Crossref
DOI: 10.31643/2024/6445.16
Earth sciences

The method of non-stationary flooding and the conditions for its effective use in the operation of an oil field

[1]Effendiyev G.M., *[2]Moldabayeva G.Zh., [2]Tuzelbayeva Sh.R., [2]Imansakipova Z.B.,[3]Hongjun Wu

[1]Azerbaijan National Academy of Sciences, Baku, Azerbaijan
[2]Satbayev University, Almaty, Kazakhstan
[3]LLP "DPS Kyzylorda", Kyzylorda, Kazakhstan

*Corresponding author email: g.moldabayeva@satbayev.university

Received: *July 26, 2023*
Peer-reviewed: *August 17, 2023*
Accepted: *August 22, 2023*

ABSTRACT
The article describes the essence of unsteady waterflooding, which is one of the most effective methods of increasing the oil recovery factor, used to change the direction of filtration flows, which makes it possible to engage in the development of undeveloped oil reserves and reduce the rate of watering of the deposit in productive reservoirs. A common technological method of unsteady water flooding is the use of cyclic modes of operation of injection wells. The essence of this method is that at an unsteady state in the oil deposit, there are conditions for the continuous manifestation of elastic forces of the reservoir system. In a heterogeneous reservoir between different zones, channels, and fluid flows there are gradients of hydrodynamic pressures, due to which there can be fluid flows from one layer to another, from fractures to blocks, as well as changes in flow directions. During unsteady flooding of heterogeneous formations, a part of oil reserves in low-permeability layers or zones remains uncovered by injected water. The waterflooded reservoir appears as an unsystematic alternation of watered and oil-saturated microflows. While creating in such reservoirs alternately changing in value and direction of pressure gradients, conditions for injection water penetration into stagnant oil-saturated low-permeable zones and channels appear in the oil reservoir and oil movement from them to active drainage zones. As a result of the analysis, the positive effect of the implementation of unsteady waterflooding technology was revealed, and recommendations for improving its application at other operational facilities of oil fields were given.

Keywords: non-stationary flooding, injection well, cyclic injection, oil recovery, filtration, heterogeneity.

	Information about authors:
Efendiev Galib Mammadovich	*Doctor of Technical Sciences, Professor. Institute of Oil and Gas of the National Academy of Sciences of Azerbaijan, Baku, Azerbaijan. Email: galib_2000@yahoo.com*
Moldabayeva Gulnaz Zhaksylykovna	*Doctor of Technical Sciences, Professor, Satpayev University, st. Satpaeva 22, 050000, Almaty, Kazakhstan. Email:g.moldabayeva@@satbayev.university*
Tuzelbayeva Sholpan Ryskulbekkyzy	*Master of technical sciences, doctoral student, Satpayev University, st. Satpaeva 22, 050000, Almaty, Kazakhstan. Email: s.tuzelbayeva@satbayev.university*
Imansakipova Zemfira Beketovna	*Master of technical sciences, doctoral student, Satpayev University, st. Satpaeva 22, 050000, Almaty, Kazakhstan. Email: z.imansakipova@satbayev.university*
Hongjun Wu	*Master of technical sciences, LLP "DPS Kyzylorda", Amangeldy Imanov street, 112A, Kyzylorda, Kazakhstan. Email: wus520@mail.ru*

Introduction

Non-stationary flooding (NC) is applicable both at an early and late stage of development. It is also possible to use it in highly watered fields developed by the method of conventional stationary flooding, even after reaching the maximum cost-effective flow rate of producing wells. Methods of non-stationary flooding are widely used in oil fields, however, they are not always effective due to insufficient strict compliance with the recommendations [1].

Since there is a high water content in them, scientific and technical solutions for blocking permeable areas of the reservoir become crucial. In this regard, ways to use effective water insulation compositions are being investigated [[2], [3]]. A considerable number of compositions are known and great experience of their application in various geological and physical conditions has been accumulated. However, their technological efficiency is low and does not exceed 40–50 % [4].

The effectiveness of this method is influenced by the geological structure of the deposit, the current state of development (the flooding system, the working stock of wells, the level of waterlogging, the proportion and nature of the production of geological reserves), heterogeneity in permeability, etc [5]. Therefore, the need to predict the effectiveness of the cyclic impact process is an urgent task. The problem of water inflows has always remained at the center of attention, and in recent years, especially more often began to attract the attention of researchers [[6], [7]]. Theoretical and experimental studies aimed at studying on mechanism of origin of water inflows, reasons for their origin, and also search for methods of struggle against this phenomenon, were carried out.

The purpose of this work was to increase the elastic reserve of the reservoir system by periodically changing the water injection pressure. The analysis of geological field data carried out by the author showed that the traditionally considered geological factors and the filtration capacity properties of rocks do not exhaust all the factors affecting the flow rate of the well. The complex nature of the distribution of reservoirs and the high heterogeneity of the section were also taken into account, which resulted in a wide variety of deposits by types of natural reservoirs and the nature of saturation. The use of non-stationary flooding made it possible to reduce unproductive injection and reduce possible losses of mobile oil reserves [8].

