Optimization of FPM system in Barsukovskoye deposit with hydrodynamic modeling and analysis of inter-well interaction

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Abstract. Development of most deposits in Russia is accompanied with a high level of crude water cut. More than 70% of the operating well count of Barsukovskoye deposit operates with water; about 12% of the wells are characterized by a saturated water cut; many wells with high water cut are idling. To optimize the current FPM system of the Barsukovskoye deposit, a calculation method over a hydrodynamic model was applied with further analysis of hydrodynamic connectivity between the wells. A plot was selected, containing several wells with water cut going ahead of reserve recovery rate; injection wells, exerting the most influence onto the selected producer wells, were determined. Then, several variants were considered for transformation of the FPM system of this plot. The possible cases were analyzed with the hydrodynamic model with further determination of economic effect of each of them.

1. Introduction.

Currently, there is a situation in the oil industry, where reserves of many oil deposits are considered depleted and a significant number of deposits are considered difficult to develop. Due to this, extraction of the majority of recovered reserve of deposits is provided with application of systems of formation pressure maintenance (FPM).

However, flooding of the reservoir being developed is accompanied with increased non-uniformity in distribution of filtration flows, both vertically and over the area, which, in its turn, may cause preliminary flooding of some wells and late flooding of others. In the end, all these factors lead to a reduction in efficiency of the system of formation pressure maintenance [1-3].

Thus, accounting of information on hydrodynamic connectivity of wells, as well as that of existing filtration flows in the reservoirs being developed, plays an important role in selection of optimization options of the flooding system.

This research is dedicated to selection of a FPM optimization variant for the BS_{11} reservoir of Barsukovskoy deposit with considerations for hydrodynamic interaction between the wells.

At that, it is necessary to solve the following tasks:
1) selection of a plot on the deposit to transform the existing development system;
2) analysis of the hydrodynamic interaction between the selected wells: both producers and injectors in the surrounding;
3) selection of candidate wells for transformation of the formation pressure maintenance system;
4) analysis of the selected transformation variants using a hydrodynamic model;
5) determination of the economic effect from each of the variants.
2. Materials and methods.

Barsukovskoye deposit was discovered in 1984. Administratively it is located in the Purovsky district of Yamalo-Nenets Autonomous Okrus of Tyumen Oblast, 52 km to the north of the township of Purpe and 110 km to the east of the township of Tarko-Sale.

The nearest deposits are Komsomol'skoye and Gubkinskoye, located 20 km to the north-east; Vyngayakhinskoye is 43 km to the south-east and East Tarkosalinskoye is 98 km to the north-east of Barsukovskoye.

Oil presence in Barsukovskoye is linked to formations BS\_1-8, BS\_2-10, BS\_11. The main object is formation BS\_11 (80% of geological reserves). The net oil pay zone for separate formations is from 2.6 to 11.4 m.

The latest reserve calculations for Barsukovskoye deposit have shown that its approved oil reserves are in categories В+С\_1: balance – 106.4 million tonnes, recoverable – 41.4 million tonnes. Oil recovery index is 0.388 (by respective objects: BS\_1-8 – 15.7 million tonnes and 4.5 million tonnes; BS\_2-10 – 5 million tonnes and 2.2 million tonnes; BS\_11 – 85.6 million tonnes and 44.8 million tonnes).

The types of accumulations are tabular-arc, massive, lithologic and limited by faults. A significant part of them is bottomed with water throughout the area, characterized with a complex non-uniform structure (in both area and section) and complex distribution of oil and gas.

Drilling-out of principal accumulations of the Barsukovskoye deposit is completed, but drilling continues in the northern accumulations of formations BS\_11, BS\_10-2 and BS\_10-1. The well count of the main objects is characterized by a high water cut; some wells are abandoned or suspended.

Initial recoverable oil reserves for the BS\_11 formation comprise 39,389 thousand tonnes in category B and 5,126 thousand tonnes in category C\_1. As of 01.02.14, 25684.4 thousand tonnes of oil are withdrawn, the withdrawal comprises 55% of IRR with water cut of 70%; the current Oil recovery index is 0.388. The production is performed with a FPM system with a nine-point scheme of well placement. Porosity coefficient for the formation is 0.18 unit fractions on average; oil saturation is 0.58 unit fractions, permeability is 1,95 mD, oil density at surface is 820 kg/m\(^3\).

Traditionally, determination of hydrodynamic connectivity between the wells is by injection of special tracer fluids through injection wells. However, this method is very costly and harms the environment [4].

In this case, the most appropriate application of specialized software modules may be, e.g., Analysis of Crossborehole Interactions developed by RN-Ufa-NIPIneft. The module, provided with a relevant mathematical apparatus, makes it possible to calculate degrees of hydrodynamic connection for each pair of a producer and injector well from the field development data, as well as to analyze directions of water breakthrough from the injectors to the producers. Analysis of Crossborehole Interactions allows determining a share of each injector in the output of each producer. Input information of the software module is water intake of the injectors, well flowrate of producers for a certain period of development. At that, the share of an injector in the output of a producer is calculated in such a way that the difference between the modeled and historical flowrates is the lowest. While modeling the fluid flowrate, a mode of well inflow is assumed including the effect of retardation and a drainage radius. The software module allows analysis of selected producers with advanced water cut and injectors surrounding them.

