MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

School of Geology, Petroleum and mining engineering

Department of Petroleum Engineering

Baltabayeva D.K.

Development of Naturally Fractured reservoirs

**DIPLOMA PROJECT**

5B070800 – Oil and gas engineering

Almaty 2021

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**APROVED FOR DEFENSE**
Head of the Petroleum
Engineering Department
Dairov Zh. K., MSc
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**DIPLOMA PROJECT**

Topic: «Development of Naturally Fractured reservoirs»

5B070800 – Oil and gas engineering

Performed by Baltabayeva D.

Academic adviser

MSc, Imantayeva A.K.
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Almaty 2021

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## Метаданные

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**Development of Naturally Fractured reservoirs**

Автор

**Балтабаева Дина**

Научный руководитель

**Асемгуль Имантаева**

Подразделение

**ИГНиГД**

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| 1 | **Current sharing between superconducting film and normal metal**<br>Paul N. Barnes,George A. Levin,John S. Bulmer; | 17 (3) | 0.18 % |
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| 1 | **A Structural Framework for a Near-Minimal Form of Life: Mass and Compositional Analysis of the Helical Mollicute <italic>Spiroplasma melliferum</italic> BC3**<br>A. V. Osipov; | 16 (3) | 0.17 % |
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MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

СӘТБАЕВ УНИВЕРСИТЕТІ SATBAYEV UNIVERSITY

School of Geology, Petroleum and mining engineering
Department of Petroleum Engineering

**CONFIRM**
Head of the Petroleum
Engineering Department
Dairov Zh. K., MSc

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**TASK**
**For completing the diploma project**

For student Baltabayeva D.K.
Topic: « Development of Naturally Fractured reservoirs»
Approved *by the order of university rector* № *762-b* from "*24*" *November* 2020
Deadline for completion the work: "*18*" *May* 2020.
Initial data for the diploma project:
Summary of the diploma project: Challenges in development of naturally fractured reservoirs; optimization of waterflooding; applicability of non-stationary waterflooding.
Recommended main literature:

1) *Development of hard-to-recover reserves - the main challenge of the future.* S.M.Durkin, A. I. Khasanov. Ukhta : 2016.

2) *Cyclic Water Injection A Simulation Study.* Henrik Langdalen. Petroleum Geoscience and Engineering. June 2014
3) Report *Analysis of the efficiency of non-stationary flooding at the N field* from 26.03.2021

## THE SCHEDULE

For the diploma work preparation

| Name of section, list of issues being developed | Submission deadlines to the scientific adviser | Note |
|---|---|---|
| Literature Review | 21.01.2021 | Task completed |
| Analysis of the development of N field | 1.03.2021 | Task completed |
| Justification of applicability of NW | 25.03.2021 | Task completed |
| Analysis of results and conclusion | 3.04.2021 | Task completed |

## Signature

Of consultants and standard controller for the completed diploma work, indicating the relevant section of the work (project).

| The section title | Consultant name (academic degree, title) | Date | Signature |
|---|---|---|---|
| Theoretical part | MSc, Imantayeva A.K. | 2.03.2021 | |
| Technical part | MSc, Imantayeva A.K. | 15.03.2021 | |
| Simulation part | MSc, Imantayeva A.K. | 1.04.2021 | |
| Nomcontroller | MSc, Imantayeva A.K. | 10.05.2021 | |

Scientific adviser ________ MSc, Imantayeva A.K.
Signature

The task was completed by student: Baltabayeva D.K. ________ Baltabayeva D.K.
Signature

Date “18” May 2021

## ABSTRACT

The development of the oil industry in the Republic of Kazakhstan, as well as in the world, at the present stage is characterized by a deterioration in the structure of oil reserves and the commissioning of fields with complicated reservoirs, abnormal oil properties, large depths of deposits, often accompanied by abnormally high reservoir pressures and temperatures. At the moment, most of the fields being developed are at a late stage of development, which are characterized by a low current production of reserves and a low rate of extraction of residual recoverable reserves due to a complex geological structure, an ineffective existing development system. In the conditions of these fields, it is necessary to use a different approach to the development of fields that require minimal investment, taking into account the difficult economic situation in the sales market. Increasing oil recovery factor is an urgent and strategic direction of the company's development in the medium and long term, which will extend the life cycle of fields, improve production and economic performance of the company and increase government revenue from additional oil production.

## АННОТАЦИЯ

Развитие нефтяной промышленности в Республике Казахстан, также, как и в мире, на современном этапе характеризуется ухудшением структуры запасов нефти и вводом в разработку месторождений с осложнёнными коллекторами, аномальными свойствами нефти, большими глубинами залегания месторождений, зачастую сопровождающиеся аномально высокими пластовыми давлениями и температурами. На текущий момент большинство разрабатываемых месторождений находятся на поздней стадии разработки, которые характеризуются низкой текущей выработкой запасов и низкими темпами отбора остаточных извлекаемых запасов вследствие сложного геологического строения, малоэффективной сложившейся системой разработки. В условиях данных месторождений необходимо применение иного подхода к разработке месторождений, требующих минимальных вложений при учете сложной экономической ситуации на рынке сбыта. Увеличение КИН является актуальным и стратегическим направлением развития компании в средне- и долгосрочной перспективе, что позволит продлить жизненный цикл месторождений, улучшить производственно-

экономические показатели компании и увеличить доход государства от дополнительной добычи нефти.

## АҢДАТПА

Қазіргі кезеңде Қазақстан Республикасында, сондай-ақ әлемде мұнай өнеркәсібінің дамуы мұнай қоры құрылымының нашарлауымен және күрделі қоймалары бар кен орындарының пайдалануға берілуімен, қалыптан тыс мұнай қасиеттерімен, үлкен тереңдіктерімен сипатталады. шөгінділер, көбінесе су қоймасының қалыптан тыс жоғары қысымымен және температурасымен жүреді. Қазіргі уақытта игеріліп жатқан кен орындарының көпшілігі игерудің кешеуілдеу сатысында, олар қазіргі кездегі қорлардың аз өндірілуімен және күрделі геологиялық құрылымның, тиімді емес қолданыстағы игеру жүйесімен қалпына келтірілетін қалдықтарды өндірудің төмен қарқынымен сипатталады. Осы кен орындарының жағдайында сату нарығындағы күрделі экономикалық жағдайды ескере отырып, минималды инвестицияларды қажет ететін кен орындарын игеруге басқаша тәсілді қолдану қажет. Мұнайды қалпына келтіру коэффициентін арттыру - бұл кеніштердің өмірлік циклін кеңейтуге, компанияның өндірістік-экономикалық көрсеткіштерін жақсартуға және қосымша мұнай өндіруден мемлекет кірісін ұлғайтуға мүмкіндік беретін орта және ұзақ мерзімді кезеңдегі компанияның жедел және стратегиялық бағыты.

# CONTENT

**List of Figures**

**List of Tables**

## INTRODUCTION

In the world, residual or non-recoverable oil reserves by industrially developed methods of development make up, on average, 55–75% of the initial geological oil reserves. Thus, every year around the world, interest in enhanced oil recovery methods is growing, and research is developing aimed at finding a scientifically based approach to the selection of the most effective technologies for field development. The efficiency of oil extraction from oil-bearing reservoirs by modern, industrially developed methods of development in all oil-producing countries is currently considered unsatisfactory.

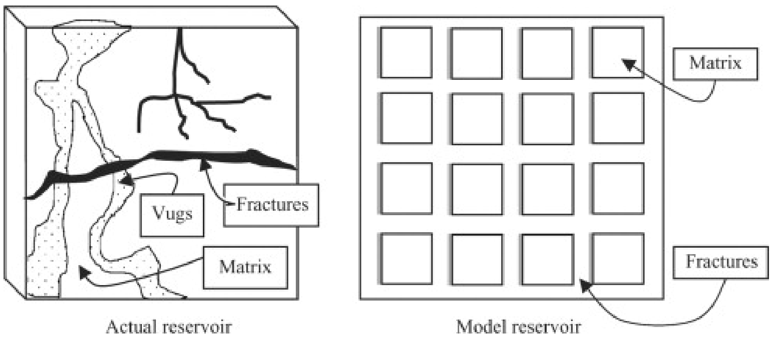


Figure 1. Idealization of a naturally fractured heterogeneous porous media. (1)

The relevance of the topic of this work is determined by the low values of the oil recovery factor in the development of naturally fractured reservoirs with waterflooding and, accordingly, large residual oil reserves. Re-exploitation of flooded wells will allow, judging by the available field data, to significantly increase recoverable oil reserves in old equipped areas, which promises high technical and economic efficiency and will increase the professional employment of the population in these areas.

The current level of knowledge of the processes occurring in the reservoirs confirms the idea of the mobility of residual oil in the reservoir after its development by waterflooding. There are sufficient grounds to assume that under the influence of natural forces after waterflooding and a complete shutdown of the wells, the initial oil saturation in the reservoir volume is partially restored under the influence of the gravitational field, capillary forces, etc. Such a process in time may turn out to be quite long, depending on the geological and physical properties of the development object. The fact that the processes of gravitational segregation of oil in depleted deposits, the production of wells of which is 98-100% watered, occur in reality, is evidenced by numerous facts of replacement of water in idle wells with oil, and these wells, once filled with water, are completely filled with oil and are included in operation.

The problems of oil production from naturally fractured reservoirs are covered in the scientific and technical literature quite widely. At the same time, the rich heritage of scientific research in the development of carbonate reservoirs is poorly applied in practice. This is due, on the one hand, to the traditional approaches to the development of carbonates, which developed during the period of mass development of highly productive terrigenous oil deposits. On the other hand, the variety of geological conditions of occurrence of carbonate deposits, their properties and development features - all this complicates the choice of universal optimal technologies for developing reserves.