The main part. Selection of a potential site for non-stationary flooding It is carried out taking into account the following circumstances, depending on the systems of development and organization of the cyclic process of injection and selection of liquid. When choosing options, it is necessary to take into account the location of injection and production wells by area, to prevent language water breakthroughs by changing the operating modes of wells, to pump water through nearby wells in opposite modes.

The stronger the heterogeneity of the formation, the higher the amplitude of pressure fluctuations should be, since with its growth the amount of pulsating energy introduced into the formation to overcome filtration resistances to the oscillatory in the fluid flow increases [9].

The choice of the optimal injection pressure should be carried out by taking into account the geological and physical characteristics of the formations, the analysis of field development data, the results of well research, and data on hydraulic fracturing. In nonlinear filtration, when the reservoir pressure increases, the permeability of the reservoir increases, and when it decreases, the periodic (cyclic) pressure change will lead to an additional increase in the average reservoir pick–up during the cycle, depending on the nonlinearity parameter and the amplitude of the oscillations [10].

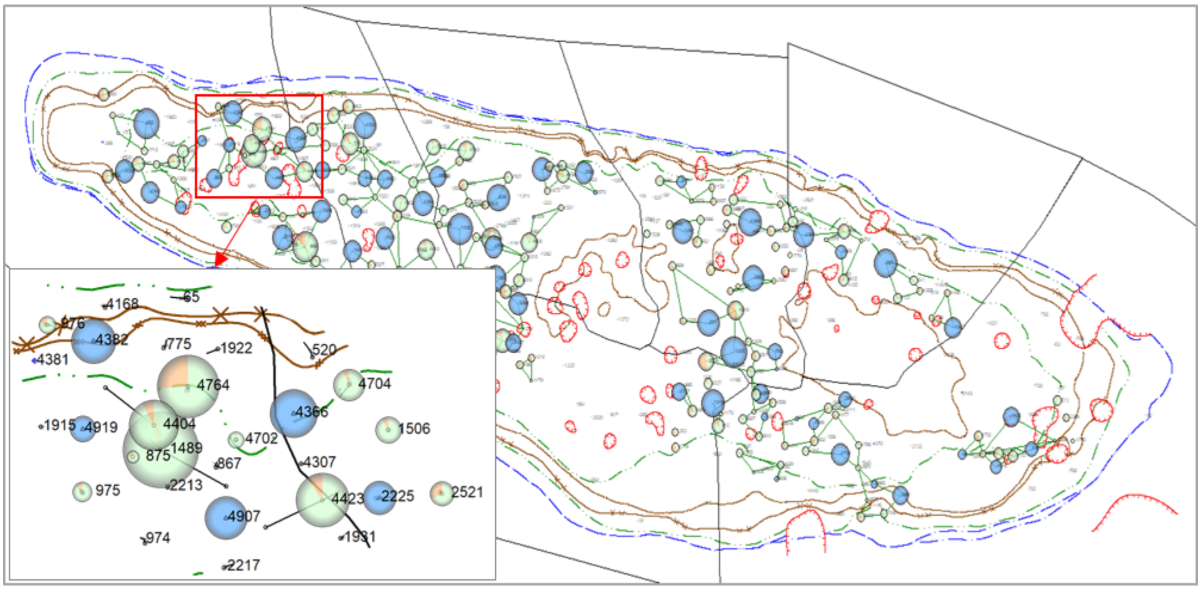

Figure 1 - Selected Yu-2+3 for experimental work

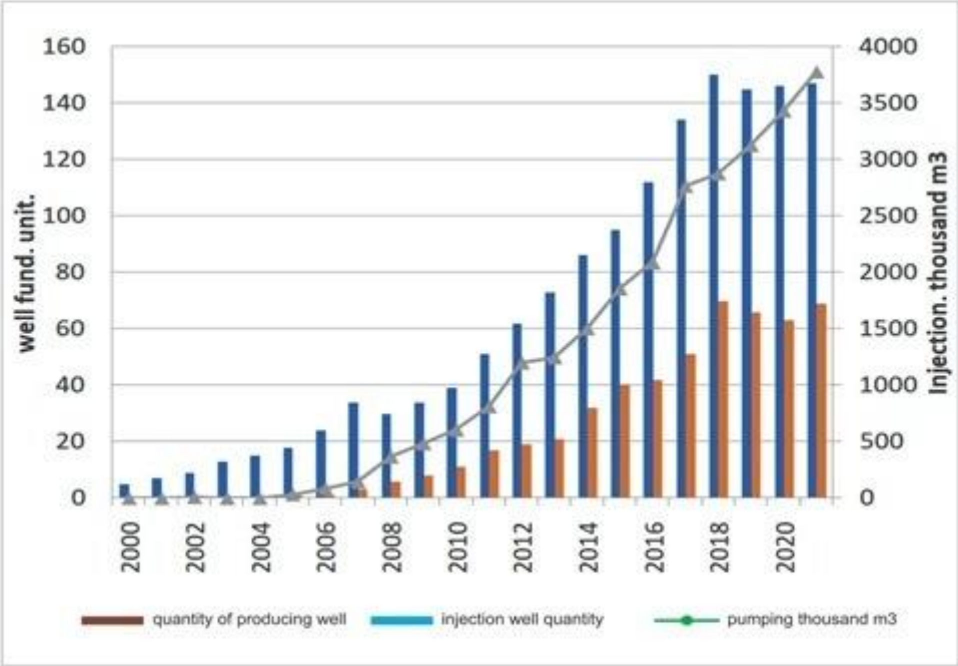

Figure 2 - Schedule of field development for the Yu-2+3 facility

The distribution of the average pressures over the cycle along the length of the formation will differ more strongly from the linear one, the higher the amplitude of the oscillations. Thus, the cyclical effect on an inhomogeneous reservoir in the presence of a dependence of permeability on pressure will give additional intensification and additional coverage of flooding due to the interaction of the nonlinearity of the process with its periodicity. Based on the review and practical application, the following conditions were formed [[11], [12]]:

