Forecasting the parameters of non-stationary water flooding of oil deposits

S A Yaskin¹, V V Mukhametshin², V E Andreev³⁴, G S Dubinskiy³⁴

¹ TPE “Langepasneftegaz”, LLC “LUKOIL–Western Siberia”,
43, Lenin Street, Langepas, Khanty-Mansi Autonomous Area – Yugra, 628672, Russian Federation
² Ufa State Petroleum Technological University, 1, Kosmonavtov st., Ufa, Republic of Bashkortostan, 450062, Russian Federation
³ State autonomous scientific institution “Institute of strategic research of the Republic of Bashkortostan”, 129/3, October avenue, Ufa, Republic of Bashkortostan, 450075, Russian Federation
⁴ FBFR “Mechanical Engineering Research Institute of the Russian Academy of Sciences”, 4, Bardina Street, Moscow, 119334, Russian Federation

E-mail: vv@of.ugntu.ru

Abstract. Non-stationary flooding and water withdrawal with changing the direction of filtration flow as a secondary advanced recovery method allow enhancing oil deposit coverage by filtration processes, reducing or eliminating the amount of bypassed oil in productive formations. Process modelling should be provided for correct forecast about the efficiency of non-stationary formation stimulation. A formation model was designed for modelling cyclic water flooding. There are cross-flows between interlayers of reservoir robbing which have different porosity and permeability properties and unbalanced thrust in pore space. It is noted that when applying ordinary water flooding, high formation heterogeneity, higher than average oil viscosity and low permeability make it impossible to reach even average efficiency of oil pool development. The choice of a stimulation technique and its justification is an important step of planning in order to apply non-stationary stimulation. A possibility to apply non-stationary flooding efficiently for the analysed object has been established.

1. Introduction
In Russia 90 % of oil reservoirs and deposits are developed by using different modifications of water flooding. In conditions of high formation heterogeneity, higher than average oil viscosity and low permeability applying just water drive method (without additional techniques and reagents) demonstrates low effectiveness. In such cases it is possible to apply hydro-dynamic enhanced oil recovery methods. Hydro-dynamic methods are rather promising to enhance oil recovery. In that respect, it is worth mentioning non-stationary flooding, water withdrawal with changing the direction of filtration flow and, as the special case, cyclic stimulation. The applied non-stationary flooding as a method of enhanced oil recovery is performed to recover the bypassed oil of the reservoir with filtration by changing the direction of filtration flow in productive formations. In fact, non-stationary
flooding is a kind of wave stimulation causing a cross-flow between interlayers of reservoir robbing which have different porosity and permeability properties and unbalanced thrust in pore space. Non-stationary flooding process (the wave one with various frequency periods) becomes quasi-stationary after some time [1]. Water flooding in non-stationary mode is carried out in oil reservoirs and deposits when the reservoir permeability is more than 0.03 mkm² and porosity is more than 12.5 %, oil saturation is up to 60 %, acceptable volume shale is not more than 5 %, oil viscosity is not more than 150 mPas. The increase in non-uniformity of productive formations improves the effectiveness of applying non-stationary stimulation. The technology can be used for the pools coincided with fractured reservoirs. Non-stationary flooding can be applied in the early stage of reservoir development as well as in the late stage.

High formation heterogeneity, higher than average oil viscosity, low reservoir permeability when applying ordinary water flooding make it impossible to reach even mean level of oil recovery efficiency and, consequently, average efficiency of oil pool development [2, 3]. Providing changes in filtration flow directions at the expense of non-stationary flooding and water withdrawal from the deposit allows enhancing the formation coverage by drainage, reducing the amount of bypassed oil or even eliminating it in productive formations which results in enhanced oil recovery. Therefore, efficiency enhancement, development and forecasting of non-stationary flooding technology are urgent for oil extraction industry.

2. Aim
To forecast the efficiency of non-stationary flooding for specific geological and physical conditions.

3. Methods and materials
The correct forecasting of efficiency of any reservoir stimulation requires using process modelling. The choice of a stimulation technique and its justification is an important step of planning in order to apply enhanced oil recovery methods including non-stationary stimulation [2, 4-10].