In this regard, the creation of new effective technologies for the development of carbonate oil reservoirs, the adaptation of existing technologies to obtain high current oil production and achieve high oil recovery rates, all this is one of the most urgent tasks facing the oil industry.

## LITERATURE REVIEW

Hard-to-recover reserves include deposits with the following features: abnormal rheological properties; complex void space of the reservoir rock; harsh climatic conditions. Development of formations composed of fractured-porous and fractured rocks is one of the most complex issues in the theory and practice of oil field development. The development of fractured and fractured-porous formations can be significantly affected by a sharp change in the volume of fractures when the pressure of the fluid saturating the fractures changes as a result of deformation of the rock formation. When waterflooding is applied in such fields, the task of their development becomes even more complicated, since there is a danger of water breakthrough through highly permeable fractures. (2)

The development of fractured reservoirs is an urgent task, since according to some estimates, carbonate rocks contain from 35 to 48% of oil reserves and from 23 to 28% of gas in the world (4). Therefore, to overcome the difficulties, the role of effective application of modern methods of studying the filtration-capacity parameters of these reservoirs increases. For example, specialists from the French Institute of Petroleum (IFP) have developed FracaFlow, a software technology for the analysis and modeling of fracture systems. This software product includes the CobraFlow geological modeling module and the PumaFlow hydrodynamic modeling module. Many software developers, such western companies as ROXAR, Shlumberger, CMG, KAPPA, have made great strides in the field of creation and forecasting of technological indicators of field development. Modeling of fractured porous reservoirs using hydrodynamic simulators is based on embedded media technology (5). A qualitatively different approach to modeling fracturing and filtration in heterogeneous reservoirs is based on a realistic representation of a fractured reservoir.

Fractures are formed when the local stress exceeds the fracture pressure gradient. Depending on the formation process, fractures can be of structural or tectonic origin. The porosity caused by the fracture system is usually low; the resulting fracture can be further filled with minerals that fall out of strata waters. In this case, fractures can have very high permeability, which is explained by the reduced tortuosity of the secondary ways of filtration of formation fluids in these fractures. Consequently, the formation of natural fractures often significantly increases the permeability of the formation. Such fractured formations are a typical example of dual porosity systems, they are characterized by heterogeneous behavior of filtration characteristics, which can be noted during reservoir testing.

At the same time, according to the data of experimental studies and development experience, it is known that oil is displaced from the fracture system itself quite efficiently and the displacement coefficient reaches 0.8-0.85. Experience also shows that oil is displaced from the matrixes of fractured-pore formations during waterflooding, although the oil displacement coefficient is relatively small, not exceeding 0.3 even for oil-wet reservoirs. But most often the carbonate reservoir is represented by a hydrophobic pore surface, largely due to the adsorbed surface-active components from the oil in contact with it.

In fractures, the movement of fluid occurs at a higher speed. In the pore space, the velocity of fluid movement is small and obeys Darcy's law. The system of equations describing the flow of a homogeneous fluid in a fractured-porous reservoir has the form:

$$\beta_n'' \frac{\partial (h_n P_n)}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}(h_n r V_n) + \Omega_n \qquad (1)$$

$$\beta_m'' \frac{\partial (h_m P_m)}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}(h_m r V_m) + \Omega_m \qquad (2)$$

where the first equation describes the movement of fluid in the pore space, and the second, in the fractured one. Index n - indicates belonging to the pore space, m - to the fracture space. The term $\Omega_{n(m)}$ - describes the exchange of fluid between the system of fracture and porous blocks. $P_{n(m)}$ is the pressure value averaged over the thickness of the pore (fracture) space, $V_{n(m)}$ is the value of the fluid filtration rate averaged over the thickness of the pore (fractured) space, $h_{n(m)}$ is the thickness of the pore (fracture) space. The velocities of fluid movement in pore and fractured spaces are presented in the following form:

$$\overline{V_n} = -\frac{K_n}{\mu}\nabla P_n = -\frac{K_n}{\mu}\frac{\partial P_n}{\partial r} j \qquad (3)$$

$$\overline{V_m} + \boldsymbol{\beta V_m \overline{V_m}} = -\frac{K_m}{\mu}\nabla P_m = -\frac{K_m}{\mu}\frac{\partial P_m}{\partial r} j \qquad (4)$$

where $K_{n(m)}$ - is the average permeability of the pore (fractured) medium, and the coefficient $\beta$ is a constant having the dimension [s/m] and describing the contribution of inertial terms in the equation of fluid motion in the fractured space.

1. Fractured carbonate reservoirs

Carbonate reservoirs rank second after terrigenous ones. Carbonate rocks are composed of low permeability matrix zones and fractures. They account for 42% of oil and 23% of gas reserves. The main differences between carbonate reservoirs and terrigenous reservoirs are the presence, basically, of only two main rock-forming minerals - calcite and dolomite. Filtration of oil and gas is primarily caused by fractures and caverns. Carbonate reservoirs are present in the fields of the Persian Gulf basin, oil and gas basins of the USA and Canada, in the Caspian basin. (3)

In most cases, marine carbonates are skeletal material that has been deposited by biochemical processes associated with organisms such as algae, mollusks and corals whose growth is controlled by parameters such as light, temperature and nutrient availability.

From a modeling point of view, the most important factors in carbonate reservoirs are their shape and porosity. Both of these parameters are initially dependent on the organisms of the builders, as well as, to a lesser extent, the place of deposition. And as already noted in connection with the high solubility of these reservoirs under the influence of diagenesis and various secondary processes, they are characterized by different types of pore space, of which fractures play the main role.

## 1.1 The nature of fractures in natural fractured reservoirs

Fractures are the product of stress applied to rocks with brittle geomechanical properties. They are formed when the applied stress begins to exceed the elastic limit of the rock, beyond which rupture occurs.

Thus, the mechanical properties of the reservoir rocks are important because different rocks behave differently in terms of rock mechanics.

When investigating the nature of fractures, for a better understanding, it is necessary to start with a regional scale. Regional fractures occur under the influence of the following three main processes:

1) Tectonic compression;
2) Regional stretching;
3) An increase in pore pressure resulting from the compression of rocks and leading to natural hydraulic fracturing, which contributes to the active propagation of fractures in space.

A feature of tensile fractures is that they are not characterized by displacement. Also, a possible mechanism of their formation lies in the fact that normal stresses applied from different sides act with different forces, which leads to stretching, which forms a rupture, parallel to the main stress. Such fractures can also refer to synsedimentary fractures formed when a huge mass of rocks slides along the slope of the carbonate shelf. It should also be noted that such fractures tend to be filled with carbonate sediment or cement. In this case, they act as barriers to fluid flow, but in the case of carbonate reservoirs, there is a possibility that the given filling material may be less chemically stable as a result of which it dissolves.

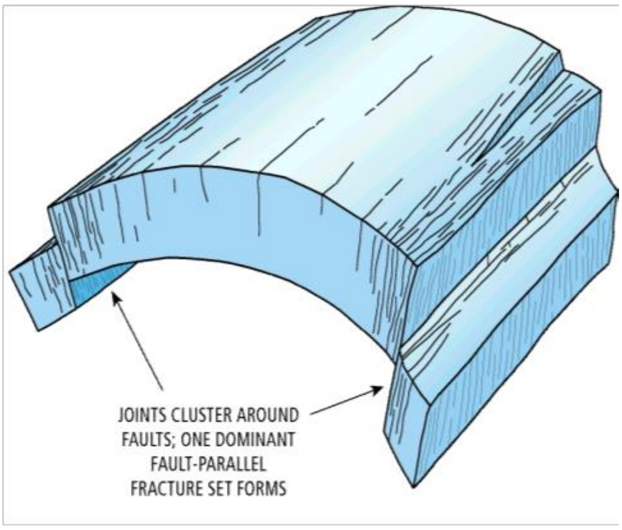


Figure 2. Schematic drawing of fracture cluster distribution around reverse faults (Hoffman, 2007)

If the reservoir is located closer to the surface than initially as a result of, for example, uplift and erosion, the balance of the equilibrium of stresses applied to the rock is disturbed. This balance tends to equilibrate, which leads to the formation of new systems of semi-orthogonal vertically oriented fracture systems. Such fracture systems are often found in carbonate deposits.

Displacement fractures are formed as a result of the movement of the planes of the fractures relative to each other. The movement can occur both longitudinally and across the plane of the displacer. Displacement fractures are often referred to as near-fault fractures. It should be noted that this type of fracture usually implies high permeability, if not the rare case when they are filled with cement. It should also be summarized that all types of fractures are characterized by high properties of fluid conductivity, especially if their significant vertical and lateral connectivity is inherent.

## 1.2 Characterization of fractured carbonate reservoirs

Characterization of carbonate reservoirs, as well as terrigenous reservoirs, is carried out using information obtained from such sources as seismic exploration, core analysis, a set of well logging methods, formation testing, and petrophysical analysis. It should be noted that in the case of seismic exploration, special methods of interpretation, attributive analysis are used. One of the most effective methods for describing fractures is the use of FMI / UBI reservoir microimages.

Descriptions of fractured reservoirs should start with a regional scale. knowledge of the main directions of regional stress allows us to characterize the most likely orientation of the main faults and fractures, on the basis of which smaller-scale fracturing can also be analyzed.

