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Techniques to Boost Oil Production in the Development of Multi-Reservoir Fields

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Abstract

The development of multi-layer oil and gas fields, the productive formations of which have low flow and reservoir properties (FRP), poses a severe problem in the operation of wells. When exploiting formations with a single well, there are challenges in effectively controlling the development of each formation. This can lead to difficulties in resolving issues related to the distribution of produced oil and injected liquid between the formations. To improve well operation efficiency, it is essential to impact the bottomhole zone (BHZ), which is determined by the geological and physical characteristics of the productive formation. In light of the reservoir›s clayey and low-permeability nature, this study has confirmed the significant success of hydraulic fracturing in conjunction with the proposed physical and chemical interventions to impact the wellbore zone within the hydrocarbon field under investigation. It has resulted in a substantial increase in oil production. This led to certain formations experiencing a significant increase in oil production, from 2.7 to 53 tons per day.

Keywords: Multi-Layer Field, Hydraulic Fracturing (HF), Botomhole Zone (BHZ), Low Permeability, Oil Production.

1. Introduction

The oil field under study is the Priobskoye field, a massive oil field located in Russia. It is situated in the Khanty–Mansi Autonomous Okrug of Western Siberia. This field was discovered in 1982 and divided by the Ob River into two parts: the left and right. Development of the left bank started in 1988, while the development of the right bank began in 1999. The oil deposits are located at a depth of 2.3-2.6 km with an oil density of 863-868 kg/m^3. The oil has a moderate paraffin content of 2.4-2.5% and a sulfur content ranging from 1.2-1.3%. As of the end of 2005, the field has 954 production wells and 376 injection wells. There were 178 wells drilled in the last year [1-4].

The main oil reserves in the Priobskoye field are concentrated in Neocomian deposits, in the AS10, AS11, and AS12 formations. A peculiarity of the geological structure of the Neocomian deposits is that they have a mega-cross-bedded structure, formed in the conditions of a deep-sea basin. The main oil deposits are associated with lens-shaped sand bodies confined to shelf and clinoform Neocomian deposits, the productivity of which is determined by the presence of reservoir rocks in the well section [5-8].

The formations AS10, AS11, and AS12 reservoir rocks exhibit low reservoir properties due to the composition of clay-carbonate cement and its distribution in rock pore space. In productive formations, two types of reservoir rocks are identified: those with dispersed clay and carbonate content and micro-heterogeneous reservoirs, represented by sandstones and siltstones interlayered with clayey-carbonate and clayey layers [9-12].

The oil reservoirs of the Priobskoye field have a complex geological structure, both in area and in section. The reservoir rocks of the AS10 and AS11 formations are classified as medium- and low-productivity, and the reservoir rocks of the AS12 formation have abnormally low productivity [13-16].

One of the main methods of enhanced oil recovery (EOR) in the Priobskoye field is maintaining reservoir pressure by injecting large volumes of water. Three types of water are used as flooding agents: Cenomanian, fresh and commercial water. All these waters differ in composition, mineralization, amount of impurities and oil-displacing properties [17-20].

Cenomanian water is injected into productive formations during the initial development stage to maximise oil production rates. When wells undergo waterflooding, they are injected with fresh water to change the flow directions

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within the productive formations. This process increases oil recovery by causing clay minerals to swell and block the main conductive pores in high-permeability reservoirs. It also connects low-permeability formation intervals to flow processes [21-24]. Injection of freshwater begins only at high values of water cut in wells - from 85 to 90%. The use of alternative flow diverter technologies, which involve injecting sediment-forming compositions, polymer-dispersed, and fiber-dispersed systems into productive formations, is restricted by the low permeability of reservoir rocks, which is less than 0.150 µm2, and by formation temperatures exceeding 88 ºC [25-28].

When attempting to enhance oil recovery from productive formations through water flooding, elevated reservoir temperatures may restrict the effectiveness of using surfactants (SF) in aqueous solutions with concentrations ranging from 0.05 to 0.1%.This high temperature leads to the destruction of surfactants, and lowers oil saturation of formations by more than 50%, with a water cut of production ranging from 30 to 60% [29-32].

In this particular research endeavour, our primary goal was to improve the overall operational effectiveness of oil wells. It is crucial to thoroughly analyze the impact on the bottom hole formation zone (BHF), which is highly influenced by the reservoir formation's geological makeup and physical properties that contribute to oil production.

