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Analysis of the causes of low oil recovery

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Review scientific paper

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Abstract

This analytical review is aimed at identifying and analysing a variety of factors affecting the low oil recovery factor. The study covers a wide range of parameters, from the mining and geological conditions of deposits to the physical and mechanical properties of rocks and hydrocarbons. Attention is also paid to such important aspects as geological features, including fracturing of rocks, waterlogging of formations and folding of deposits, which can significantly complicate oil production. Statistical data on current oil recovery rates from different regions and countries were collected and analysed, which helped to identify the most common problems and typical oil recovery rates. The review highlights that, along with well-known factors such as high oil viscosity and low rock permeability, oil recovery factor is significantly influenced by resistance to extraction by gravity, and complex tectonic conditions such as the presence of folds and faults. In addition, the problems related to the modelling and representation of the oil reservoir are considered, which can lead to errors in the assessment of oil reserves and, consequently, to an underestimated oil recovery factor. In conclusion, the review suggests possible areas for the development of oil production technologies that can help to overcome the identified obstacles. Suggestions are given for improving methods of increasing oil recovery, such as the introduction of new technologies, improvement of existing methods, and conducting more accurate geological studies.

Keywords:

geological, physical and physico-chemical properties of oil, well operation technology, fracturing, flooding, rocks

1. Introduction

The need for this review is conditioned by the unsatisfactory oil recovery factor in most fields. The development methods used in the 2020s ensure oil recovery in the range of 25-40%, which is significantly lower than the potential of the fields. This is happening against the background of growing global consumption of petroleum products, which makes the issue of improving production efficiency extremely relevant. The oil recovery factor ranged from 0.09 to 0.75, depending on numerous factors. For example, in Latin America and Southeast Asia, the average oil recovery was 24-27%, in Iran – 16-17%, in the USA, Canada, and Saudi Arabia – 33-37%, in the countries of the Commonwealth of Independent States – up to 40%, depending on the structure of oil reserves and the applied development methods (**Oil recovery, 2013**). The problem of low oil recovery from deposits is one of the most urgent in the oil industry. The efficiency of oil production directly depends on many factors, including geological, physico-chemical, and technical aspects. Despite significant advances in mining technologies, the oil recovery factor in many fields remains low, which jeopardises the economic feasibility of their development.

According to the alternative model by **Limberger (2015)**, two systems of interconnected pores coexist simultaneously in an oil reservoir. One of them ensures the permeability of the collector and its ability to filter fluids, while the other prevents this. The first system – effective porosity – serves as a container for mobile fluids (hydrocarbons and water in the corresponding parts of the deposit), while the second – inefficient porosity – serves as a container for residual water in any part of the deposit. In other words, the oil and gas collector are much more complicated: part of the open porosity (a fraction of the void volume) is filled with oil or gas together with a film of residual water, is permeable and provides fluid filtration; the other part of the open porosity is completely filled with residual water, is impermeable and unable to filter fluids. More detailed information on this area is presented in the paper by **Dawe and Grattoni (1998)**.

Ahmadi and Hosseini (2021) studied the use of surfactants and smart water in chemically enhanced oil re-

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covery (EOR), focusing on wettability alteration in carbonate reservoirs. They highlighted key surfactant properties, such as critical micelle concentration and hydrophilic-lipophilic balance, which influence interfacial tension reduction and wettability changes. The study demonstrated that combining surfactants with smart water effectively shifts carbonate rocks from oil-wet to water-wet, enhancing spontaneous imbibition and oil displacement. Their findings emphasize the need for tailored surfactant formulations to optimize recovery in challenging oil-wet reservoirs. **Ahmadi and Chen (2020)** reviewed the challenges and advancements in chemical-assisted heavy oil recovery, emphasizing the need to address limitations of steam injection, such as uneven distribution and residual oil retention. They highlighted the potential of surfactant and polymer flooding, as well as nanotechnology, to enhance oil mobilization by improving sweep efficiency and reducing interfacial tension. The study also underscored the importance of optimizing chemical formulations for thermal stability and cost-effectiveness while integrating these methods with existing recovery techniques to improve overall efficiency in heavy oil reservoirs.