More detailed information comes from the study of outcrops and analogous deposits. Such information can be presented in the form of a map of outcrops, on a scale ranging from less than a meter to several meters. It should be noted that the representativeness of outcrops in relation to rocks that occur deep in the bowels must be carefully checked. This is primarily due to the fact that the history of the burial of the outcrop is most likely very different from the history of those rocks lying deep in the bowels. This is due to the fact that the outcrops can be characterized by new systems of fractures, which were formed as a result of a decrease in stress and a disturbance in the balance of stresses applied to it initially. Those. this means that the fractures in the outcrops must be checked to see if they were originally labeled or postsedimentary, resulting from the uplift and erosion of the fracture system. It also needs to be done on karstified reservoirs. The karstification process always takes place closer to the surface in subaerial conditions. As a result, the presence of karst forms can be taken as a sign of shallow bedding of rocks during karstification. As a conclusion, it must be said that the analysis of information obtained from the above sources allows us to present a conceptual model of the reservoir

The next source of information for describing a fractured reservoir is seismic data. Seismic allows you to identify the presence of large faults and fractures, using, for example, such seismic attribute such as Anttracking, or reflection amplitude versus offset analysis. Ideally, seismic exploration in fractured carbonate reservoirs should be carried out with both P-wave and S-wave velocities and determination of the bulk density of the target rocks. these parameters in fractured zones differ significantly from intervals not affected by fractures. It should be noted that there is a high probability that the healed tension fractures will not be identified by seismic data.

Various downhole methods are also an important source of information for describing fractures, the main of which are listed in the following list:

1. Core analysis
2. FMI / UBI
3. A set of methods for well logging
4. Test trial

From the above list, core analysis and reservoir microimaging (FMI) are methods that identify fractures on a straight line. The most reliable of these two methods, of course, is core analysis, which allows you to determine the angle of inclination, density and type of fractures in the core, as well as identify other types of porosity. It is also possible, on a core scale, which is not reliable, to assess the individual impact of matrix and fractures on fluid flow in the reservoir. The main disadvantage is that there is no possibility of coring over the entire interval.

A set of well logging and reservoir testing methods are indirect methods for identifying and characterizing fractures in carbonate reservoirs. A typical set of well logging methods for describing a fractured reservoir are acoustic logging, caliper, mud logs, gamma ray logs, etc. The fact that the P-wave amplitude decreases significantly as it travels through the fluid, especially if the fluid fills the fractures, makes it possible to identify the fractured zone using sonic logging. The total porosity of the rock, which can also be determined using acoustic and radioactive logging, is used to describe the structure of the reservoir pore space. The increase in overall porosity is relatively effective, which is a sign of an increase in secondary voids, and serves as a good criterion for typing a carbonate reservoir. This process becomes more reliable if in the identified interval there is an increase in drilling time and the presence of dolomite in the drilling fluid. Also, borehole enlargement intervals detected with a caliper can form in fractured intervals due to the crumbling properties inherent in fractured rocks. In turn, there may be a loss of drilling fluid in fractured intervals, which should be looked at.

## 2. General information about the N field

The N field deposit is located in the Aktobe region. Structurally, the field is confined to an anticlinal fold of the meridian orientation, complicated by two reverse faults; the oil-bearing area is 58.98 $km^2$. Seven tectonic blocks were identified on the plane, two deposits and two oil-water systems were identified along the longitudinal direction. At the N field, the reservoirs are represented by carbonate rocks of the Carboniferous system, only 3 reservoir complexes are developed, KT-I (minor oil-bearing object), MKT (small reserves, undeveloped), KT-II (main oil-bearing object).

The complex structural structure of the N field, complicated by uplifts and faults, is the result of tectonic stresses that led to the formation and significant propagation of fractures in the reservoir. The presence of fractures is confirmed by core material studies, downhole electric microimagers, tracer studies, production history (interference) of a number of wells.

Taking into account the complex structure of the fractured-porous reservoir, the low efficiency of the implemented reservoir pressure maintenance, water breakthroughs through fracture systems and the complex nature of flooding (non-uniform) of production wells, as well as the positive world experience in the implementation of non-stationary waterflooding (hereinafter referred to as NZ) in the fields represented by fractured reservoirs , it was decided to apply this enhanced oil recovery method in the N carbonate field.

3. Main challenges in the development of the N field

In the carbonate deposits of the N field, the fracturing of the reservoir introduces a large heterogeneity in the reservoir properties along the section and strike. Significantly lower rock permeability is observed compared to the permeability of the surrounding fractures. The average permeability of the reservoir rock according to the results of core studies was 6 mD. The presence of open fracturing and wide spread of fractures makes it possible to classify most of the reservoir of the N field as a fractured-porous reservoir (hereinafter - FPR). Fractures divide the formation into separate rock blocks (matrix blocks), which contain all the main hydrocarbon reserves (average porosity is 10-12%). The main reservoir of hydrocarbons (hereinafter referred to as HC) in such reservoirs are matrix blocks, while filtration in this type of reservoir occurs mainly along fractures.

Figure 3. Outcrop of a fractured-porous reservoir, an example of identifying matrix blocks and fractures as the main filtration paths

Fractures are characterized by high conductivity and a significant effect on the water cut of the well production of a significant part of the well stock. This leads to a breakthrough of the injected water through the fracture system, a decrease in the efficiency of oil displacement through the reservoir and an uneven decrease in reservoir pressure below the bubble point pressure due to the rapid development of active fractured oil reserves: as a result, an increase in the gas-oil ratio (hereinafter referred to as GOR) is observed.

The complex geological structure of the N field structure requires a more detailed study of the reservoir properties, fracture studies, a number of laboratory studies, effective decisions at this stage of development aimed at increasing the coverage by displacement by working agents, reducing the influence of "flushed" channels in the "injection - production ".

To control the development, it is necessary to carry out a number of qualitative and quantitative field studies. Namely, there is a need for high-quality field geological and hydrodynamic studies at the mechanized fund of the N field.

The main difficulties of the developed porous-fractured reservoirs:

- A rapid and uneven decrease in reservoir pressure below the bubble point pressure due to the rapid development of active reserves of fractured oil, as a result of gas breakthrough through fractures in the gas cap zones, an increase in GOR;
- Significantly lower permeability of matrix blocks in comparison with the permeability of surrounding fractures;
- To a greater extent, the hydrophobicity of the matrix block rocks, the resistance of capillary forces to the displacement of oil by water;
- Low efficiency of the reservoir pressure maintenance system, water in a very short time reaches the zone of production wells along fractures, significantly reducing the replacement of oil in the matrix;
- A strong decrease in oil production rates and productivity factors, due to a rapid drop in reservoir pressure, fractures are closed, as a result of which fracture permeability decreases;
- Uneven production of reserves across the section.

## 3.1 Development of reserves at N field

The field develops two massive carbonate strata KT-II-1 and KT-II-2, combined into one operational development target.

Table 1. The main technological indicators of development for the strata of the KT-II horizon of the N field

| **Horizon** | **KT-II-I-1** | **KT-II-I-2** |
|---|---|---|
| Average overall thickness, m | 152 | 64,4 |
| Average oil pay, m | 15 | 29 |
| Initial recoverable reserves, thousand tons | 6504,6 | 14260,9 |
| RF, | 0,332 | 0,438 |
| Cumulative oil production , thousand tons | 826,2 | 3884,0 |
| Current RF, | 0,045 | 0,125 |
| Remaining recoverable reserves, thousand tons | 5678,4 | 10376,9 |
| Cumulative water injection, thousand $m^3$ | 1516,8 | 7227,0 |

Reservoir rocks of the KT-II-I horizon, according to the results of laboratory analysis of the core, are characterized by open porosity, varying from 4.02 to 19.12% and equal to an average of 9.0%. Reservoir permeability ranges from 0.1 - 37.17 mD and averages 2.426 mD. According to well logging data, the average porosity of the KT-II-I reservoirs is 0.08 and varies within the range of 0.04-0.18. The oil saturation variation interval is 42 - 99% and the average value is 80%. Productive deposits of the KT-II-II horizon according to laboratory core studies are represented by reservoirs with an average open porosity of 10%, varying from 4.01 to 20.17%. Permeability varies in the range of 0.1-132.04 mD and is equal on average to 8.489 mD. According to well logging data, the average porosity is 0.07 unit fractions, the average oil saturation is 82%. Oil density at surface conditions - 0.871-0.828 g/$cm^3$, API: 37-40 °, initial gas factor 76.8-244.1 $m^3$/t, bubble - point pressure 14.8 - 24.4MPa, formation volume factor 1.15-1.51. The main reservoir is a carbonate reservoir with an average depth of occurrence, low porosity, and medium-low permeability.

Production is predominantly from fractured-porous reservoirs, fractures significantly enhance the permeable properties of reservoirs, increased reservoir interference. In the direction of the fractures, it is rapidly watering, at the moment the watercut is 50%. The state of fracture development, the direction of the fractures and the direction of movement of the injected water strongly affect the effect and production. Water production from different production wells is not simultaneous, it is easy to get water along the high energy shallow facies directions. Wells with a water cut of less than 20%: their share is 34.0%, mainly located in the upper part of the roof or at a great distance from injection wells. Wells, the water cut of which is 60-80%: the share is 34.0%, are mainly located in the wings of the roof, near the OWC, and in a close distance from injection wells.

