Recommendations on thermal non-stationary waterflooding when modeling oil field development

E.M. Almukhametova

Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54a, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation
E-mail: elikaza@mail.ru

Abstract. The work shows the efficiency of non-stationary waterflooding at first and second exploitation zones under contemporary conditions of Severnye Buzachi oil field. Moreover, at the sites with cyclic treatment, the volume of non-stationary waterflooding significantly decreased due to implementation of the technology of thermal treatment. The problem is the choice of a most preferable oil production method in terms of technological and economical conditions of high-VI oil reservoir development. However, the most important issue is the study of the possibility to combine two said technologies with joint benefit from their strong points for the sake of maximum oil displacement efficacy.

1. Introduction
The implementation of combined technologies for development of high-VI oil deposits is a promising direction.

Combined technologies are the methods of oil reservoir development that at some point: 1) combine different advanced recovery methods (ARM) that differ in physical, physicochemical principles or treatment time, mutually increasing their efficiency, extending the range of efficiency range and/or mitigating negative effects on the development parameters and residual oil reserves; 2) use the specificity of mining and geological conditions of the reservoir and geological and physical properties of rocks and fluids as an element of a development technology; 3) account for the development history, current condition of reservoirs and development system.

2. Materials and Methods
Obtained results given in the paper are justified using hydrodynamic simulators tested and recommended for application in oil and gas production industry. The field data were processed on a personal computer using analytical methods. The developed recommendations were tested at an oil field and demonstrated positive technological effect.

The data presented in the work were used for planning and implementing the program of thermal non-stationary waterflooding (combined technology) at Severnye Buzachi oil field.

3. Results and Discussion
After comparing the methods of oil recovery increase, the following conclusions were made [2]:

1. The technology of thermal treatment has slowly growing efficiency, which is connected with slow warm-up of the reservoir. To achieve appreciable results, one should pump into the reservoir

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
colossal volume of hot water. However, during the reservoir warm-up, the efficacy of thermal treatment increases, i.e. the effect persists for long. The technology of non-stationary waterflooding has progressive effect, which after some time decreases.

2. An obvious development of both technologies is the combination of their strong points. The application of non-stationary thermal waterflooding has shown that the technological effect—at some periods—becomes synergistic.

The only direction of the non-stationary waterflooding method development at Severnye Buzachi oil field is the combination of the technology with thermal treatment [3, 5]. Severnye Buzachi oil field has all conditions to develop such direction.

1. The method of non-stationary waterflooding has proven itself to be efficient in development of oil field production facilities.

2. The major project solution in further development of the field is the application of thermal treatment by pumping in hot water.

3. Currently, thermal treatment is performed at the major part of the oil field. Even at the sites of non-stationary waterflooding, a fraction of intake wells involved into non-stationary waterflooding pump in hot water.

4. Modern equipment allows performing the non-stationary thermal treatment.

The choice of a site for non-stationary thermal treatment was made with due consideration of technological and geological requirements.

Block 6b of the first production facility was chosen as the candidate site for cyclic thermal treatment [7, 10].

The reservoir of block 6b of the first production facility of Severnye Buzachi oil field belongs to highly permeable multi-compartmentalized and stratified reservoirs with high variety of average permeability values. On the other hand, the average permeability of the reservoir changes little along the lateral; the reservoir decompression zones mostly situated beyond the developed zone.

Laboratory studies of the oil property change during heating demonstrated the preferability of thermal treatment. On the other hand, oil field conditions proved the efficiency of non-stationary treatment. The investigation using hydrodynamical models has shown that the combination of these technologies will enable synergistic effect.

Current situation at block 6b of Severnye Buzachi oil field is characterized by the following features: high current water cut of produced oil (more than 92% on average) at target IRR no more than 32% on average. The rate of water cut increase does not correspond to the level of target initial recoverable reserves of oil.

This development state is mostly conditioned by high difference in the viscosities of displacing and displaced agent, high nonuniformity of the reservoir field permeability. In such conditions, the stationary system of Complete Recovery Maintaining (CRM) performing thermal treatment at the initial moment of time has low efficiency, since the thermal front has low propagation velocity. This means that the oil will be displaced under high water cut of the product.

In terms of this effect, the combination of the technologies of non-stationary waterflooding and thermal treatment at the proposed site will allow significant increase in the oil recovery efficacy.

The proposed technology of non-stationary thermal waterflooding can be effective for application at other deposits of high-VI oil. However, for this technology to be economically attractive, several conditions should be met. The technological criteria of the applicability of non-stationary thermal treatment technology come to the fore.