Chowdhury et al. (2022) considered the possibilities of increasing the efficiency of oil production from fractured carbonate reservoirs by changing their moisture content and matrix density. They found that modified seawater with the addition of certain surfactants can change the moisture content of carbonate rock from oil-wet to water-wet, which contributes to increased oil recovery. In one of the latest studies, **Luo et al. (2020)** investigated the parameters and working conditions that determine the efficiency of oil extraction from oil sludge. The mechanism of ultrasonic dispersion of oil sludge was analysed. The main thing considered was the effect of ultrasound frequency on the formation of cavitation bubbles, which has an effect on the desorption of oil from solids.

Existing research in the field of EOR covers a wide range of methods, ranging from physico-chemical effects to innovative technologies for managing the production process. However, many of these studies do not consider the complex influence of various factors on the oil extraction process, which leads to ambiguous and sometimes contradictory results. Thus, there is a need for a detailed analysis of the causes of low oil recovery and the development of approaches that will increase production efficiency.

The purpose of this review was to identify the main causes of low oil recovery from reservoirs. To achieve this goal, the physico-chemical and geological-physical properties of oil reservoirs were analysed, and recommendations for improving production efficiency were developed.

2. Materials and methods

In 2023, Perm National Research Polytechnic University jointly with OOO LUKOIL-PERM conducted research to improve the oil recovery factor. This study, along with similar studies by other researchers, used data on the physical and geological-physical properties of petroleum reservoirs provided by various oil-producing companies and scientific institutions. The main materials included geological maps, core samples, results of laboratory analyses of rock and fluid properties, and statistical data on current oil recovery rates.

Several methods were used to achieve the objectives of the study. The geological and physical analysis included the study of the mining and geological conditions of deposits using structural analysis and modelling of rock fracturing. The physical properties of rocks, such as permeability, porosity, and oil viscosity, were analysed based on laboratory measurements and field research data. Physico-chemical studies were carried out to determine the viscosity and density of oil under various temperature and pressure conditions. Special attention was paid to the interaction of oil with various chemical reagents to evaluate the effectiveness of EOR methods, such as injection of chemicals, gas, and water. The statistical analysis included the processing of data on current oil recovery factor using methods of correlation and regression analysis, which helped to identify the relationship between geological characteristics and production efficiency. Statistical tests such as the Student's t-test were used to assess the reliability of the results obtained. Mathematical modelling was aimed at developing models of fluid flow in porous media, taking into consideration fracturing and heterogeneity of formations. Using numerical methods and software packages, changes in the oil recovery factor were predicted when using various exposure methods, including water and gas pressure methods, and chemical exposure.

Mining and geological conditions were also investigated. This included the analysis of the physical and mechanical properties of rocks and hydrocarbons, and the study of fracturing of formations and its impact on the productivity of producing wells. Field tests included conducting pilot tests of EOR methods at various fields, which evaluated their effectiveness in real conditions. Well performance monitoring before and after the application of new technologies was carried out to assess their impact on the oil recovery factor. The study was part of a multi-year project carried out at large oil-producing regions, which covered a wide range of geological conditions and oil production technologies. Specialised equipment was used for laboratory and field research, including instruments for measuring permeability and porosity of rocks, viscometers for determining oil viscosity, installations for modelling fracturing and filtration processes, and software for numerical simulation of fluid flow in porous media.

The objects of the study included oil fields with different reservoir types and conditions of occurrence. Thermal, gas, chemical, and microbiological methods of oil injection and displacement were tested at these fields.

The results of measurements and tests carried out both in the field and in laboratories became the basis for the analytical data of the study. The research procedure was carefully planned and included several successive stages. At the first stage, data on the physical and chemical properties of oil reservoirs, their conditions of occurrence and current development methods were collected and analysed. Further, laboratory tests of various EOR methods were carried out to assess their potential under controlled conditions. Computer models were used to predict the effectiveness of various methods and their possible impact on well productivity. Pilot tests were carried out on real deposits to confirm the data obtained in the laboratory and using modelling. At the last stage, the processing and analysis of the data obtained allowed the authors to identify the most effective EOR methods and develop appropriate recommendations.