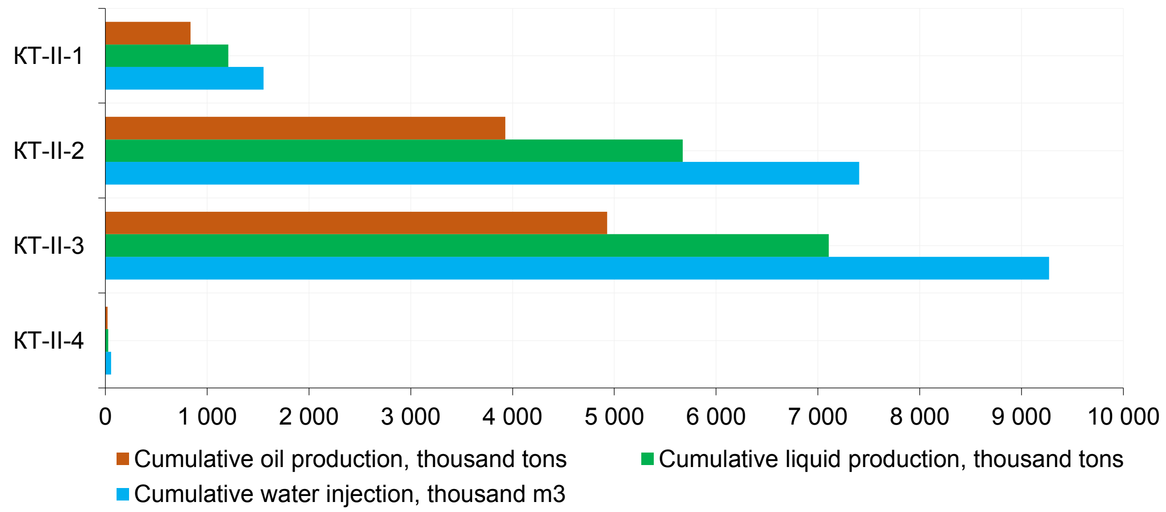


Figure 4. The ratio of cumulative oil production and water injection in the N field

The potential in the section is relatively large, the conventional oil recovery factor of the N field is 36.5%, the average withdrawal from the geological reserves of the KT-II horizon is 9.28%, the residual reserves are 88.3821 million tons, the development of the KT-II-2 horizon is relatively good, the withdrawal from geological stocks 12.87%. The geological reserves of the N field are large, the degree of production is low, the selection from the geological reserves is low, according to the study of water isolation technology, the optimization of isolation is one of the ways to improve the effect of field development.

3.2 Low efficiency of the implemented formation pressure maintenance system

The main factor affecting the achievement and excess of the approved oil recovery factor of the N field is the effective development of the fractured-porous reservoir. The wide spread of fractures increases the sweep efficiency of the injection wells, however, it is the cause of premature water breakthrough from injection wells. In a fractured reservoir, 2 main approaches/options for organizing development are applicable:

1. Organization of displacement of formation fluid through the formation by isolating highly conductive fractures (flow diverting technologies);
2. Development in natural mode of depletion or cyclic/non-stationary waterflooding of fractures.

Analysis of the current state of development of the N field shows an annual drop in the rate of oil withdrawal. Decrease in production, including caused by periodic suspension of wells due to technical restrictions on gas production (high GOR). Due to a decrease in reservoir pressure below the bubble point pressure, an increase in GOR is observed, which indicates a significant decrease in the energy state of the reservoir in the production zones due to the low efficiency of the implemented formation pressure maintenance system.

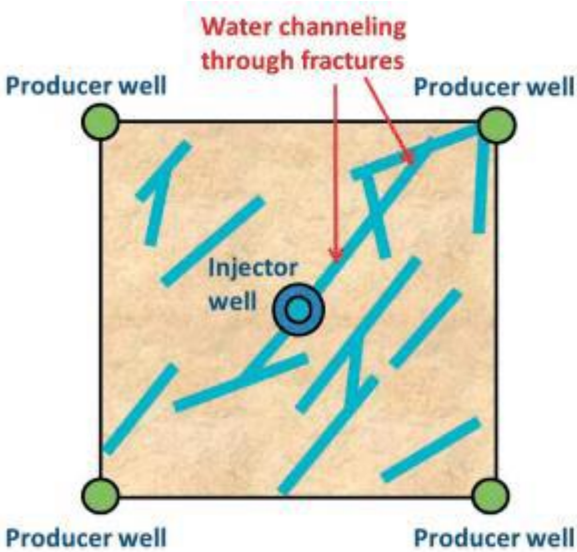


Figure 5. Fracture channeling during water flooding **(3)**

Water through the fracture system enters the production wells without efficient displacement and maintenance of reservoir pressure. The increase in water cut of well production reached 67% in 2019 and continues to increase at the current oil recovery factor of 10%. The reserves involved in the development are much less than the approved recoverable ones, which is associated with the complex geological structure of the field and the carbonate type of the reservoir, the decrease in reservoir pressure and the weak influence of the pressure drop not taking into account the specific fractured structure of the reservoir of the N field.

All these factors indicate the low efficiency of the existing formation pressure maintenance system, which does not take into account the specific fractured structure of the reservoir of the N field. Thus, taking into account the production indicators and the state of hydrodynamics in the sampling zone, it must be recognized that the implemented reservoir pressure maintenance system requires improvement specifically for the conditions of the N field. The areal location of the inverted five-spot development system when injecting an agent under constant wellhead pressure is implemented by analogy with terrigenous reservoirs. In the upcoming project document, it is planned to reorganize the reservoir pressure maintenance system into an in-line system by transferring wells for injection, including design wells after oil development. This solution is based on the existing system of fractures and high conductivity channels in the field.

In order to improve the work of the pressure maintenace system, it is necessary to make adjustments to the water treatment process, since one of the factors that have a significant impact on the efficiency of the pressure maintenace system operation and the injection capacity of injection wells is the quality of the injected water. The physicochemical composition of the injected water affects the degree of oil displacement, changes in capillary impregnation in the fractured-porous reservoir.

The study of the vertical connectivity of the reservoir makes it possible to determine the direction and rate of advancement of the injected water in the fractured-porous reservoir. Accordingly, based on the results of earlier studies and studies of the vertical connectivity of the reservoir, it becomes possible to control targeted elements in the reservoir pressure maintenance system: by "switching on/off" injection and production wells, changing the operating modes of wells, reduce the water cut, GOR, equalize the pressure in the "fracture -the matrix".

Non-stationary waterflooding technology and cyclic injection takes into account the specifics of the development conditions of the fractured-porous reservoir and allows using in the waterflooding and displacement system “idle” channels of fractures and matrix blocks, thereby increasing the coverage of the reservoir by waterflooding.

3. Theoretical basis of non-stationary waterflooding

Let us consider a part of the fractured-porous reservoir represented by two matrix blocks and a fracture that separates and forms these blocks. Pumping wsater into injection wells in the N field is organized in such a way that water entering the bottomhole formation zone under pressure carries out the opening process (under the coverage of injection) active fractures or the formation of new fractures according to the principle of auto-hydraulic fracturing. As a result, water breakthrough from injection wells to production wells along fractures leaves most of the matrix blocks uncovered by displacement. Injected water in a fracture at a pressure exceeding the formation pressure of matrix blocks in fracture zones close to the bottom of injection wells counteracts the displacement of oil from the matrix into the fracture (the main path of oil migration to the production well, the fracture permeability can reach several tens, hundreds or even thousands of Darcy, since it is essentially emptiness). Such a stable injection under pressure above the reservoir leaves a significant part of the matrix oil reserves isolated, practically along the entire strike of the fracture, since the pressure in it does not propagate according to the logarithmic type of radial flow (reverse funnel of repression), but along the linear type of the hollow fracture. As a result, a zone of penetration of the injected water is formed on the surface of the matrix block, the parameters of which depend on the distance from the injection well. This invasion zone, however, cannot serve as an alternative to the classical waterflooding system and fully replace the organization of displacement along the formation, due to the low piezo conductivity of the formation.

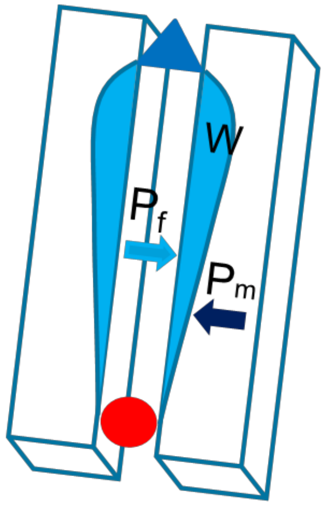


Figure 6. Fractured-porous reservoir element with production and injection wells, water flood front along the fracture (W), fracture pressure (Pf), pressure in the matrix block (Pm).

To involve in the development of isolated matrix blocks, it is necessary to consider alternative methods of organizing waterflooding. One of these methods is non-stationary waterflooding. The essence of the method consists in periodically stopping injection wells in order to reduce the pressure in the fracture, upon reaching which there is an inflow of fluid from the matrix into the fracture. Following the stage of shutting down the injection well, the start-up of the injection well leads to the displacement of fluid from the fracture into the production well. The production well works without interruption and provides periodic “drainage” of the fracture. The initial stages of the implementation of this method may not be distinguished by a change in the mode and nature of the inflow into the production well. However, as this operation is repeated, more and more involvement of matrix oil reserves occurs, the so-called "buildup of the matrix", as a result, a decrease in water cut or its wavy nature is observed. The duration of the first signs of matrix involvement depends on the relationship between fractures and matrix blocks, as well as the volume of water in the matrix that did not sink into the lower parts of the block under the influence of gravitational forces and stand in the way of oil to the fracture.