A simplified model of the reservoir under study was developed by using geological and physical information about the productive formations of the deposit, by using well-known techniques [2, 4-6, 9-14] to forecast and analyze the efficiency of applying cyclic water flooding. This model is suitable for modelling cyclic water flooding. The calculation of cyclic stimulation parameters was done by using a two-dimensional computational model of two-phase filtration in the stratified inhomogeneous formation.

4. Results
Non-stationary flooding has some cyclical pattern. Here total operating and shut-in time of the well is accepted as a complete cycle for one well. One of the most important parameters of non-stationary (cyclic) stimulation is a time period of injection semi-cycle. The main interlayers of X-Eganskoye deposit and their parameters were sorted out based on the analysis of the averaged geological-statistic sections of net pay thicknesses. The values of these parameters are like the average values of the formation model permeability, porosity and net pay thickness which correspond to typical values of the deposit. The properties of the sorted-out interlayers are constant along the strike. Mathematical modeling of non-stationary (cyclic) stimulation was first carried out on the basis of quasi-one-dimensional equations of two-phase filtration considering the hypothesis that there is a phase redistribution between contiguous zones with different permeability happening instantly and uniformly within the cross sectional area of the interlayer [4, 10, 13].

For the conducted research the calculation of cyclic stimulation parameters was done by using a two-dimensional computational model of two-phase filtration in the stratified inhomogeneous formation. It is supposed that the formation is developed by applying line-drive water flooding. There is a distance of 500 m between the row of injection wells and the row of producers. The task was solved in a two-dimensional variant due to the vertical slice without taking gravity and capillary forces
into account. The vertical formation permeability was considered equal to 1 % of the horizontal permeability value.

The model of J1 formation of X-Eganskoye deposit used in calculations is represented in Table 1.

Table 1. The formation model used for mathematical modeling

| Formation, deposit | Layer number | Layer thickness, m | Absolute layer permeability, mkm² | Layer porosity, % |
|--------------------|--------------|--------------------|-----------------------------------|------------------|
| J1, X-Eganskoye    | 1            | 3                  | 0.014                             | 16               |
|                    | 2            | 1.5                | 0.005                             | 16               |

The period of cyclic stimulation consists of two equal half-cycles corresponding to the shut-down period of injection wells and producers. The initial formation saturation with water and oil was determined due to the task solution for flooding till the moment of reaching 72 % by the current water cut at the formation under study. The calculations were done for several dozens of stimulation cycles.

The cumulative oil production when applying non-stationary flooding was compared with the analogous figure got by ordinary water flooding. The difference between the cumulative oil volumes got at non-stationary flooding and ordinary water flooding is incremental oil production obtained due to the stimulation. This difference, averaged due to the periods of several cycles, is represented for different periods in Figure 1.

![Figure 1](image)

**Figure 1.** The incremental growth dynamics of daily oil production at non-stationary flooding normalized to several periods of stimulation within the area of 500 m².

As it is seen from the figure, incremental oil production increases when the period increases reaching its maximum when the period is equal to 13 days and then it decreases up to negative values. Thus, the optimal period of the cycle and incremental oil production were determined for the analyzed object.
The prepared forecast for results of non-stationary flooding based on the given model (Table 2) revealed the evident considerable expected efficiency of the method for conditions of X-Eganskoye deposit.

### Table 2. The forecast for incremental oil production due to applying non-stationary flooding

| Formation, deposit | Volume, m³ | Incremental oil production, tons per zone | The type of wells |
|-------------------|------------|-------------------------------------------|------------------|
| J1, X-Eganskoye   | 30-day period | 1800 tons per year within 1000 m² | Producers +Injection wells |

The conducted hydrodynamic calculations by using a layer-inhomogeneous model of the formation revealed that non-stationary flooding for the given geological and physical conditions results in enhanced oil recovery. In future it is possible to forecast non-stationary flooding efficiency based on the actual data analysis of reservoir and deposit developments and hydro-dynamic model building for real deposits.