2. Materials and Methodology

The use of technology for displacing oil with hydrocarbon gases will significantly increase oil production since the hydrocarbon composition of the oil is in the optimal area of its application [33-36]. The content of fatty hydrocarbons in the associated gas of the Priobskoye field is more than 30%, which helps to maximize the oil recovery factor. Reservoir pressures in productive formations vary from 23.9 to 25.0 MPa and significantly exceed saturation pressure, which facilitates the use of this technology.

To increase the productivity of wells, it is planned to use physical and chemical methods of influencing the wellbore zone. To treat the bottom-hole zones of injection wells, it is recommended to use clay acid treatments (CAT) of the following composition: 14% HCl + 5% HF + Surfactant. Processing of reservoir zones of production wells is carried out in two stages. In the first stage, clay acid composed of 10% HCl + 4% HF is pumped into the wellbore zone along with acetone or glycol up to 35% and surfactant up to 1%.In the second stage, the wellbore zone is exposed to strong organic solvents, which are forced into the formation. After the completion of solvent injection, the well is developed without technological shutdown.

Hydraulic fracturing (HF) is one of the most effective methods for increasing the production and development of oil and gas reserves from low-permeability reservoir rocks [37-40].

Horizontal oil well operations in low-permeability, layered, and clayey productive formations at the Priobskoye field can lead to a notable decrease in the oil recovery factor. This is primarily because the wells may penetrate individual permeable layers, leaving a significant portion of the productive formation without proper coverage during the development process [41-44]. To address this issue, it is essential to create directional wells whose boreholes penetrate the entire oil-saturated formation. The efficiency of operating directional wells is not high enough, since the drainage area of the formation is very limited. To overcome these difficulties, it is proposed to use hydraulic fracturing, both in directional and horizontal wells. In this case, during the development of the Priobskoye field, a special development system is created, which can be defined as a borehole-fracture development system.

For all the main productive formations of the Priobskoye field, a linear three-row development system was adopted with the placement of wells along a triangular grid with a distance between rows and wells of 500 m. The first development option was placing injection rows in a cross-strike of the productive formations. In the second development option, changes were made to the placement directions of cutting rows of wells, which is associated with the need to use deep-penetrating hydraulic fracturing in these formations. During hydraulic fracturing, cracks propagate in productive formations mainly in the meridional direction. In the case of placing rows of injection wells across the strike of formations, it remains possible to experience accelerated water flooding of production wells. The fractures propagate perpendicular to the injection rows, reducing the distance between the fracture and the injection row. For the second development option, the injection wells should be oriented along the strike of the formation. This orientation reduces the chances of rapid water flooding of production wells. When the injection wells are oriented in this manner, the cracks formed during hydraulic fracturing run parallel to the injection wells, leading to a significant increase in the flow rate of production wells and the infectivity of injection wells [45-48].

Enhanced oil recovery methods, such as hydraulic fracturing, allow us to keep the rate of decline in oil and gas production at a low level, ensuring the rational development of oil and gas fields. A generalized analysis of the impact of hydraulic fracturing on the development indicators of fields in Western Siberia shows that most of them have common features that characterize the success of this type of work. In a generalized form, they represent a system of criteria reflecting a set of ranges of changes in geological, field, technological, and economic criteria within which high efficiency of hydraulic fracturing can be expected. The main purpose of the criteria is to ensure the ability to quickly sample the wellbore for hydraulic fracturing at a given development site. The presented group of criteria includes both geological and technological factors [49-52].

Geological factors to consider at the development site include oil and gas reserves, which will contribute to additional production. It's important to ensure that the deposit is not

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depressurised during the hydraulic fracturing process and that aquifers are not connected to production. The presence of a gas cap near the oil deposit and the proximity of the hydraulic fracture to the oil-water contact (OWC) can result in gas breakthroughs or premature flooding of wells with bottom water.

Hydraulic fracturing is affected by factors such as the volume of hydraulic fracturing fluid and the concentration of propane material. These factors determine the depth of penetration of the hydraulic fracture into the formation and its conductivity [53-56].

The basic requirements for production wells for hydraulic fracturing are reduced to the following criteria. In the section of wells undergoing hydraulic fracturing, the thickness of both the overlying and underlying screens must be a minimum of 5 meters. Additionally, the current reservoir pressure ratio to the initial reservoir pressure must be at least 0.9. It should be sustained by employing injection wells two to three months before the commencement of hydraulic fracturing. The technical condition of wells must meet specific requirements relating to the annulus condition and cementing quality. Cementing of the annular space should be 20 m above and below the perforation interval in the presence of aquifers. The object recommended for hydraulic fracturing must have a thickness of at least 5 m and produce an influx of oil with a water cut of less than 50%. Similar requirements apply to injection wells. All these criteria and factors affect the technological efficiency of hydraulic fracturing and additional oil production.