- an existing development system with an organized PPD system;
- production of reserves significantly lags behind waterlogging;
- presence of significant residual recoverable oil reserves;
- significant heterogeneity of the interlayers within the layers, in terms of permeability;
- maximum full opening of the effective oil-saturated thickness in production and injection wells;
- Reservoir pressure at the initial level;
- technical serviceability of wells;
- hydrodynamic connection of wells (tracer studies). According to the above criteria, a site was selected at the Yu-2+3 facility in the field Figure 1.

Experimental studies of non-stationary flooding

The geological structure, reservoir permeability heterogeneities, and their relationship to each other have been studied for this site. Maps of losses (liquid, oil, Keksp), sedimentary microfacies, RMS attributes, electrofacies, lithotypes, total thicknesses, and isobars were constructed, and reports of JSC "NIPIneftegaz" and LLP "ALSTRON" on tracer studies (wells) were analyzed №№4309, 4366) [[13], [14]]. As of 01.01.2022, geological reserves for the Yu-2+3 facility amount to 36,360 thousand tons, initial recoverable reserves – 9,332 thousand tons, OIZ – 3,493 thousand tons, production from the bottom – 63%, accumulated oil production – 5839 thousand tons. 147 producing and 67 injection wells are located at this facility. The accumulated water injection is 27,413 thousand m3, and the current compensation for the selection by injection is 107% (Figure 2).

According to geological and physical criteria, the most suitable is site No. 1. Plot No. 1. 4 injection wells No.4382, 4919, 4366, 4907 are operating in the selected area in the area of BCNS 1.

The intake capacity of injection wells averages 188 m3/day, the average annual water content of the site is 90%, the current compensation is 165%. Maintenance of reservoir pressure at the site is carried out by pumping Alb Cenomanian water [15].

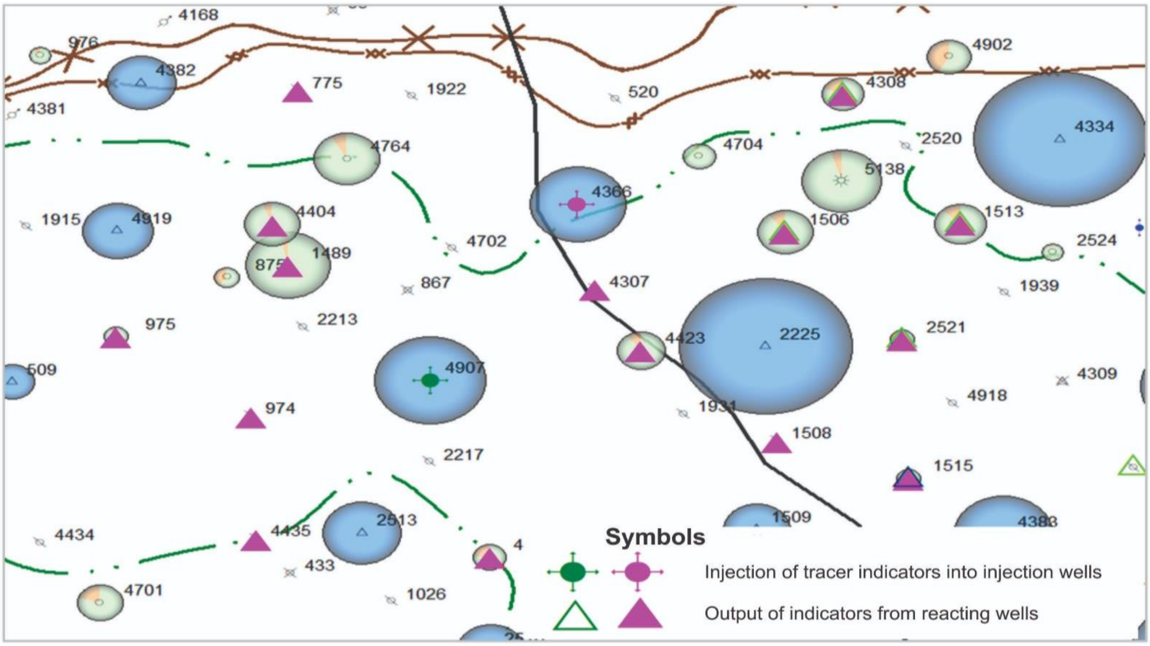

Figure 3 - Indicator output from reacting wells

To determine the direction of filtration flows, carbamide (2020) and disodium phosphate (2014) were injected in 2014 and 2020.

