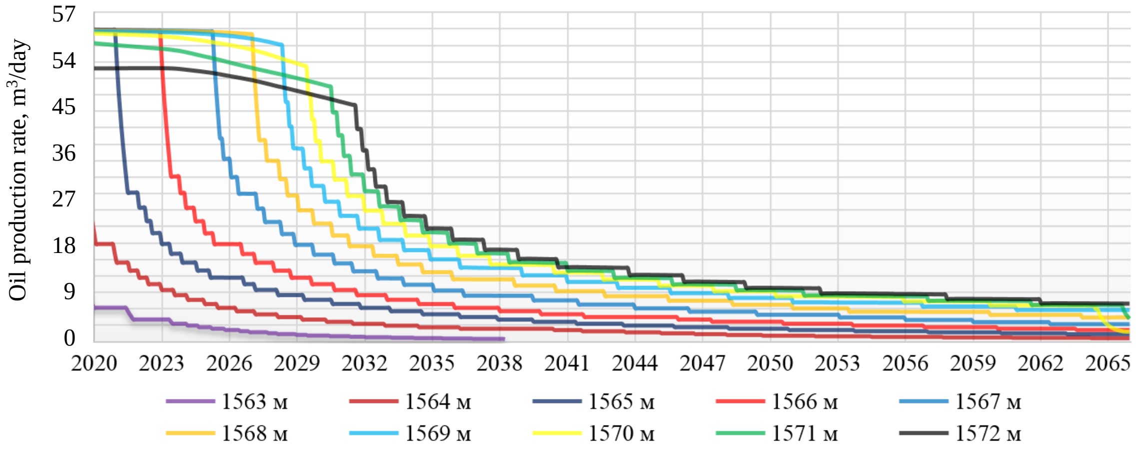

Fig.3. Dynamics of oil production at different depths of MGZS location

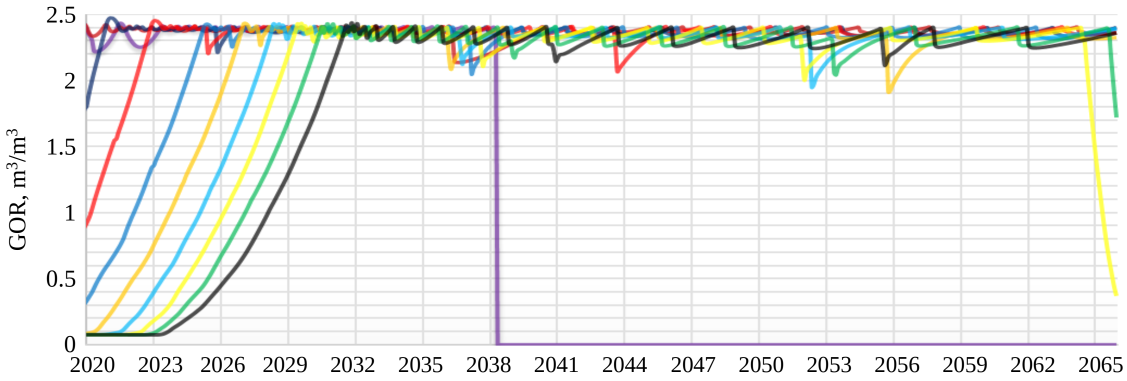

Fig.4. GOR dynamics at different depths of MGZS location
Symbols see in Fig.3

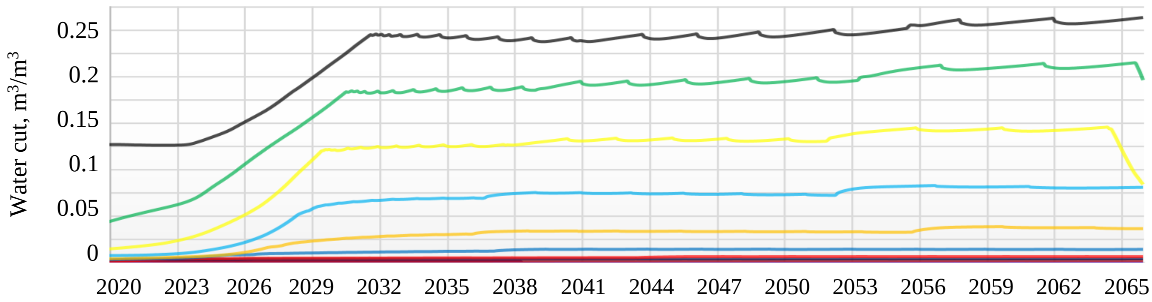

Fig.5. Dynamics of water cut at different depths of MGZS location
Symbols see in Fig.3