The main criterion for the effectiveness of hydraulic fracturing is the amount of additional production due to hydraulic fracturing, which ensures the feasibility of using this method. The additional production is calculated by comparing the average oil production rate over the five months before hydraulic fracturing was performed to the increase in oil production rate after hydraulic fracturing. The completion time of the hydraulic fracturing effect is taken based on the reduction in oil flow rate below the base flow rate.

3. Results and Discussions

The study of well performance results allows us to identify the main reasons for the low efficiency of hydraulic fracturing in individual wells. The first group includes wells where a low increase in oil and fluid production after hydraulic fracturing is associated with low reservoir potential. The second set of wells demonstrates a rise in fluid production and a modest increase in oil production following hydraulic fracturing. This is due to the water flooding of production wells near injection wells and the existence of inter-casing cross-flows.

The main parameters that determine the value of well flow rates are the effective thickness of reservoir rocks and reservoir properties of rocks in the bottom hole zone of the formation. The composition of the inflow in a well proposed for hydraulic fracturing is determined by the current oil saturation of reservoir rocks, the ratio of the thicknesses of oil-saturated and water-saturated formations and the size of the thicknesses opened during hydraulic fracturing, oil-saturated and water-saturated reservoir rocks.

The minimum oil saturation level at which reservoir rocks can release oil and water is between 46% and 52%, while the minimum oil saturation level at which rocks do not contain mobile oil ranges from 28% to 36%.

The clay interface between oil-saturated and water-saturated reservoirs must have a minimum thickness of 6 to 14 meters to ensure water isolation from aquifers. This requirement varies depending on the hydraulic fracturing technology used, as it is influenced by the height restrictions of the fracture.

Calculations can be used to determine the dependence of the height of a clay screen broken through by a crack on the thickness of the formation, the rate of injection of hydraulic fracturing fluid and its viscosity. In this case, average values for the deposits are taken for parameters characterizing the strength characteristics of rocks: Young's modulus and Poisson's ratio. The magnitude of stress between the formation and the clay screen is assumed to be 4 MPa for formations with a sandiness coefficient below 0.6; 5 MPa for formations with a sandiness coefficient above 0.6. When injecting hydraulic fracturing fluid at a minimum rate of 2.0 to 2.5 m3/min, the crack can penetrate the clay screen from 5 to 7 meters.

Hydraulic fracture penetration into the overlying and underlying clay screens changes when the perforation interval shifts relative to the middle of the formation. To calculate the penetration depth of a hydraulic fracture into the upper and lower screens, the following formulas are used [57, 58]:

$$D_U = \frac{h}{2-(h_P-h_{FR})} \quad (1)$$

$$D_L = \frac{h}{2-(h_{FB}-h_P)} \quad (2)$$

Where D_U is the depth of crack penetration into the upper screen, m; D_L—depth of crack penetration into the lower screen, m; h—maximum crack height, m; h_P—depth of the middle of the perforation interval, m; h_{FR}, h_{FB} - depths of the roof and bottom of the formation, m.

To make a conclusive decision on hydraulic fracturing, it is imperative to thoroughly evaluate the formation's overall thickness, the section's dissection, and the specific position of the perforation interval for the intended hydraulic fracturing technology.

To clarify the limiting values of the thickness of the clay screen, it is necessary to conduct a large amount of additional research into the strength properties of rocks.

Before the hydraulic fracturing process is carried out, the technical condition of the well is determined: absence of breakage or crushing of the production casing, its tightness, quality of cementing of the casing in the perforation interval 15–20 m up and down from it, depending on the hydraulic fracturing technology. These requirements are determined by forming a hydraulic fracturing crack (height from 30 to 50 m).

The optimal value of the well deviation angle from the vertical when entering the productive formation should be no more than 10°, and the formation perforation interval should be no less than 2–4 m with a perforation depth of 0.2 to 0.8 m. Fulfilment of these conditions for studying the influence of the zenith and azimuth angles of the wellbore on the structure of the cracks formed on cased well models. This allowed us to conclude that in wells with a zenith angle of no more than 10°, one hydraulic fracture is formed, rather than a system of cracks, as in wells with a zenith angle between 10° and 30°.It is necessary to ensure an effective volume of perforation of the productive formation, considering the ratio of the height of the perforation interval and the depth of penetration of the perforation channels into the formation.

A smaller perforation interval must correspond to a greater depth of perforation channels. The criteria for selecting a well for hydraulic fracturing depends on the proximity of the injection zone, the state of reserves development, and the formation pressure in the deposit [3, 60-63].