In 2020, a tracer study was conducted in the injection well No. 4907 (injection of carbamide). According to the results of laboratory studies, the output of the indicator was recorded for 14 wells (№№875, 975, 1489, 1506, 2517, 4404, 4421, 4423, 4435, 4702, 4704, 4764, 4824, 4881). In 4 wells (№№2213, 3213, 4307, 4965) no samples were taken because the wells were in conservation.

Disodium phosphate was injected into well No. 4366 in order to determine the distribution of hydrodynamic flows in the formation. The output of the indicator is fixed for all 16 wells (№№775, 974, 975, 1489, 1502, 1506, 1508, 1513, 1515, 2521, 4307, 4308, 4404, 4421, 4423, 4435). It can be noted that the indicator was traced in reacting production wells No. 4907 and No. 4366 (Figure. 3), which was the rationale for choosing this site.

Further, the time of operation and shutdown of wells during cyclic injection is determined, which is determined by the formula of M.L.

Surguchev using the reservoir parameters:

ω = 2 p /L2

T= L2/2 ρ where p =K/ με is the average piezo conductivity of low-permeable interlayers; K-permeability μ -viscosity ε is the compressibility coefficient of the rock Calculated, the average duration of cycles (stop/work) was 7 days, further durations up to 14 days.

This made it possible, by increasing the period of cyclic exposure, to shift the area of maximum intensity of fluid exchange between layers of different permeability into the inter-well space in the direction of the selection area. The cycle begins with the shutdown of the injection wells of the western group No. 4382 and 4919.

Wells of the eastern group No.4366, 4907 have been operating for 7 days. After 7 days, the wells of the western group are working and the wells of the eastern part of the group are shut down. At the end of 7 days, wells in the southern part No. 4919, 4907 are working, and wells No. 4366, 4382 are shut down in the northern part [[16], [17], [18]]. Wells No. 4366, and 4382 in the northern part are operating for 7 days, and wells No. 4919, and 4907 in the southern part are shut down. At the end of 7 days, wells No. 4919, and 4382 in the western part are turned off for 14 days, and wells No. 4366, and 4907 in the eastern part work for 14 days. Then the cycle repeats. Non-stationary flooding in 2022 at this site of the first operational facility began in March. Symmetrical cycles with the duration of the work period (downtime) of 7 and 14 days were used. Prior to the start of the experimental work, an audit and verification of the tightness and serviceability of the shut-off valves were carried out, the current state of the faces of injection wells involved in the process was determined, and a hydrodynamic study was carried out by the efficiency method for injection wells. It is recommended to conduct a GDIS to determine dynamic levels and to take control samples to determine water availability in all 9 reacting wells [[19], [20]].

The effect of cyclic injection was monitored for 9 wells. Production well No. 4702 did not participate in the analysis due to high water availability. Accumulated oil production is shown in Figure 4. that before the cyclical flooding in February, oil production was 438.3 tons, after the completion of the cycle, oil production was 895.5 tons, respectively.

At the start date of the application of non-stationary flooding, the water content of the wells of the site was 88%, with an average monthly oil flow rate of 5.4 t/day. In the first cycle of application of the NC, the water content decreases by (1%) with a significant increase in the oil flow rate to 7.3 t/day (Figure 5) [21]. A month after the start of non-stationary flooding, the water content decreases to 77% with an increase in the average monthly oil flow rate to 12.8 t/day.

