Forecasting for application of formation stimulation to BV6 formations of Las Eganskoye oil field

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Abstract. Studies described in this paper were aimed at solving a set of problems related to selection, technological justification and design of enhanced oil recovery. Theoretical and laboratory studies of remaining reserves production were conducted, as well as prediction of their efficiency if applied to formation of Las Eganskoye oilfield.

1. Introduction
Commercial oil content within the Las Eganskoye oilfield is established for the BV6 formation, represented by grey fine sandstone with interlayers of siltstone and mudstone. In the roof of the subseries, there is a Pokachevsky band of clays. The formation is characterized with a uniform thickness along the section. [1, 2].

During 1989-2019, there were over 450 instances of injection well treatment with various compounds at the oil field, aimed at improving oil recovery from the field, as well as over 120 operations of water-alternating-gas injections. The aim of these interventions was to increase the efficiency of residual reserve recovery from the BV formations. In total, counting from the beginning of the oil field development, over thirty various processes were applied to the production formation BV6, including creation of insulating screens in high wipeout zones to change the direction of filtration flows of the fluid.

By properties of their components, the technologies are divided into gel-forming, sludge-forming (forming precipitation by means of specific chemical reactions in formation conditions), emulsion and acidic compositions [3–5]. Application of such technologies is necessitated by a high stratification factor, significant non-uniforming of the reservoir permeability, high water cut of production wells due to a premature water breakthrough from the water injection wells. As a result of formation of flow-diverting screens in the formation, a process starts that involves low-permeability intervals with high residual reserves into production, thus leading to reduced water cut in production wells and an increase in total oil recovery from the field as a whole. An indirect efficiency criterion for the...
measures undertaken is leveling-off (change) in input profiles of treated wells, witnessing to a change in filtration flows and possible involvement of low-permeability intervals that were previously not covered by the action, as well as reduced water cut [5].

2. Materials and methods
Under conditions present in development targets of the Las Yeganskoye deposit, in order to reduce progressing water cut and improve efficiency in remaining reserve recovery, it is recommended to apply a complex enhanced oil recovery method that includes application of polymer thickener systems (in injection wells) and measures to stimulation of production in observation wells [6, 7]. Process implementation of the complex method implies injection of a gel-forming component with a thickener into the bottom-hole and uninvaded zones, leading to reduced hydroconductivity of the flushed part of the formation. As a result of increased pressure gradient between the injection zone and the recovery zone, the technology allows involving remaining reserves of oil-saturated sublayers with low permeability into active recovery, as well as those sublayers that were previously insufficiently influenced by the flooding [8–12].

Simultaneously with activities in injection well stock, there are process activities performed at the production wells with the aim to well stimulation. If it is necessary to reduce water cut of the production fluid before the production stimulation commences, it is recommended to treat the wells with emulsifying agents.

Water-alternated-gas injection is one of the most efficient methods of oil reservoir development for the BV₆ formation group of the Las Eganskoye deposit. The technology is applied as a method for maintaining reservoir pressure and consists in mixing separated associated gas and water with subsequent injection of the water-gas mixture (WGM) into the productive formations. On WGM injection, a process of active mass exchange starts between the formation fluids, as the gas is being dissolved in the formation oil, resulting in the improved mobility of the latter; at that, the gas permeates the most flushed interlayers and changes direction of filtration flows. As a result of the formation stimulation, oil displacement efficiency and formation coverage values improve. In general, application of the method is aimed at recovery of high viscosity oils with viscosity over 5 mPa sec., with asphaltene content of under 16%, paraffin content under 4%, and sulphur content under 2%. The bubble point pressure shall not exceed the initial value, or be lower than the initial formation pressure by 25–50%. Such values of the parameters will ensure increased efficiency of the process, as they significantly decrease the injection pressure requirements.

3. Results and discussion
From analysis of well data and generalization of theoretical and laboratory field studies, general criteria were developed for selection of formations for WGM injection. The first criterion is the formation depth, which is limited by technical capabilities of the pumping units used. When the oil-saturated formations are deposited within 2 to 5 degrees and oil displacement has a horizontal nature of motion, efficiency of the process is in inverse ratio to decrease in formation thickness. Additionally, the method is applicable under various temperature differentials, e.g., when the temperatures are quite low and the formation pressure is low, a small transition layer is formed due to increased content of light components coming to oil from the gas phase. When the temperatures and formation pressures are rather high, the transition layer is more active and extensive, which is additionally driven by evaporation of light oil fractions and their transition into the gas phase. One of the most advantageous criteria for application of the technology is presence of lithologically-linked interlayers with low and high permeability within the pay-zone deposit. Remaining oil reserves shall provide profitability of the method application with state-of-the-art technical means. For the conditions at the production formation BV₆ of the Las Eganskoye deposit, the remaining oil reserves shall exceed 5.5 thousand tonnes per well.