Based on the existing picture of the identified problems in the course of field development, it is necessary to understand and study the nature and role (in reservoir development) of the fractured-vuggy-pore system not only along the bedding, but also in the vertical relation. Such aspects include:

- Revealing a decrease in reservoir and bottomhole pressures below the critical fracture closure pressure (minimum lateral rock pressure), taking into account small inertial resistances along the inflow of fluids, which makes it difficult to study fracturing by hydrodynamic method;
- Fractures have a structural-hierarchical organization, representing sequentially nested networks of fractures of different scales: ultramicrofractures, microfractures, mesofractures, macrofractures, meta fractures and mega fractures;
- The change in the productivity factors of wells with a drop in reservoir pressure below the lateral rock pressure of fractured layers is mainly due to deformation (compression) of fractures and an insignificant manifestation of inertial resistance.

As you know, in the course of reservoir development, due to subsidence of reservoir pressure, the voids in the reservoir decrease. According to numerous experimental studies, when injecting a working reagent (water, kerosene, etc.), the opening of fractures and voids increases, and abruptly. This indicates the gradual connection of large voids connected by thin filtering channels to the volume of systems filled with fluid.

It was found that with a decrease in the volume of voids, i.e. specific pore volume, due to the manifestation of capillary forces, the displacement of oil by water occurs in two ways: due to the movement of water along the water surface (film displacement of oil) and meniscus movement of water in systems of small channels and large pores. These processes are proportional to the degree of rock hydrophilicity. In fact, the reservoir has very strong variability in hydrophilicity and heterogeneity, which greatly complicates the process of oil displacement by water.

Based on the results of experiments on fractured carbonate reservoirs in world practice, in the conditions of the N field, the use of non-stationary waterflooding is expedient and effective. The ongoing areal flooding during the long-term development of a fractured field does not have the desired effect in the form of maintaining reservoir pressure and displacing oil by the injected water.

With non-stationary waterflooding during periods of increasing reservoir pressure, hydrodynamic pressure gradients appear towards low-permeability reservoir elements, incl. strengthening the process of capillary impregnation. This increases the elastic reserve and, consequently, the volume of water introduced into the reservoir. During the period of reservoir pressure decrease, the pressure gradient sign changes, and the penetrated water, together with oil, gets the possibility of a reverse flow into highly permeable areas. Due to the microheterogeneity of the pore medium and its hydrophilic properties (especially wetting), part of the oil in the smallest pores is replaced by water under the action of capillary forces. In the pool-cycle of reservoir pressure reduction, the reservoir-fluid system expands, which helps to equalize the pressure in areas with different piezo conductivity, i.e. overflow of fluid into highly permeable components.

4. Well Test results

The results of the well testing at the N field confirm the complex structure and low filtration characteristics of the matrix part of the reservoir. For example, as we can see on the Figure 7 despite the fact that the duration of the pressure build-up test in well No. N1 was 1434 hours (60 days), the linear flow regime was not achieved.

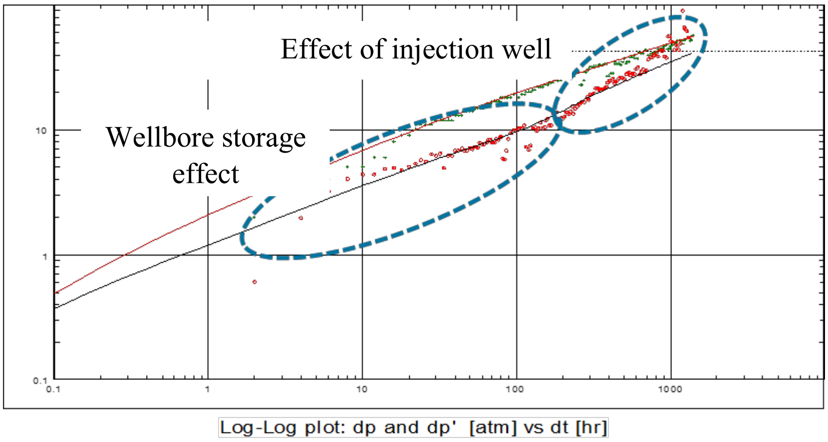


Figure 7. Pressure build-up graph of the well N1.

There is no straight horizontal section (radial inflow). This is due to the influence of the injection well, which continues to increase the pressure due to the long downtime of the production well. This well is directly connected with injection wells through a fracture system.

Well testing performed in well No. N2 indicates that the possible influence of the matrix on the oil production rate starts from 12-13 days (Figure **8**). The graph shows the beginning of the unstable pressure reduction zone, which is characterized by the transition zone of fracture operation. However, due to the insufficient duration of the study and the absence of an unambiguous typical change in the pressure derivative curve necessary to isolate the effect of fractures, this conclusion had to be verified by a direct field study on the trial introduction of the non-stationary waterflooding with a shutdown cycle of injection wells of more than 12-13 days. This study was carried out in 2020, because of which a decrease in water cut was achieved from 80% in the previous 1.5 years to 40% after the active phase of the study.

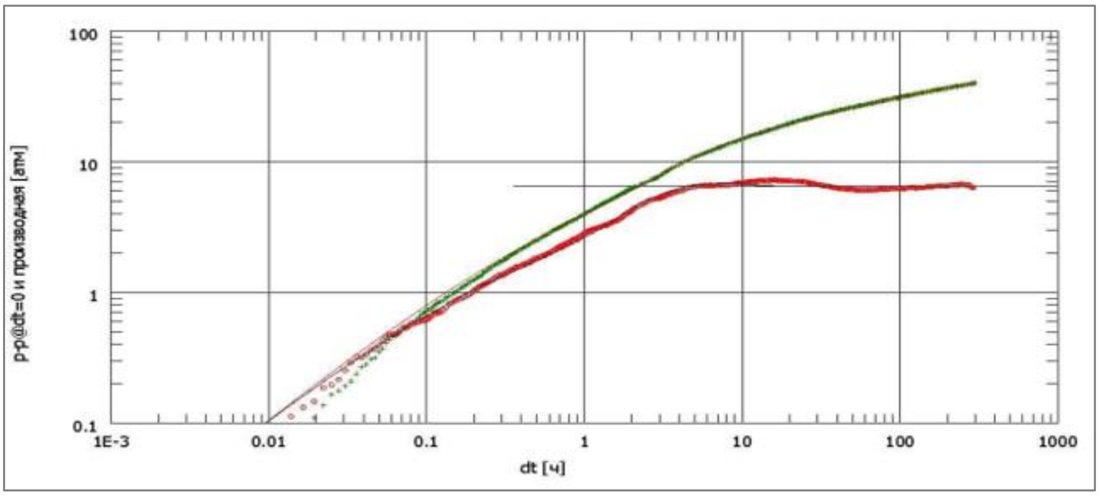


Figure 8. Pressure build-up graph of the well N2.

It should be noted that in the conditions of the N field, high-quality hydrodynamic studies are required, which is often not observed: underrecovered pressure in time, the effect of the influence of neighboring working wells, disturbance of the dormant state during recording. Distorted factors do not make it possible to clearly define the boundaries of the productive formation, to distinguish between the influence of the matrix and the fracture in the considered inflow area.

According to the interpretation of the results of the efficiency of injection well No. N3, the characteristic work of the fractures can be seen on the graph with the subsequent influence of the matrix - reaching the radial inflow

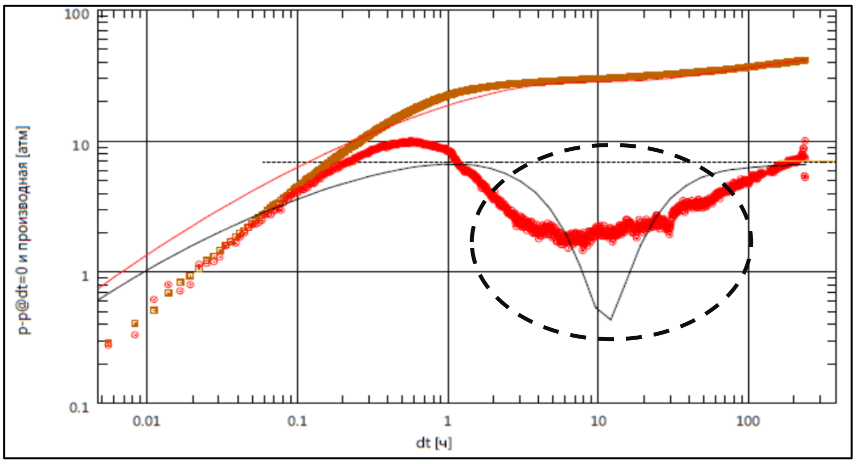


Figure 9. Pressure drawdown graph of the well N3.

All well tests carried out indicate an extremely heterogeneous structure of the reservoir and the absence of general regularities in the influence of the matrix part of the reservoir reserves due to the different intensity of fracture propagation and their characteristics, such as opening, length and volume. Based on the analysis of the well tests carried out, it is difficult to select the general shut-in cycles of injection wells, since the vast majority of the studies carried out were not carried out properly. Due to the need to fulfill the production plan, the time of pressure build-up to pseudo-radial inflow was not kept and the time was not reached to assess the effect of fractures.

5. Microimages FMI and CMI

Microimaging studies were also carried out at the field to study the occurrence of structural zones, the development of fractures, their nature, the nature of the strike and fall.

The field studies carried out in the N field confirm the description of the hierarchy of fracture systems. As an example, various depth intervals in the injection well #1, represented by the processed FMI microimager, are given. The total perforation floor is 125 m in the interval of 3130–3438 m.