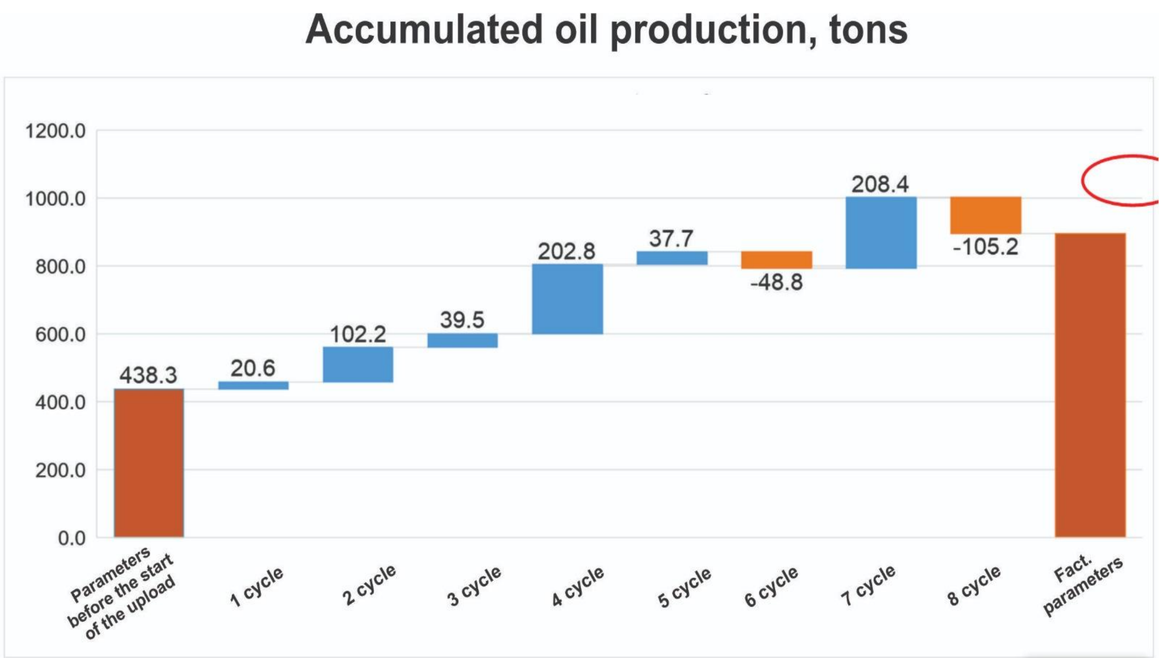

Figure 4 - Accumulated oil production by cycles

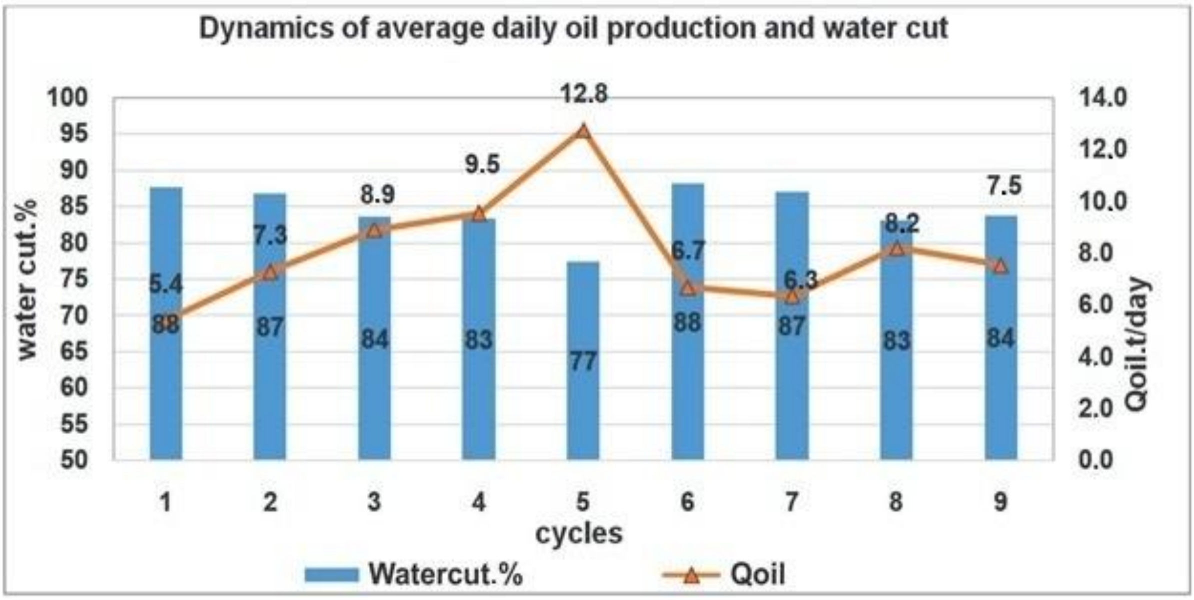

Figure 5 - Dynamics of average daily oil production and water availability

Results and discussion

Thus, the non-stationary flooding program was implemented in full and confirmed its technological effectiveness. The duration of the OPI for non-stationary flooding was 84 days, during this period 8 cycles were carried out. Due to the impact of non-stationary flooding, an increase of 457.2 tons of additional oil production was obtained.

The water content of reacting wells has decreased №№4764, 875, 1489, 4764, 4704, 4423, and in the whole area from 88% to 78%. During the analyzed period, 50% less water was pumped into the reservoir than before the event, and compensation for selection by injection decreased by 65%. At the same time, the reservoir pressure rose from 193 to 234 kg/cm^2.

The results of experimental studies allowed obtaining the dependence of the resistance factor on the permeability of the medium and the concentration of the solution, which will make it possible to create conditions for the isolation of water inflows using a non-stationary flooding program in the considered medium. The application of the methodology of rational planning of experiments allows one to get maximum information during the realization of the experiment plan. Reduction in water mobility can be achieved even at minimum concentrations. In this regard, the expression for determining the necessary concentration depending on the permeability of the medium is obtained. The application of appropriate methods of data processing and information analysis makes it possible to justify the choice of polymer solution.