**Technological criteria:**

1. The site (oil field), before application of thermal non-stationary waterflooding, should already have hot water being pumped into the reservoir, i.e. all issues regarding the hot water supply of intake wells are already solved. In this case, non-stationary thermal treatment increases the efficiency of constant pumping of hot water at the expense of increased treatment coverage at periodical change of pressure field and initiation of interlayer fluid communication.
2. The water cut of extracted product of site (oil field) wells should be higher than 70-75%. According to modeling [2, 8], thermal stationary waterflooding is effective at initial development stage of high-VI oil deposits. In this case, heating of oil occurs that is concentrated in highly permeable channels (layers). After waterflooding of highly permeable channels (layers), the efficacy of thermal treatment abruptly drops. However, it is waterflooding of highly permeable layers which is recommended to be followed by non-stationary water flooding, for the water to penetrate into low-permeability layers of the reservoir and displace oil there. According to a number of authors, hot water has better washing properties. Concurrently, the target level of IRR should be low, i.e. the reservoir should contain large amount of hard-to-drain oil reserves.

3. The number of acting intake wells and reacting recovery wells should be sufficient to organize intense periodic treatment with large amplitude.

4. The number of combined intake wells (for two objects) should be minimal. This is conditioned by significant probability of interstratal downhole fluid communication in the combined well inventory, which appreciably degrades the efficiency of non-stationary waterflooding.

5. The accumulated compensation of fluid drainage by flooding should be no less than 75%. This requirement is stated by virtual loss of efficacy of non-stationary waterflooding technology under low reservoir pressure.

6. The preferable development systems are line-drive, block and block-closed systems.

**Geological criteria:**

1. The site should have reservoir with nonuniform permeable stratum. According to the results, the most preferable are reservoirs with nonuniform permeable stratum with small-thickness super reservoir and heavy low-permeable layers.

2. The fraction of movable oil reserves, concentrated in low-permeable reservoir layers, should be significant.

3. To organize the cyclic thermal treatment, the site should have minimal decompression zone volume and sufficiently uniform reservoir along the lateral. This is connected with non-effective thermal waterflooding in the presence of focused, spatially confined channels with low flow coefficient.

4. Oil viscosity under reservoir conditions can vary from 100 to 300 mPa*s. Oil can demonstrate non-Newtonian (viscoelastic) properties [1, 4, 6].

4. **Conclusions**

According to afore mentioned criteria, the effective non-stationary thermal treatment is applicable for many deposits of high-VI oil developed using thermal treatment (flooding with hot water). The examples are oil fields of Kazakhstan (Karazhanbas), Udmurtia, Tatarstan, Perm region.

**References**

[1] Almukhametova E M 2015 Analysis of the effectiveness of the current system of field development of Severnie Buzachi in the termination of non-stationary flooding and the transition to pumping hot water. *The problems of gathering, treatment and transportation of oil and oil products* 3 (101) 36-45

[2] Vladimirov I V, Veliyev E M, Almukhametova E M 2015 Complex technology heat non-stationary flooding for periodic operation of producing wells. *The problems of gathering, treatment and transportation of oil and oil products* 2 79-90

[3] Vladimirov I V, Almukhametova E M 2016 Non-stationary thermal effects in the development of high-viscous oil deposits. *Geology, Geophysics and development of oil and gas fields* 4 23-27

[4] Vladimirov I V, Almukhametova E M, Veliyev E M 2016 Conditions of the effective use of hot water flooding for development of heavy oil deposits with non-uniform permeability. *Neftyanye Khvoyastvo - Oil Industry* 9 62-65
[5] 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

[6] Akhmetov R T, Mukhametshin V V and Andreev A V 2017 A quantitative assessment method of the productive formation wettability indicator according to the data of geophysical surveys SPE Russian Petroleum Technology Conference (United States of America: Society of Petroleum Engineers) DOI: 10.2118/187907-MS

[7] Andreev A V, Mukhametshin V Sh and Kotenev Yu A 2016 Deposit productivity forecast in carbonate reservoirs with hard to recover reserves SOCAR Proceedings 3 40-45 DOI: 10.5510/OGP20160300287

[8] Zeigman Yu V, Mukhametshin V Sh, Khafizov A R and Kharina S B 2016 Prospects of application of multi-functional well killing fluids in carbonate reservoirs SOCAR Proceedings 3 33–39 DOI: 10.5510/OGP20160300286

[9] Wang J. et al. 2011 Low gas-liquid ratio foam flooding for conventional heavy oil. Petroleum Science 8, 3 335-344

[10] Zhdanov S A, Amiyan A V, Surguichev L M, Castanier L M, Hanssen J E 1996 Application of foam for gas and water shut-off: review of field experience. European Petroleum Conference. (Milan)