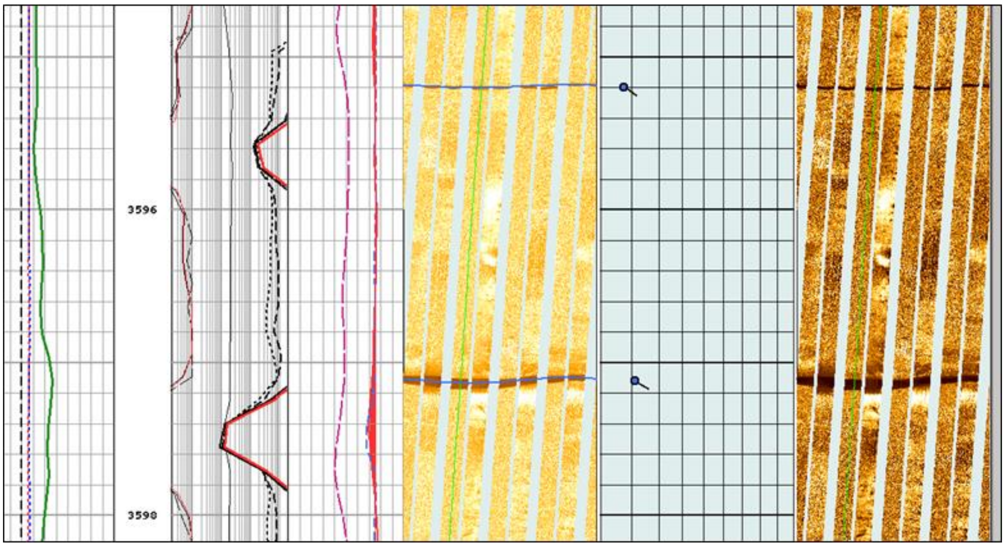


Figure 10. Part of the imager of the well #1 at a depth of 3590 m with identifiable horizontal fractures

In Figure 10, in the section of this well at a depth of 3590 m, 2 horizontal fractures are observed, differing in opening width, not filled with mineral matter. In the interval of 3362–3372 m, the reservoir is characterized as porous and permeable, with numerous conductive fractures, the direction of which is determined as from west to east.

According to this study in well #1 it is noted that in the dense carbonate there are visible large conductive fractures that are flatter horizontally, while in the more porous and permeable rocks there is a network of numerous fractures with steep dip angles.

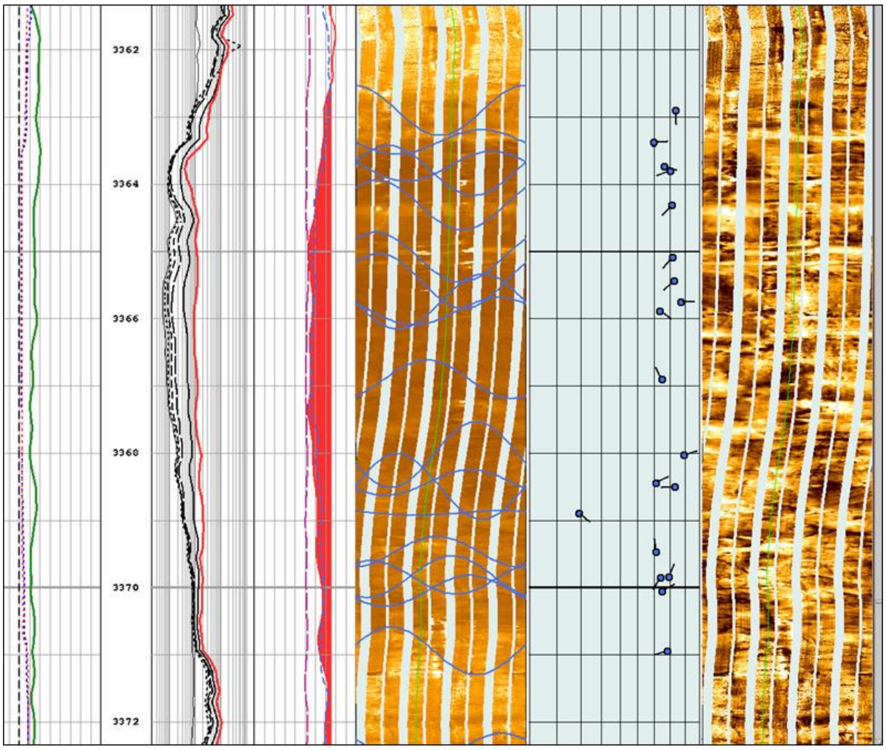


Figure 11. Part of the wellbore imager #1 at a depth of 3362-3372 m, characterized as a porous and permeable interval

## 6. Calculation of the efficiency of non-stationary waterflooding

### 6.1 Matrix oil flow calculations

To calculate the flow of oil from the matrix to the fracture, and from the fracture to the well, 3 methods are proposed for calculating the oil flow rate of horizontal wells, where the distance between the wells corresponds to the horizontal wellbore, and the fracture diameter corresponds to the diameter of the horizontal well.

1) Method of Yu.P. Borisov, who assumes that the zone drained by the horizontal well has the shape of a circle:

$$\boldsymbol{Q}_{\mathrm{H}} = \frac{2\pi kh\Delta P}{\eta\left[\ln\frac{4R_k}{L} + \frac{h}{L}\ln\frac{h}{2\pi R_c}\right]} \quad (5)$$

2) Method of S.D. Joshi, who assumes that the drainage area of the horizontal well is ellipsoidal in area:

$$Q_{\mathrm{H}} = \frac{2\pi kh\Delta P}{\eta B_{\mathrm{H}}\left[\ln\left(\frac{A+\sqrt{A^2-\left(\frac{L}{2}\right)^2}}{\frac{L}{2}}\right) + \frac{h}{L}\ln\frac{h}{2R_c}\right]} \quad (6)$$

$$\boldsymbol{A} = \frac{L}{2}\left[\frac{1}{2} + \sqrt{\frac{1}{4} + \left(\frac{2R_k}{L}\right)^4}\right]^{0.5} \quad (7)$$

3) F.M. Giger's method, which assumes that the zone drained by a horizontal well over the area has the shape of an ellipsoid:

$$\boldsymbol{C} = \frac{2\pi kh}{\mu_{\text{H}} B_{\text{H}}} \frac{1}{\left[\frac{L}{h}\ln\frac{1+\sqrt{1-\left(\frac{L}{2}R_k\right)^2}}{L/2R_k}+\ln\frac{h}{2R_c}\right]} \quad (8)$$

6.2 Calculation of the production rate of production wells. No. N3, N4 in the absence of reservoir pressure maintenance

Calculation of production rates ext. well No. N3, N4 based on 3 methods for calculating flow rates of horizontal wells: Yu.P. Borisov, S.D. Joshi, F.M. Giger

Table 2. Well rate calculation No. N3

| L_hor, m | A | Q1, m3/day | Q2, m3/day | Q3, m3/day | Qavrg, m3/day |
|---|---|---|---|---|---|
| 200 | 308,45 | 5,9 | 5,7 | 3,8 | 5,2 |
| 250 | 313,29 | 6,8 | 7,2 | 4,5 | 6,2 |
| 300 | 319,30 | 7,8 | 8,7 | 5,2 | 7,2 |
| 400 | 334,96 | 9,8 | 11,5 | 7,1 | 9,5 |
| 500 | 355,70 | 12,3 | 14,3 | 10,8 | 12,5 |

Table 3. Well rate calculation No. N4

| L_hor, м | A | Q1, m3/day | Q2, m3/day | Q3, m3/day | Qavrg, m3/day |
|---|---|---|---|---|---|
| 200 | 308,4 | 8,8 | 5,6 | 5,7 | 6,7 |
| 250 | 313,3 | 10,2 | 7,1 | 6,7 | 8,0 |
| 300 | 319,3 | 11,6 | 8,5 | 7,7 | 9,3 |
| 400 | 335,0 | 14,7 | 11,4 | 10,5 | 12,2 |
| 500 | 355,7 | 18,4 | 14,2 | 15,9 | 16,2 |

7. Simulation results

Reservoir simulation represents an essential tool for the management of oil and gas reservoirs. A key aspect of reservoir simulation is the representation of the well in the simulator and the linkage of the well to the reservoir.

When developing layer-by-layer-heterogeneous formations in permeability, the technology has found wide application non-stationary waterflooding (NW) of reservoirs, the effect of which is expressed in the redistribution of reservoir pressure between interlayers and increased production of oil reserves from low-permeability layers. Moreover, the more pronounced the heterogeneity of the formation, the more significant the effect of the NZ technology.

A hydrodynamic reservoir model was built, by the example of which we will consider two types of waterflooding: stationary and NW. Based on the results, we will identify the optimal parameters of the NW operation and the conditions of bedding, corresponding to the maximum efficiency of the application of this method.

Table 4. Permeability distribution along layers

| | PermX (mD) | DZ (ft) |
|---|---|---|
| Layer 1 | 13.64 | 20 |
| Layer 2 | 60.64 | 70 |
| Layer 3 | 190.91 | 30 |
| Layer 4 | 136.36 | 15 |
| Layer 5 | 654.55 | 30 |
| Layer 6 | 13.64 | 40 |
| Layer 7 | 136.40 | 60 |
| Layer 8 | 1.36 | 25 |
| Layer 9 | 40.91 | 12 |
| Layer 10 | 231.82 | 26 |

Table 5. Rock and fluid data.

| Rock and fluid data | |
|---|---|
| Rock Compressibility | 4,0E-06 psi-1 |
| Water Compressibility | 3,0E-06 psi-1 |
| Oil Density | 45,00 lbm/ft3 |
| Water Density | 63,02 lbm/ft3 |
| Porosity | 0.15 |

The two dimensional model consists of 100 active grid cells distributed in a 10x1x10 grid system along the x, y and z-direction for a corner point grid. The simulation model consists of one open hole perforated producer and injector located in grid block (1,1) and (1,10), respectively. The length of a grid block in x- and ydirection is 328ft, and the total length between the injector and producer is 3280ft (approximately 1000m) in the base case. Both the injection and production well is completed throughout the reservoir (from z=1 to z=10).