Conclusion

In most fields, after almost complete production, the residual oil is in a capillary-pinched form or in the form of separate oil columns. To increase the completeness of its extraction, the method of non-standard flooding is widely used, the effectiveness of which has been proven during pilot work at the Yu-2+3 field facility.

Analysis of geological and physical characteristics of objects and the existing development system, it can be noted that this method is applicable almost everywhere. In order to achieve the greatest efficiency from the introduction of cyclic impact, it is recommended to use the criteria proposed in this paper for the selection of sites and the technology of work.

The results obtained and the workflow presented in this paper provide a better understanding of the mechanism of polymer solutions in waterflooding. In addition, the definition of optimized workflows to evaluate any solutions in porous media and changes in permeability is supported.

Acknowledgments. This article was carried out with the financial support of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (No. AR19674847).

Cite this article as: Effendiyev GM, Moldabayeva GZh, Tuzelbayeva ShR, Imansakipova ZB, Hongjun Wu. The method of non-stationary flooding and the conditions for its effective use in the operation of an oil field. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2024; 329(2):54-62. https://doi.org/10.31643/2024/6445.16

Тұрақталмаған (стационарлы емес) су жіберу әдісі және оны мұнай кен орнын игеру кезінде тиімді пайдалану шарттары

[1]Эфендиев Г.М., *[2]Молдабаева Г.Ж., [2]Түзелбаева Ш.Р., [2]Имансакипова З.Б.,[3]У ХунЦзюнь

[1] Әзірбайжан Ұлттық Ғылым академиясы, Баку, Әзірбайжан
[2] Сәтбаев университеті, Алматы, Қазақстан
[3] ЖШС "DPS Қызылорда", Қызылорда, Қазақстан

ТҮЙІНДЕМЕ
Мақалада стационарлы емес су жіберудің мәні көрсетілген, бұл сүзгі ағындарының бағытын өзгерту үшін қолданылатын мұнай өндіру коэффициентін арттырудың тиімді әдістерінің бірі болып табылады. Бұл әдіс өндірілмеген мұнай қорларын игеруге және өнімді коллекторлардағы кен орындарының сулану қарқынын төмендетуге мүмкіндік береді. Тұрақталмаған су жіберудің кең таралған технологиялық әдісі ретінде айдау ұңғымаларының циклдік жұмыс режимдері қолданылады. Бұл әдістің мәні мынада: мұнай кен орнында тұрақталмаған жағдайда қабат жүйесінің серпімді күштерінің үздіксіз болатын жағдайлар туындайды. Әр түрлі аймақтар, арналар мен сұйықтық ағындары арасындағы біріңғай емес қабатта гидродинамикалық қысым градиенттері пайда болады, соның арқасында сұйықтықтың кейбір қабаттардан екіншісіне, жарықтардан блоктарға ағуы мүмкін. Сонымен қатар ағындардың бағыттары өзгереді. Тұрақталмаған су жіберу кезінде біріңғай емес қабаттардың төмен өткізгіш қабаттардағы немесе аймақтардағы мұнай қорларының бір бөлігі айдалатын сумен қамтылмаған күйінде қалады. Су басқан қабат суланған және мұнаймен қаныққан микроағзалардың жүйесіз ауысқан түрінде болады. Мұндай коллекторларда көлемі мен бағыты бойынша кезектесіп өзгеретін қысым градиенттерін құру кезінде мұнай қабатында қысымды суды мұнаймен қаныққан өткізгіштігі төмен аймақтар мен арналарға енгізу және олардан мұнайды белсенді дренаждық аймақтарға ауыстыру үшін жағдайлар туындайды. Талдау нәтижесінде стационарлық емес су жіберу технологиясын іске асырудың оң әсері анықталды, сондай-ақ оны мұнай кен орындарының басқа объектілерінде қолдануды жетілдіру бойынша ұсыныстар берілді.

Түйін сөздер: Стационарлық емес су айдау, айдау ұңғымасы, циклдік айдау, мұнай беру, сүзу, гетерогенділік.

Мақала келді: *26 шілде 2023*
Сараптамадан өтті: *17 тамыз 2023*
Қабылданды: *22 тамыз 2023*

Авторлар туралы ақпарат:

Эфендиев Галиб Мамедович	*Техника ғылымдарының докторы, профессор, Әзірбайжан Ұлттық Ғылым академиясының Мұнай және газ институты, Баку, Әзірбайжан. Email: galib_2000@yahoo.com*
Молдабаева Гульназ Жаксылыковна	*Техника ғылымдарының докторы, профессор, Сәтбаев Университеті, Алматы, Қазақстан. Email: g.moldabayeva@satbayev.university*
Түзелбаева Шолпан Рысқұлбекқызы	*Техника ғылымдарының магистрі, докторант, Сәтбаев Университеті, Алматы, Қазақстан. Email: s.tuzelbayeva@satbayev.university*
Имансакипова Земфира Бекетовна	*Техника ғылымдарының магистрі, докторант, Сәтбаев Университеті, Алматы, Қазақстан. Email: z.imansakipova@satbayev.university*
У ХунЦзюнь	*Техника ғылымдарының магистрі, ЖШС «DPS Қызылорда», Қызылорда, Амангелді Иманов көшесі, 112А. Email: wus520@mail.ru*