WGM injection may be applied at any stage of oil field development. It should be noted that efficiency of the method is significantly higher if it is undertaken at an early stage. Large-scale WGM
interventions with optimal ratios require significant hydrocarbon resources in the form of gas (dry, associated or rich). When WGM is injected through the production string, in order to ensure zonal isolation and production casing integrity, the candidate wells shall have continuous cementing through the whole interval from the casing shoe to the wellhead. Annular space shall be made tights with a packer and filled with corrosion inhibitors. The production string shall be used with gas tight connections and be provided with inhibitor and circulation valves.

Analysis of laboratory studies of oil displacement with WGMs (Figure 1) allows for a conclusion that when one reservoir pore volume of WGM is injected, displacement coefficient and oil recovery are improved by means of displacing remaining oil from the high-permeable part of the formation model (permeability of 0.976 μm²). After that, increase of the coefficients from the high-permeable interlayer is decreasing and active displacement of hydrocarbons from low-permeable interlayers starts. This period is related to formation of maximum gas saturation in the porous part of the formation model, resulting in reduction of phase permeability of oil and water. This is confirmed by increased displacement coefficient due to low-permeable interlayers in the formation model. When 1.6 of reservoir pore volume of WGM is injected, the displacement coefficient for the high-permeable formation model amounts to 7.77%, comprising 81.8% of the total oil volume produced from the flooded volume model of the formation by means of water-alternating-gas injection. For the low-permeability model, coefficient increment during the WGM injection amounted to 3.56%.

Increase in recoverable reserves was calculated according to A.P. Krylov, using the following formula:

$$K_{REC} = K_{DIS} \cdot K_{COV},$$

where $K_{REC}$ is the oil recovery coefficient, unit fraction; $K_{DIS}$ is the displacement coefficient, unit fraction; $K_{COV}$ is the coverage coefficient, unit fraction.

Figure 1. Results of laboratory experiments in oil displacement. Curve marking: 1 – oil displacement from high-permeable reservoirs using WGMs; 2 – oil displacement from high-permeable reservoirs by formation water; 3 – oil displacement from low-permeable reservoirs using WGMs; 4 – oil displacement from low-permeable reservoirs by formation water.

Laboratory experiments and numerical modeling of oil displacement processes with WGMs have shown that increase in the displacement coefficient by 5-7 points (average values with considerations
for oil reserves) will provide an increase in oil recovery coefficient by 4.1–5.5 points with the same coverage coefficient. As a result of integral physical and chemical action onto the productive formation, an insignificant increase of the displacement coefficient by 1.1–1.5 points is predicted then displacement increases by 4.8–5.3 points, thus allowing increasing the oil recovery coefficient by 4.5–5.7 points.

Implementation of proposed measures to improve flooding efficiency, an integrated physical and chemical action and injection of WGMs is proposed for four sources in the BV₀ formation. The action sources include 1-2 injection wells and 4–6 observation wells. As a result of the action, it is predicted that oil rate increases (on average) by 1.8–3.2 t/day and water cut in produced fluid decreases by 7-15 points. Numerical simulation shows 1600–2100 t/well in operation increase in production. Increase in oil recovery coefficient is predicted at a level of 4–5 points, on condition that the measures are taken before development of the formation ceases. If the measures prove to be successful, it is recommended to expand the experiment to other areas of the same production formation and to consider field experiments at other oil fields of West Siberia.

4. Conclusion
In conclusion, let us note that application of gas-based methods of formation stimulation provides additional reserves for oil production. The studies undertaken made it abundantly clear that application of water-alternating-gas injection to productive formations in West Siberia will allow water cut of produced fluid by 7-15 points, increasing the oil rate of observation wells by 1–3 t/day. Stimulation of remaining and hard-to-recover reserves in the BV₆ formation will allow increasing resource recovery by 4-5 %.

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