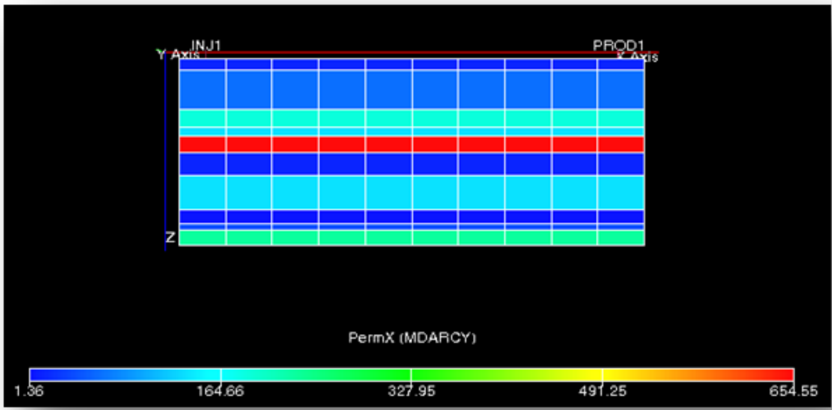


Figure 12. Permeability distribution

On the Figure 13**Figure 13** the lower permeability layers (pink circle) are better swept, due to the effect of cyclic injection. High permeable layers in the center of the reservoir (yellow circle) appears to be less swept with the cyclic injection due to two reasons; first, the less permeable areas surrounding the high permeable layers are contributing with oil. Second is that more water has entered the low permeable zones from the high permeable layers due to capillary imbibition.

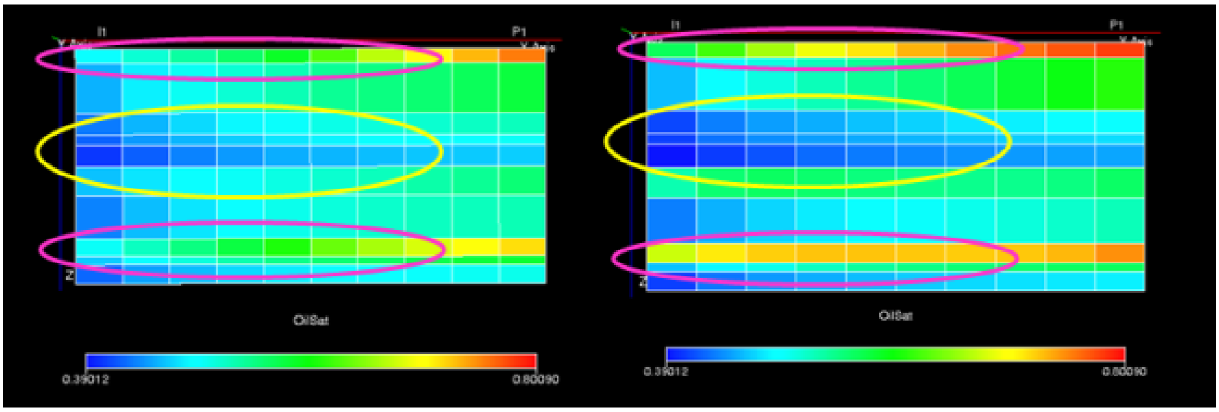


Figure 13. Cyclic injection (left) compared to conventional waterflooding (right) at the end of simulation

The essence of the method consists in periodically stopping injection wells in order to reduce the pressure in the fracture, upon reaching which there is an inflow of fluid from the matrix into the fracture. With non-stationary waterflooding during periods of increasing reservoir pressure, hydrodynamic pressure gradients appear towards low-permeability reservoir elements, incl. strengthening the process of capillary impregnation. This increases the elastic reserve and, consequently, the volume of water introduced into the reservoir. During the period of decrease in reservoir pressure, the sign of the pressure gradient changes, and the penetrated water, together with oil, gets the possibility of a reverse flow into highly permeable areas. Due to the microheterogeneity of the pore medium and its hydrophilic properties (especially wetting), part of the oil in the smallest pores is replaced by water under the action of capillary forces. In the pool-cycle of reservoir pressure reduction, the reservoir-fluid system expands, which helps to equalize the pressure in areas with different piezo conductivity, i.e. overflow of fluid into highly permeable components.

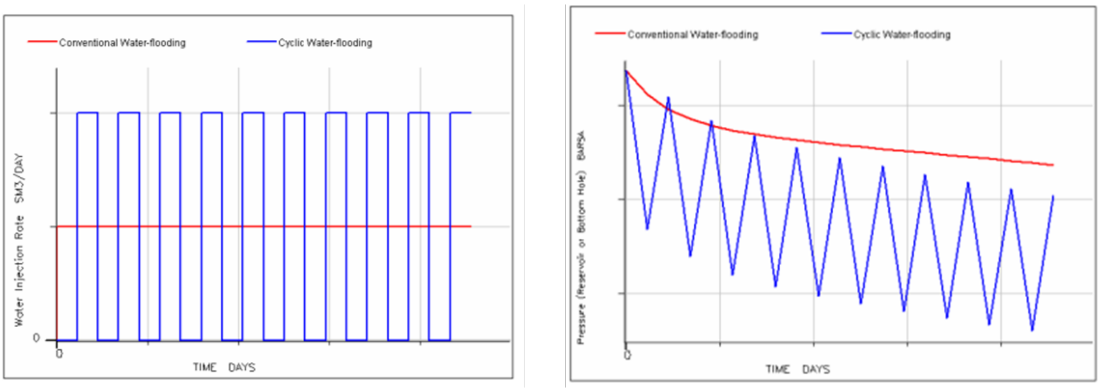


Figure 14. Conceptual illustration of cyclic injection (blue) and conventional injection (red). Left: Injection rates. Right: Pressure (reservoir or bottom hole).

Another aspect with the cyclic injection is the reduction in water production. As this operation is repeated, matrix oil reserves are increasingly involved, as a result, a decrease in water cut is observed

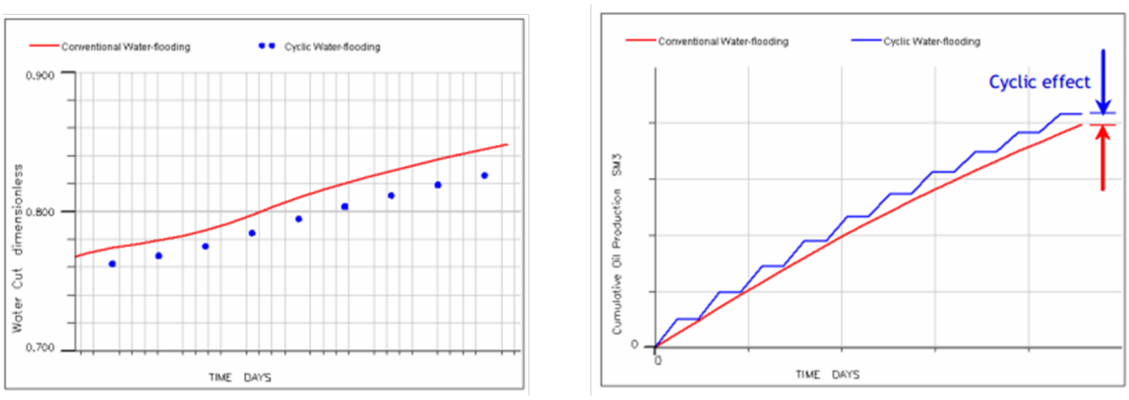


Figure 15. Conceptual illustration of cyclic injection (blue) and conventional injection (red). Left: Water Cut. Right: Cumulative production to the corresponding pressure in the right side figure.

8. Implementation of non-stationary waterflooding on the N field

The NW results in the showed good effects in the form of significant increases in oil production rates of wells No. 1, 2, 3 due to the change in the filtration regime of the FPR and a decrease in water cut. A decrease in GOR with an increase in oil production rates in the first period indicates the involvement in the development of previously undrained reserves of matrix blocks of the FPR of this part of the N field; in the second period, the influence and involvement of these reserves was reduced for the reasons described above.

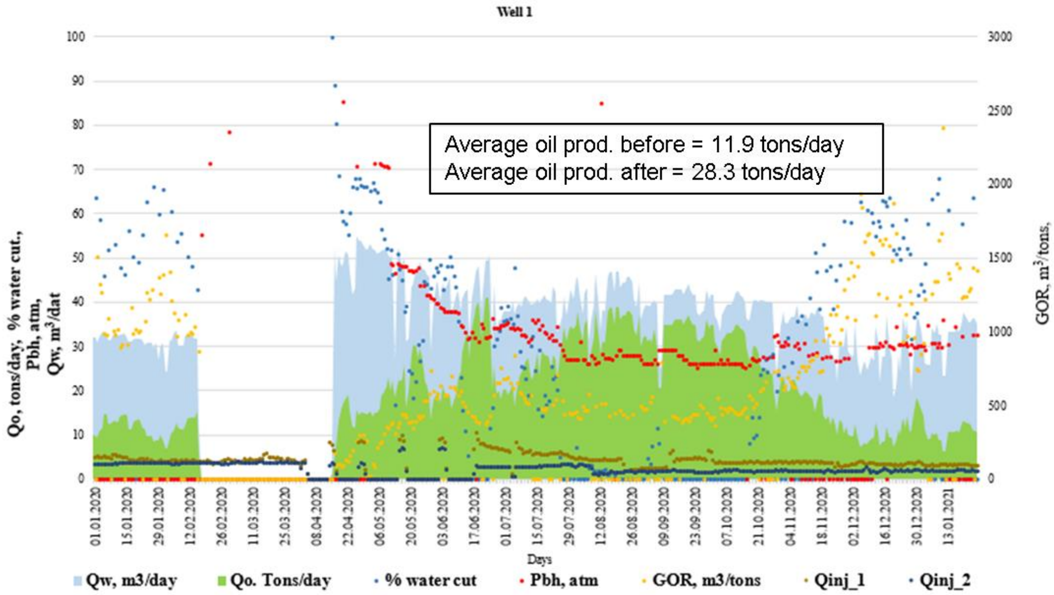


Figure 16. Dynamics of performance indicators of Well 1 and influencing injection wells

Wells that show clear rapid water breakthroughs through fractures are characterized by relatively small cumulative oil volumes and significant cumulative water production. The displacement curves of these wells are very different from the rest of the wells in the field. It is noteworthy that some of these wells are consolidated into two groups of displacement characteristics, which allows them to be judged as wells that, fell into two widespread flooded / flooded fracture systems.