Метод нестационарного заводнения и условия его эффективного применения при эксплуатации нефтяных месторождении

[1]Эфендиев Г.М., [*2]Молдабаева Г.Ж., [2]Тузельбаева Ш.Р., [2]Имансакипова З.Б., [3]У ХунЦзюнь

[1]Национальная академия наук Азербайджана, Баку, Азербайджан
[2]Satbayev University, Алматы, Казахстан
[3]ТОО "DPS Кызылорда", Кызылорда, Казахстан

АННОТАЦИЯ
В статье изложена сущность нестационарного заводнения, которое является одним из достаточно эффективных методов увеличения коэффициента извлечения нефти, применяемого для изменения направления фильтрационных потоков, что позволяет вовлечь в разработку невыработанные запасы нефти и снизить темпы обводнения залежи в продуктивных коллекторах. Распространенным технологическим методом нестационарного заводнения является использование циклических режимов работы нагнетательных скважин. Сущность такого метода заключается в том, что при неустановившемся состоянии в нефтяной залежи возникают условия для непрерывного проявления упругих сил пластовой системы. В неоднородном пласте между различными зонами, каналами и потоками жидкостей возникают градиенты гидродинамических давлений, за счет которых могут происходить перетоки флюида из одних слоев в другие, из трещин в блоки, а также изменяются направления потоков. При нестационарном заводнении неоднородных пластов часть запасов нефти в низкопроницаемых прослоях или зонах остается неохваченной закачиваемой водой. Заводняемый пласт представляется как бессистемное чередование обводненных и нефтенасыщенныхмикропотоков. При создании в таких коллекторах попеременно изменяющихся по величине и направлению градиентов давления, в нефтяном пласте возникают условия для внедрения нагнетаемой воды в застойные нефтенасыщенные малопроницаемые зоны и каналы, и перемещения из них нефти в зоны активного дренирования. В результате анализа выявлен положительный эффект от реализации технологии нестационарного заводнения, а также даны рекомендации по совершенствованию ее применения на других эксплуатационных объектах нефтяных месторождений.

Ключевые слова: нестационарное заводнение, нагнетательная скважина, циклическая закачка,нефтеотдача, фильтрация, неоднородность.

Поступила: *26 июля 2023*
Рецензирование: *17 августа 2023*
Принята в печать: *22 августа 2023*

Эфендиев Галиб Мамедович	***Информация об авторах:*** *Доктор технических наук,профессор. Институт Нефти и газа Национальной академии наук Азербайджана, Баку, Азербайджан. Email: galib_2000@yahoo.com*
Молдабаева Гульназ Жаксылыковна	*Доктор технических наук,профессор. Satbayev University, Алматы, Казахстан. Email: g.moldabayeva@satbayev.university*
Тузельбаева Шолпан Рыскулбековна	*Магистр технических наук, докторант, Satbayev University, Алматы, Казахстан. Email: s.tuzelbayeva@satbayev.university*
Имансакипова Земфира Бекетовна	*Магистр технических наук, докторант, Satbayev University, Алматы, Казахстан. Email: z.imansakipova@satbayev.university*
У ХунЦзюнь	*Магистр технических наук, [3]ТОО "DPS Кызылорда", Кызылорда, ул.Амангельды Иманов, дом 112А. Email: wus520@mail.ru*