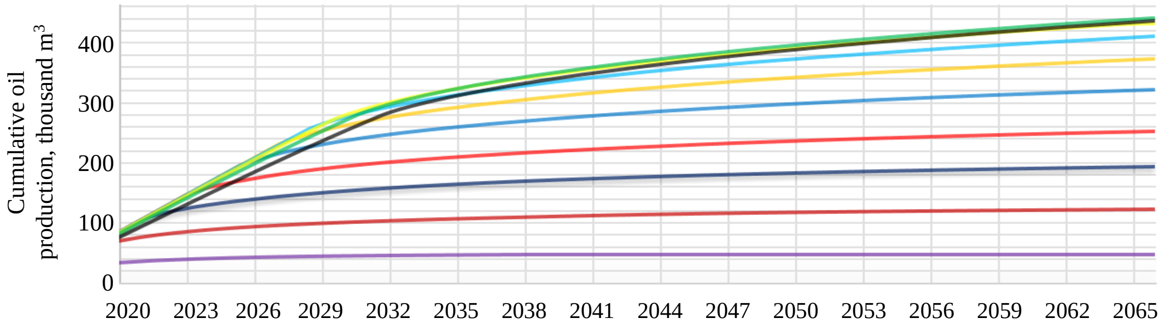

Fig.6. Dynamics of cumulative oil production at different depths of MGZS location
Symbols see in Fig.3

Based on the results of calculating the main technological indicators for different location of the fishbone well in the oil-saturated thickness, it can be concluded that the location of the multilateral well at a depth of 1571 m (9 m from the GOC) is optimal in terms of cumulative oil production, which will be 440,000 m^3 after 50 years of operation. At the same time, the cumulative oil production by the beginning of the gas breakthrough is of greater interest, which is tantamount to shutting down the well. With such a consideration, it can be concluded that the well with a depth of 1571 m shows the best results in terms of "cumulative oil production". By 2031, the cumulative oil production from a 1572 m well will be 274,000 m^3; by 2030, the cumulative oil production from a 1571 m well – 280,000 m^3; by 2029, the cumulative oil production from a 1570 m well – 267,000 m^3.

The adopted optimal wiring for gas-water-oil zones at the SBNGKM corresponds to the option with a 2-3 m distance from the water-oil contact, which is confirmed by the calculations. However, it should be taken into account that for the conditions of development of the SBNGKM, due to the thickness of the oil-saturated layer and the size of the gas cap changing over the area of the field, it is necessary to drill the well individually for a certain area of the field depending on the existing restrictions [25, 26].

An important feature of the SBNGKM, which should be taken into account when drilling a well, is the presence of an inclined oil-water contact. According to the results of the data from the wells of the SBNGKM, it is possible to map the inclined oil-water contact. In this case, a layer with increased viscosity is found in the contact zone. The current working version of the presence of a non-horizontal OWC is accepted as "relatively young neotectonic movements, the consequences of which are currently not fully compensated by gravitational forces due to the high viscosity of oil in the lower part of the deposit and the low phase permeability of water" [28].

The existence of inclined oil-water contacts in fields, especially those associated with the ancient deposits is an established fact. Attempts to explain the nature of the OWC slope are still debatable [30].

At the SBNGKM, in the intervals of 1564-1580 m, there is a slight inclination of the OWC in the southeast direction. According to the results of well logging, core study and analysis of reservoir samples approximately in the indicated intervals, an oil layer with an increased viscosity is established. This observation is confirmed by the results of field and laboratory studies of reservoir fluids and core. According to laboratory analyzes of deep interval oil samples, an increase in oil viscosity in the reservoir section is noted from 6.5-9 cP in the upper part of the section to 24-28 cP at the level of water contact. The thickness of the high viscosity zone is 1-1.5 m [29-31].

Let us conclude that well drilling in the presence of high-viscosity oil zones can be carried out even closer to the OWC. In this case, the high-viscosity oil zone will be a kind of screen against water breakthrough into production wells. Thus, it is possible to justify the drilling of the well at the closest possible distance from the OWC (closer than 2 m), thereby obtaining the maximum possible increase in oil production.

The results of the work allowed us to draw the following conclusions:

1. With the help of hydrodynamic modeling, using the sector model of the SBNGKM, the optimal location of the fishbone well was determined at an absolute mark of 1571 m, which corresponds to a distance of 9 m from the GOC and 2 m from the OWC. At this location, the maximum value of cumulative oil production is observed both until the moment of gas breakthrough into the well (which is observed after 10 years of operation) and for the estimated period of 50 years.

2. The need for an individual approach to well drilling was determined, taking into account changes in the thickness of the oil-saturated layer and gas cap in the field, as well as the presence of zones with high-viscosity oil. Given these limitations and circumstances, it is possible to justify and carry out well drilling at the closest possible distance from the OWC.

Conclusion. In the work, using hydrodynamic modeling, the optimal location of a multilateral fishbone well with nine branches with a total length of a horizontal wellbore of 5050 m in an oil rim with a thickness of 11 m in difficult geological conditions of the SBNGKM was revealed. It is necessary to further study and refine the zones of high-viscosity oils of the SBNGKM to make additions and changes to the filtration model, at the same time it, is possible to justify the drilling of a complex multilateral fishbone well at a minimum distance from the oil-water contact in certain zones of the field, which will lead to an increase in the oil recovery factor in this field.

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