The main condition for the success of hydraulic fracturing is the availability of reserves in the well drainage zone. When more than 75% of the recoverable reserves are recovered, the probability of increased water cut after hydraulic fracturing increases. It is crucial to avoid hydraulic fracturing in water injection zones to reduce the risk of behind-the-casing flows, especially when dealing with a 10 to 15-m thick clay section.

Hydrocarbon-based fluids are used to carry out hydraulic fracturing at the Priobskoye field, containing diesel fuel and a special fluid OG-4, consisting of a thickener (gellant) and an activator to enhance the effect of the gellant. To destroy the polymer structure of the hydraulic fracturing fluid, the destroyer (breaker) is introduced into its composition, which destroys the gel structure of the hydraulic fracturing fluid after 48 hours. Artificial propane is used as a propane - aluminium production waste of grades 20/40, and 40/70. It is suggested that materials such as glass, plastic balls, corundum grains, or agglomerated bauxite be utilized for hydraulic fracturing in deep formations with high temperatures.

According to the technological schemes for conducting hydraulic fracturing, it is recommended to conduct single local or directional and multiple hydraulic fracturing. In single hydraulic fracturing, all formations opened by perforation are simultaneously exposed to the pressure of the hydraulic fracturing fluid. With directional hydraulic fracturing, the hydraulic fracturing fluid only affects the selected formation with low productivity. Multiple hydraulic fracturing allows the hydraulic fracturing process to be carried out in many layers simultaneously. In single and multiple hydraulic fracturing operations, the positions of the cracking are influenced by the addition of blocking materials into the hydraulic fracturing fluid. These materials include elastic balls made from granular, oil-soluble naphthalene and other substances. They are introduced using two-packers or preliminary hydro-sandblasting perforation.

Before hydraulic fracturing, hydro-sandblast perforation is performed in the well, and two packers or one packer and a sand bridge are installed in the hydraulic fracturing interval. The orientation of the hydraulic fracturing crack in the horizontal plane depends on the direction of natural stresses in the rocks of the productive formation. During hydraulic fracturing, a crack is formed in the productive formation, developing in both directions from the well. When performing a single local hydraulic fracturing, 5 to 10 tons of propane are consumed, and during massive hydraulic fracturing, the amount of propane increases to several tens of tons. During hydraulic fracturing in a productive formation, the concentration of prop pant in the hydraulic fracturing fluid is set depending on its holding capacity and the purpose of the hydraulic fracturing. For the wells of the Priobskoye field, fluids with a bearing capacity of 200 to 500 kg/m^3 are used.

An analysis of hydraulic fracturing work in wells of the Priobskoye field shows the high efficiency of hydraulic fracturing in low-permeability reservoir rocks of Encomia deposits. This method of intensifying oil production makes it possible to drain trapped oil reserves in intermittent reservoirs of the field. It is considered the primary method for increasing oil production (see Table 1).

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Table 1: List of Wells Recommended for Hydraulic Fracturing

Well number	Formation	Actual mode		Potential mode		Increase in oil flow rate, t/day
		Liquid flow rate, m^3/day	Oil flow rate, t/day	Liquid flow rate, m^3/day	Oil flow rate, t/day	
1 069	AS10	5,7	4,7	38,0	31,0	26,3
1 222	AS10	6,0	4,8	14,0	11,0	6,2
1 083	AS10	4,0	3,4	9,0	8,0	4,6
1 084	AS10	4,7	3,9	13,0	11,0	7,1
3 059	AS10	1,6	1,3	5,0	4,0	2,7
3 060	AS10	2,5	1,7	6,0	4,0	3,3
2 020	AS10	12,0	10,1	75,0	63,0	53,0

Table 1 shows that the use of hydraulic fracturing at the Priobskoye field, following the implementation of physical and chemical methods suggested in this study to affect the wellbore zone, has been remarkably successful. This has led to a substantial increase in oil production rates.

4. Conclusions

The application of hydraulic fracturing at the Priobskoye field has proven to be highly successful, enabling significant growth in oil production rates. This method has been instrumental in increasing the productivity of production wells and the infectivity of injection wells, particularly when dealing with challenging clayey, low-permeability reservoir rocks at the Priobskoye field. By intensifying oil production in this way, trapped oil reserves in intermittent reservoirs of the field can be drained.

The implementation of the proposed technology to impact the bottom hole formation zone (BHF), determined by the geological and physical characteristics of the productive formation, unequivocally led to significant advancements resulting from the use of hydraulic fracturing. This resulted in certain formations experiencing a significant increase in oil production, from 2.7 to 53 tons per day.

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