In the end, the calculations allow constructing diagrams from the algorithm proposed by the software by solving relevant differential equations, which show historical and modeled flowrates of the wells in question [8].

The characteristic curves plotted allow assessing hydrodynamic interaction between the producers and injectors, as well as a share that each injector has in the output of each producer.

For the experiment, a plot is chosen in the field with advancing water cut producers, and several variants of the existing development system transformation are selected.

Then, on the basis of the existing hydrodynamic model, a forecast is made for the selected plot, with the help of a Roxar Tempest hydrodynamic simulator. A base case of development without any changes in the FPM system is analyzed first, then – some variants with changes of the well lattice.
3. Content of the method and assessment of its efficiency.

The plot for transformation of the development system was selected in such a way that it has wells with water cut going ahead of the recovery rate.

Further, it is necessary to detect injectors which are sources of this advance flooding and their share in the output of a given producer. These data will allow optimizing the FPM system by lowering the water intake of the injectors exposed or by turning them off altogether. Thus, the result of the operations shall be a lower water cut in the produced liquid, including involvement of previously undrained reserves of the deposit into development.

Four variants of FPM transformation were analyzed for the concerned plot:

1) base case - without any changes in the development of BS$_{11}$ formation, it will be used for comparison against all other transformation cases;
2) case 1 – disengaging the wells which have the most influence on the flooding;
3) case 2 – disengaging the wells with the highest influence with simultaneous engaging of one injector which is currently off-line;
4) case 3 – disengaging the wells with the highest influence with simultaneous engaging of two injectors which are currently off-line, switching one well which is currently in the accumulation mode to injection, limiting water intake of the well two-fold with the most influence.

The analysis resulted in obtaining indicators of development system dynamics for all four transformation cases, which are shown in Table 1.

| Parameter                  | Base case | Case 1 | Case 2 | Case 3 |
|----------------------------|-----------|--------|--------|--------|
| Oil flowrate, t/day        | 385       | 340    | 480    | 535    |
| Fluid flowrate, m$^3$/day | 1200      | 950    | 1250   | 1170   |
| Cumulative fluid production, m$^3$ | 9,000,000 | 8,600,000 | 8,900,000 | 9,070,000 |
| Cumulative oil production, t | 5,900,000 | 4,900,000 | 5,200,000 | 5,400,000 |
| Water intake, m$^3$/day    | 1100      | 950    | 1050   | 1300   |
| Water cut, unit fraction   | 0.77      | 0.71   | 0.68   | 0.69   |
| Number of producers        | 110       | 110    | 110    | 109    |
| Number of injectors        | 39        | 35     | 36     | 38     |

For each of the proposed FPM system transformation cases, an economic effect of such optimization was calculated with the results given in Table 2.

| Indicator                               | 2015 | 2016 | 2017 | 2018 |
|-----------------------------------------|------|------|------|------|
| Economic effect, basic variant, in millions of rubles | 165.8 | 220.0 | 353.2 | 410.6 |
| Economic effect, variant 1, in millions of rubles   | 158.2 | 195.5 | 326.4 | 357.4 |
Economic effect, variant 2, in millions of rubles

|        |        |        |        |
|--------|--------|--------|--------|
|        | 166.8  | 222.4  | 372.5  |
|        | 448.2  |        |        |

Economic effect, variant 3, in millions of rubles

|        |        |        |        |
|--------|--------|--------|--------|
|        | 175.4  | 230.5  | 380.5  |
|        | 460.1  |        |        |

The data obtained show that the most efficient variant is Case 3 of the FPM transformation, that is, disengaging the wells with the highest influence when simultaneously engaging two injectors that are currently off-line, switching to injection one well that is currently in the accumulation mode, limiting water intake of the well two-fold with the most influence.

4. Conclusion.
This research was dedicated to selection of the FMP system optimization variant with considerations for hydrodynamic interactions between the wells by analysis of degree of their connectivity and further hydrodynamic modeling, taking the BS\(_{11}\) formation of Barsukovskoye deposit as an example.

A plot was selected at the deposit, containing wells with advancing flooding, developing ahead of the reserve recovery. Then, a software module was used to determine the injector wells which exert the most influence onto the selected producer wells, as well as their share in the output of these producers.

From the results of this analysis, several options for the FPM transformation were proposed, aiming to reduce the water cut in the produced fluid and to involve previously undrained reserves into development. Analysis of the FPM system optimization cases was performed on the basis of a hydrodynamic model of the BS\(_{11}\) formation in the Roxar Tempest simulator. The results of the calculations for the proposed cases were compared to that of the base case.

For each of the proposed FPM system transformation cases, an economic effect of such optimization was calculated.

The data obtained show that the most efficient variant is the Case 3 of the FPM transformation, that is, disengaging the wells with the highest influence with simultaneous engaging of two injectors that are currently off-line, switching to injection one well that is currently in the accumulation mode, limiting water intake of the well two-fold with the most influence. The total economic effect of optimization, following this case, will be 60.4 million rubles over 4 years. Additional oil extraction will amount to 70,000 tonnes.

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