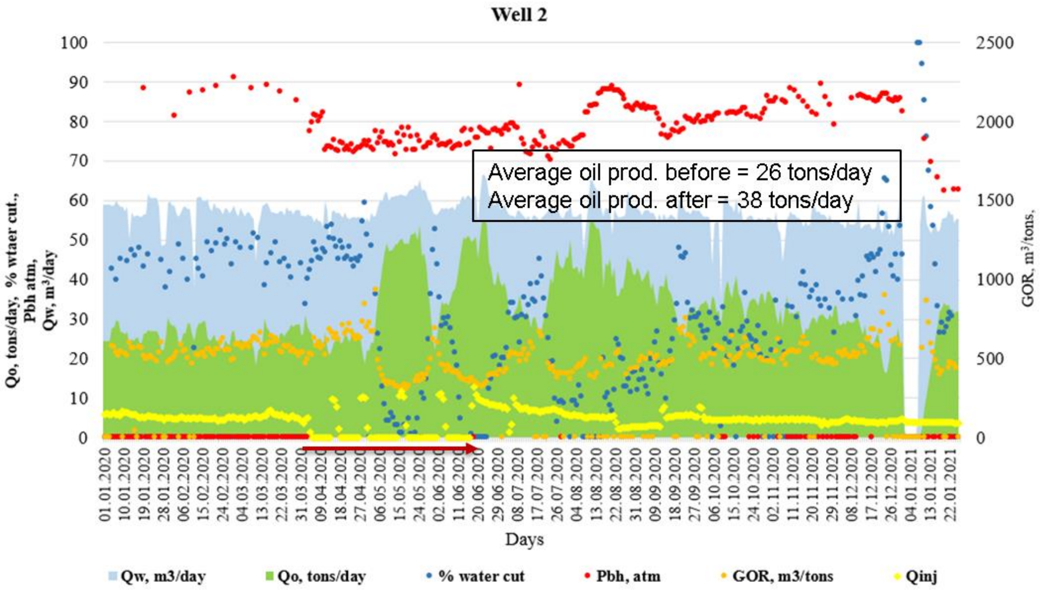


Figure 17. Dynamics of performance indicators of Well 2 and influencing injection wells

It should be noted that when cyclic waterflooding is used from the beginning of development, there is practically no mobile water in the reservoir and crossflows between interlayers only lead to the exchange of an equal amount of oil - cyclic waterflooding reduces the rate of oil production and practically does not affect the dynamics of waterflooding. Cyclic waterflooding begins to work as the high-permeability reservoir is saturated with water.

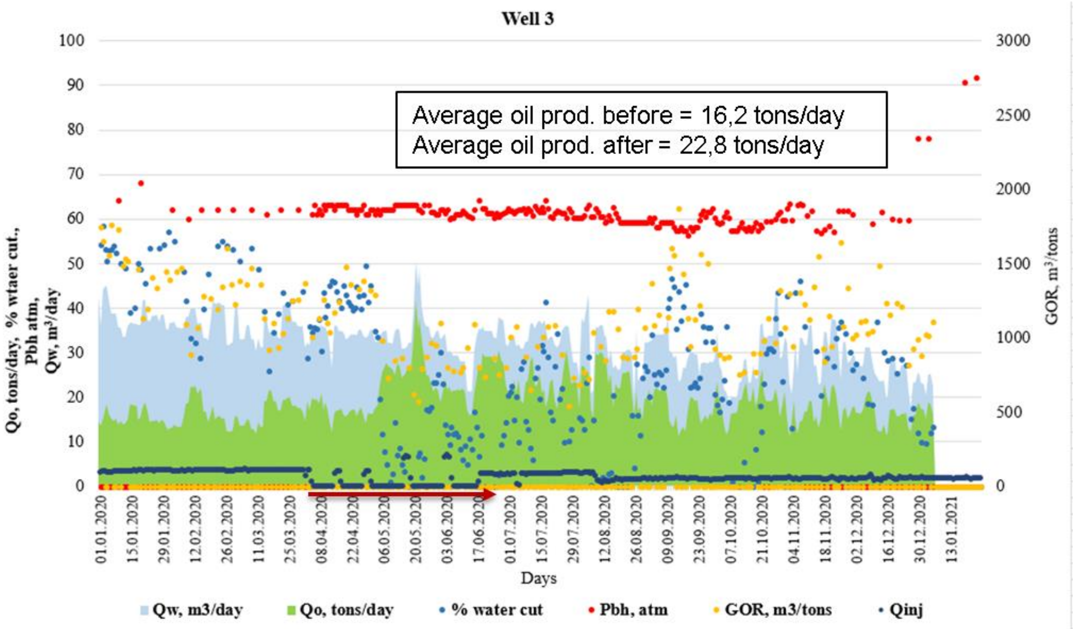


Figure 18. Dynamics of performance indicators of Well 3 and influencing injection wells

Technological efficiency is observed in the form of an increase in oil production and a decrease in water cut.

On the well level:

• the degree of water cut reduction and oil production rate increase depends on the ratio of downtime days and operation of the injection well. With an increase in the ratio, the increase in oil production increases

• it should be noted that an increase in the ratio of downtime and injection well operation negatively affects the energy potential of the deposits.

The pilot implementation of NW has shown the validity of this method, as well as its effectiveness for individual wells that have opened fractures:

• the nature of displacement has changed;

• decreased water cut;

• poorly drained reserves are involved;

• GOR decreased.

9. Environmental impact of NW

The service life of a well depends on the region where it is drilled (soil quality, climatic features ...), the method of field development, the quality of production pipes, corrosion resistance and a number of other factors. The average term of reliable well operation is 30 years. The shortest duration of its reliable operation can be in fields with a reservoir pressure maintenance system based on highly saline waters, as well as offshore fields, where salty sea water is pumped into the strata, which affects not only the inner part of the pipe, but also, partially, the outer and the outside. In some cases, internal and external special coatings are applied to the production strings to prevent rapid corrosion.

If, due to corrosion, the wells fail prematurely, the management of the formation development will be sharply complicated (more expensive). The most mobile oil will be selected in the early years, and the recovery of the remaining reserves will require drilling a large number of backup wells. Such field development may be ineffective.

Well design should provide for their operational reliability for many years, as well as subsequent reliable abandonment. Since it is quite clear that even under the most ideal conditions there comes a time when the production strings will corrode. Therefore, it is necessary to prevent the possibility of overflow of saline formation water into the upper layers containing fresh water. Otherwise, this can lead to the fact that in the territory where oil fields were developed, underground freshwater horizons will begin to saline, causing pollution of drinking sources.

A positive aspect of the implementation of the proposed cyclic waterflooding program was a significant reduction in the produced water due to the shutdown of injection wells in selected areas.

## CONCLUSION

In the course of this work, an analysis of information sources was carried out to describe fractured carbonate reservoirs for their modeling. It is concluded that for the characterization of fractures in carbonate reservoirs, the necessary methods to be carried out are mainly seismic exploration and reservoir microimages, both electrical and acoustic.

• Development of fractured reservoirs is ineffective by classical methods of waterflooding;

• maintaining a consistently high pressure in the fracture by continuous injection minimizes the potentially high coverage of the formation by the fracture (well);

• there are significant residual reserves of mobile oil in the matrix blocks of the FPR, bypassed by the injected water as a result of the implementation of the current development system;

• Isolation of high-water-cut formation intervals in wells does not increase displacement in the formation, but on the contrary removes from the development process the intervals associated with fractures characterized by the greatest reservoir coverage;

• It is necessary to revise the main approaches to the development of this field.

The pilot implementation of NW has shown the validity of this method, as well as its effectiveness for individual wells that have opened fractures:

- the nature of displacement has changed;
- decreased water cut;
- poorly drained reserves are involved;
- GOR decreased.

The oil production rates in such reservoirs are mainly influenced by the presence of fractures, which is why understanding their changes in natural fractured reservoirs is a key factor for the study, design and development of these fields. In practice, the development method, production forecasts and economic efficiency depend on the quality of the construction of the geological and hydrodynamic model and its reliability.

## NOMENCLATURE

| | |
|---|---|
| FMI | Formation Micro Imager |
| PLT | Production Logging Test |
| FPR | Fractured – porous reservoir |
| NW | Non – stationary waterflooding |
| RF | Recovery factor |
| GOR | Gas – oil ratio |
| HC | Hydrocarbon |

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