References

1. Liu Wenzheng, He Hong, Yuan, Fuqing, Liu Haocheng, Zhao Fangjian, Liu, Huan, Luo, Guangjie. Influence of the Injection Scheme on the Enhanced Oil Recovery Ability of Heterogeneous Phase Combination Flooding in Mature Waterflooded Reservoirs. ACS OMEGA. 2022; 7(27):23511–23520 https://doi.org/10.1021/acsomega.2c02007
2. Leng, Jianqiao, Sun, Xindi, Wei, Mingzhen, Bai, Baojun. A Novel Numerical Model of Gelant Inaccessible Pore Volume for In Situ Gel Treatment. GELS. 2022;8(6), 375 https://doi.org/10.3390/gels8060375
3. Bai Baojun, Zhou Jia, Yin, Yin Mingfei. A comprehensive review of polyacrylamide polymer gels for conformance control. PETROLEUM EXPLORATION AND DEVELOPMENT. 2015; 42(4):525-532. https://doi.org/10.1016/S1876-3804(15)30045-8
4. Zhang Guoyin, Yu Jianjia. Effect of commonly used EOR polymers on low concentration surfactant phase behaviors. FUEL. 2021; 2:286. https://doi.org/10.1016/j.fuel.2020.119465
5. Wang Dongmei, Namie Shane, Seright Randall. Pressure Modification or Barrier Issues during Polymer Flooding Enhanced Oil Recovery. GEOFLUIDS. 2022. https://doi.org/10.1155/2022/6740531
6. Peter Mora, Gabriele Morra, Dave Yuen, Ruben Juanes. Study of the Effect of Wetting on Viscous Fingering Before and After Breakthrough by Lattice Boltzmann Simulations. SPE Middle East Oil & Gas Show and Conference. 2021. https://doi.org/10.2118/204536-MS
7. Ximena Guerrero, Daniel Ricardo Medina, Alberto Munoz, Jhon Rubiano, Alied Bejarano, Hernando Trujillo, Nicolas Saltel, Julian Trillos, Jerson Becerra, Diego Castellanos, Cesar Coronado. Water Isolation and Sand Control: Breaking Barriers with Expandable Steel Patch Technology. Society of Petroleum Engineers (SPE). 2020. https://doi.org/10.2118/201432-MS
8. Ximena Guerrero, Daniel Ricardo Medina, Alberto Munoz, Jhon Rubiano, Alied Bejarano, Hernando Trujillo, Nicolas Saltel, Julian Trillos, Jerson Becerra, Diego Castellanos, Cesar Coronado. Water Isolation and Sand Control: Breaking Barriers with Expandable Steel Patch Technology. SPE Annual Technical Conference and Exhibition. 2020.
9. Ali Al-Azmi, Hassan Al-Qattan, Mohamad Al-Do. An Effective Solution for Unwanted Water Production Obtained from Water Coning Mechanism: Field Application" International Petroleum Technology Conference. 2022. https://doi.org/10.2523/IPTC-22371-MS
10. Tariq K Khamees, Ralph E Flori. Can the Viscoelasticity of HPAM Polymer Solution Make the Polymer Flooding Compete with Gel Treatment to Improve Sweep Efficiency? A Comparison with Different Polymer Gel Systems" SPE International Conference on Oilfield Chemistry. 2022. (https://doi.org/10.2118/193592-MS
11. R. S. Seright, Dongmei Wang. Polymer Retention “Tailing. Phenomenon Associated with the Milne Point Polymer Flood. SPE Journal. 2022; 27(05):2863-2881. https://doi.org/10.2118/209354-PA
12. Miguel Gonzalez, Tim Thiel, Nathan St. Michel, Jonathan Harrist, Erjola Buzi, Huseyin Seren, Subhash Ayirala, Lyla Maskeen, Abdulkarim Sofi. A New Viscosity Sensing Platform for the Assessment of Polymer Degradation in EOR Polymer Fluids. SPE Annual Technical Conference and Exhibition. 2022; SPE-210014-MS. https://doi.org/10.2118/210014-MS
13. Jiaming Li, Guang Zhao, Ning Sun, Lihao Liang, Ning Yang, Caili Dai. Construction and evaluation of a graphite oxide Nanoparticle-Reinforced polymer flooding system for enhanced oil recovery. Journal of Molecular Liquids. 2022; 367(B). https://doi.org/10.1016/j.molliq.2022.120546
14. Javad Razavinezhad, Arezou Jafari, Seyed Masoud, Ghalamizade Elyaderani. Experimental investigation of multi-walled carbon nanotubes assisted surfactant/polymer flooding for enhanced oil recovery. Journal of Petroleum Science and Engineering. 2022; 214. https://doi.org/10.1016/j.petrol.2022.110370
15. Moldabayeva G ZH, Agzamov AKh, Suleimenova RT, Elefteriadi DK, Abileva SZh, Baluanov B.A. Hydrodynamic modeling of field development using enhanced oil recovery methods. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2021; 317(2):14-22. https://doi.org/10.31643/2021/6445.13
16. Abhijit Chaudhuri, R Vishnudas. A systematic numerical modeling study of various polymer injection conditions on immiscible and miscible viscous fingering and oil recovery in a five-spot setup. FUEL. 2022; 232:431-443. https://doi.org/10.1016/j.fuel.2018.05.115

17. Moldabayeva GZh, Suleimenova RT, Agzamov AKh, Abileva SZh, Baluanov BA. The effectiveness of the use of physical impact on the reservoir to reduce the viscosity and increase oil recovery, Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2021; 316(1):53-61 https://doi.org/10.31643/2021/6445.07

18. AL-Obaidi SH, Smirnov VI, Khalaf FH. New Technologies to Improve the Performance of High Water Cut Wells Equipped With ESP. Technium. 2021; 3(1):104-113.

19. Wojtanowicz AK, and et al. A New Completion Method to Minimize Oil Well Production Water cut in Bottom-water-drive Reservoirs. The Journal of Canadian Petroleum Technology. 1995; 34(8):56-62.

20. Lon A. Stuebinger and Gerald M. Elphingston. New opportunities offered by downhole oil/water separation. Word Oil. 1998; 219(12):71-78.

21. Bowlin KR, and et al. Field application of in-situ gravity segregation to remediate prior waterconing. Journal of Petroleum Technology. 1997; 49(10):1117-1120.