### 5. Conclusion

Based on the obtained results of forecasting non-stationary flooding efficiency on the two-layer model of the formation, the conditions of successful application of the stimulation on the example of the particular deposit are shown.

Non-stationary flooding in the given geological and physical conditions can provide perceptible incremental oil production. Non-stationary flooding is a fairly promising method for enhanced oil recovery.

### References

[1] Dubinsky G S 1998 The solution of the equation filtration under cyclic stimulation Geology, Geophysics and Development of Oil and Gas Fields **12** 29-31

[2] Mukhametshin V V, Andreev V E, Dubinsky G S, Sultanov Sh Kh and Akhmetov R T 2016 The usage of principles of system geological-technological forecasting in the justification of the recovery methods SOCAR Proceedings **3** 46–51 DOI: 10.5510/OGP20160300288

[3] Yakupov R F, Mukhametshin V Sh, Zeigman Yu V, Chervyakova A N and Valeev M D 2017 Metamorphic aureole development technique in terms of Tuyumazinskiye oil field Oil industry **10** 36–40 DOI: 10.24887/0028-2448-2017-10-36-40

[4] Alvarado V, Manrique E, Vasquez Y and Nordeide L M 2003 An approach for full-field EOR simulations based on fast-evaluation tools 24th Annual Workshop and Symposium IEA Collaborative Project on Enhanced Oil Recovery

[5] Bibars O A and Hanafy H H 2004 Waterflood Strategy-Challenges and Innovations Abu Dhabi International Conf. and Exhibition (United States of America: Society of Petroleum Engineers) DOI: 10.2118/88774-MS

[6] Joseph J, Taber F, David M and Seright R S 1996 EOR Screening Criteria Revisited SPE/DOE Improved Oil Recovery Symposium (United States of America: Society of Petroleum Engineers)

[7] Kadyrov R R, Nizaev R Kh, Yartiev A F and Mukhametshin V V 2017 A novel water shut-off technique for horizontal wells at fields with hard-to-recover oil reserves Oil industry **5** 44–47 DOI: 10.24887/0028-2448-2017-5-44-47

[8] Khisamov R S, Abdrahmanov G S, Kadyrov R R and Mukhametshin V V 2017 New technology of bottom water shut-off Oil industry **11** 126–128 DOI: 10.24887/0028-2448-2017-11-126-128

[9] Manrique E 2009 Enhanced oil recovery (EOR): trends, risks, and rewards ACI Optimising EOR Strategy (London)
[10] Stirpe M T, Guzman J, Manrique E and Alvarado V 2004 Cyclic water injection simulations for evaluations of its potential in lagocinco field *SPE/DOE Symposium on Improved Oil Recovery* (United States of America: Society of Petroleum Engineers) DOI: 10.2118/89378-MS

[11] Schiozer D J and Mezzomo C C 2003 Methodology for field development optimization with water injection *SPE Hydrocarbon Economics and Evaluation Symposium* (United States of America: Society of Petroleum Engineers) DOI: 10.2118/82021-MS

[12] Seccombe J C, Lager A, Webb K J, Jerauld G and Fueg E 2008 Improving waterflood recovery: LoSaITM EOR field evaluation *SPE Symposium on Improved Oil Recovery* (United States of America: Society of Petroleum Engineers) DOI: 10.2118/113480-MS

[13] Alvarado V 2002 Analytical simulation for evaluation of EOR opportunities in Venezuela *IFL Projects and Opportunity Maps Master’s Thesis in Exploration and Production* (Paris)

[14] Alvarado V, Ranson A, Hernandez K, Manrique E, Matheus J, Liscano T and Prosperi N 2002 Selection of EOR/IOR opportunities based on machine learning *European Petroleum Conference* (United States of America: Society of Petroleum Engineers) DOI: 10.2118/78332-MS