Forecasting the use of non-stationary waterflooding in the conditions of oil deposits in Western Siberia

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Abstract. The researchers have developed simplified models of the studied formations in the Langepasneftegaz TPP to forecast the effectiveness of using non-stationary waterflooding with flow control and flow diverting technologies. To increase oil recovery and intensify the influx of oil from the reservoirs, they recommended the integration of technologies. The article shows that complex technologies for impacting oil and gas deposits using non-stationary waterflooding aimed at increasing the oil recovery coefficient and limiting the movement of water in the reservoir while stimulating the bottom-hole zones of the reservoir will significantly increase the efficiency of field development.

1. Introduction

Oil recovery enhancement methods are usually based on increasing the coverage of productive formations by the impact of different waterflooding modifications [1–6]. In recent years, there has been an intensive increase in water cutting of well production that leads to a decrease in the energy efficiency of oil production and in general the efficiency of field development. It resulted in an urgent need to increase the coefficient of oil recovery from productive formations while reducing the amount of associated water and intensifying the production of wells.

Meanwhile, it is important to develop approaches to planning effective impact on oil deposits using the technology of non-stationary waterflooding and increase oil recovery with a decrease in water cutting in well production and intensification of oil production.

To forecast the effectiveness of the use of non-stationary waterflooding with flow control and flow diverting technologies, the authors developed simplified models of the studied formations. They
recommend a combination of technologies to increase oil recovery and intensify the flow of oil from the reservoir.

Integrated technologies for dealing with oil and gas deposits by means of non-stationary waterflooding aimed both at increasing the oil recovery coefficient and limiting the movement of water along with the productive formation with simultaneous intensification treatments of the bottom-hole zones of the formation, will significantly increase the efficiency of field development [7–9].

2. Materials and methods

The specific geological and physical conditions of the fields of the Langepasneftegas TPP determine the main directions for choosing a stimulation effect and increasing oil recovery, which allow covering almost all factors affecting the completeness and rate of oil recovery. They include:

- hydrodynamic methods: non-stationary waterflooding;
- treatment of the bottom-hole zone (BHP): measures for the intensification of oil production covering both the producing and injection well stock;
- physical methods: hydraulic fracturing;
- chemical methods: measures to control the coverage of formations by waterflooding through injection wells.

In its fields, Langepasneftegas TPP in large volumes uses hydrodynamic methods to enhance oil recovery divided into:

- non-stationary waterflooding;
- development of non-drained reserves, including drilling wells in stub zones of the reservoir and compaction of the grid of wells.

Non-stationary waterflooding allows to change the direction of filtration flows in productive formations. Non-stationary waterflooding is one of the types of wave action that causes flows between layers with different characteristics and unbalanced pressure in a porous medium. The process eventually moves to a quasistationary form.

Non-stationary waterflooding is used in deposits and fields with a reservoir permeability of at least $0.03 \mu \text{m}^2$, formation porosity of at least 12.5%, formation clay content of not more than 5%, oil viscosity of not more than 150 MPa · s, and oil saturation of up to 60%.

Efficiency increases with formations heterogeneity.

The technology is applicable in fractured reservoirs. It is suitable both in the early and late stages of reservoir exploitation [10–12].

Correct forecasting the effectiveness of any impact on the formation includes a methodological approach using process modelling. The choice of the impact method and its justification are important stages in the design of the application of enhanced oil recovery (EOR) methods, including non-stationary effects.

We have developed a simplified model of the studied formation using geological and physical information about the productive formation of the field with well-known techniques for forecasting and analyzing the effectiveness of cyclic waterflooding. Based on the analysis of averaged geological and statistical sections of productive thicknesses, we identified the main interlayers of the Las Yeganskoye field and their parameters.

The values of these parameters are such that the average values of the permeability of the reservoir model, porosity and productive thickness correspond to typical values for the field. The properties of the selected interlayers are constant along strike. We modelled mathematically cyclic waterflooding based on quasi-one-dimensional equations of two-phase filtration assuming that between adjacent zones of different permeability there occurs an instantaneous uniform redistribution of phases over the entire cross-section of the interlayer.

In this work, we calculated the parameters of the cyclic effect using a two-dimensional numerical model of two-phase filtration in a layered-heterogeneous formation.

We assumed that the formation is being developed by an in-line well system with a distance of 500 m between the injection and producing rows. We solved the problem in a two-dimensional vertical
section, excluding capillary and gravitational forces. The vertical permeability of the formation is 0.01 of the horizontal component.

Table 1 shows the model of the formation of JV 1/1 of the Las Yeganskoye field used in the calculations.

### Table 1. Formation model used for mathematical modelling

| Formation, field         | Interlayer number | Thickness, m | Absolute permeability, μm² | Porosity, % |
|--------------------------|-------------------|--------------|-----------------------------|-------------|
| JV 1/1, Las Yeganskoye   | 1                 | 3.0          | 0.014                       | 16          |
|                          | 2                 | 1.5          | 0.005                       | 16          |

The cyclic exposure period consists of equal half-periods corresponding to the shutdown regime of injection wells and production wells. We determined the initial saturation of the formation with water and oil from solving the waterflooding problem until the current water cutting in the production on the studied formation (72%).

### 3. Results and Discussion

We performed the calculations for several tens of exposure cycles. Figure 1 presents examples of calculations results of the rate of oil production during normal waterflooding and the application of cyclic impact.

Cumulative oil production during waterflooding and cyclic impact is equal to the area under the corresponding curves in this figure. The difference between the accumulated volumes of oil during cyclic exposure and waterflooding is the additional oil production from the impact.

Figure 2 shows periods of this difference averaged over the periods of several cycles. As shown in Figure 2, additional production increases with the growth of period, peaks on 13 days and then falls to negative values. Thus, we determined the optimal cycle period and additional oil production for the analyzed object. Table 2 presents forecasting the results of cyclic waterflooding in the above model. The significant expected effectiveness of the method for the conditions of the Las Yeganskoye field is obvious.

The application of complex effects gives good results. The analysis of the results of the implemented measures to improve the waterflooding system shows a high predicted effect when combining non-stationary waterflooding with flow diverting and regulatory technologies while systematically applying treatments of bottom-hole formation zone to intensify production.

### Table 2. Forecast of the cyclical waterflooding results

| Formation           | Volume, m³ | Additional oil production, t / area | Type of processed wells |
|---------------------|------------|-----------------------------------|-------------------------|
| JV 1/1 Las Yeganskoye field | Period 30 days | 1,800 t per year per 1000 m² | Production and injection wells |
Figure 1. Examples of calculating the rate of oil production during flooding and cyclic exposure for different half-periods - 30 days (a) and 90 days (b)

Figure 2. Additional oil production during cyclic exposure, reduced to several periods of exposure per 500 m² of the affected area
4. Conclusion
To forecast the effectiveness of the use of non-stationary waterflooding with flow control and flow diverting technologies, the authors developed simplified models of the studied formations.

They recommend a combination of technologies to increase oil recovery and intensify the flow of oil from the reservoir.

Integrated technologies for impacting oil and gas deposits using non-stationary waterflooding, aimed both at increasing the oil recovery coefficient and limiting the movement of water along with the productive formation while intensifying treatments of the bottom-hole zones of the formation, will significantly increase the efficiency of field development [7–9].

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