3. Results

In most oil-producing countries, the coefficient of oil losses is determined by the subsurface user, who proceeds from their economic interests, regardless of significant volumes of losses. The cost of production of easily recoverable oil is low, and as a result of oil sales, oil-producing companies receive extra profits. As a result, oil companies are not interested in increasing production volumes by increasing the cost of extracting residual oil (**Cost of oil production, 2024**). **Table 1** shows the cost of oil production by country.

Table 1. Cost of production per barrel of oil in USD by country worldwide (**Cost of oil production, 2024**).

No.	Country	Prime cost, USD
1	2	3
1	USA (shale oil)	35-50
2	USA (liquid oil)	43-45
3	Canada (bitumen oil)	120-150
4	Nigeria	15-17
5	Mexico and Venezuela (bitumen oil)	37-40
6	Kazakhstan	20-50
7	Iran	27
8	Saudi Arabia	2.8
9	Kuwait	8.79

The price of oil as of 06/28/2024 was USD 84.93 per barrel (**Oil price today, 2024**). Evidently, the profit from the sale of oil was enormous (the price exceeds the cost by 2-8.75 times), therefore, the development and application of new technologies to increase oil recovery are not in demand. As mentioned above, one of the factors influencing low oil recovery are technological solutions such as the integration of development facilities, the sequence and speed of development, methods of impact on formations, the number of wells and their placement, field management and environmental protection. An important part of creating such a system is the allocation of development objects. Although pooling formations may seem advantageous at first due to a decrease in the number of wells, excessive pooling can lead to deterioration in technical and economic indicators due to losses in oil recovery. The incompatibility of geological, physical, and chemical properties of rocks, the phase state of hydrocarbons and the conditions for managing the development process also affect the allocation of development facilities.

Thus, it is necessary to consider a number of factors when determining development sites to ensure the efficiency and economic feasibility of the field development process. Before deciding on the allocation of facilities for development, the impact of each of these factors is carefully analysed from a technological and economic standpoint. Thus, the allocation of the development facility has a significant impact on the oil recovery factor. Oil moves through the reservoir to the producing well under the influence of a pressure drop, which must be higher at the bottom of the well to ensure oil inflow. At the beginning of field development, reservoir pressure is usually sufficient for oil to flow to the well, but it gradually decreases, and special measures are required to maintain it, such as organising the injection of water or gas. There are three classes of development methods – primary, secondary, and tertiary, which are determined by the energy source for moving oil to the well. Usually, different methods are used at different stages of development, starting with the primary ones and moving on to more complex ones (**Moldabayeva et al., 2023**).

An adapted approach is required for unconventional oil fields. Sometimes they immediately begin with the application of tertiary development methods, creating new unique approaches. Each development mode, such as water-pressure, elastic, gas-pressure, etc., has its own characteristics and affects the final oil recovery (**Li et al., 2020b**). The experience of field development confirms that the restriction on oil production solely by the forces of nature leads to significant losses of oil remaining in the subsurface. Therefore, additional methods, such as secondary or tertiary treatment of the formation, are already used in the early stages of the field to increase oil recovery. In the secondary method, reservoir pressure is maintained by pumping water or gas into the reservoir. Although this helps to increase production, the loss of oil in the subsurface is still significant.

Tertiary methods based on the use of internal reservoir energy help to increase oil recovery by injecting agents with an increased displacement potential. In this case, not only the pressure is maintained, but also the properties of oil and agents in the reservoir change. In order to increase oil production, various measures are being taken, such as reducing non-drained zones and preventing the development of low-pressure zones. In addition, the probability of dagger water breakthroughs, which can lead to the extraction of water instead of oil, is reduced (**Li et al., 2020a; Ivanchina et al., 2019**). EOR methods can be divided into several groups: thermal, gas, chemical, and microbiological. Although each method has the potential to increase production, its effectiveness depends on the specific deposit and its geological features. The development of deposits and the application of EOR methods should be adapted to each specific case, considering the geological structure and features of the formations. The physical properties of oil that significantly affect the oil recovery factor are considered below (**Song et al., 2022**).

The main components of oil are carbon (up to 87%) and hydrogen (up to 14%). In addition, small amounts of sulphur (up to 6%), nitrogen (up to 0.3%), and oxygen (up to 3%) are present in the oil. It may also contain heavy metals and various gases of organic and inorganic origin. Depending on the predominant hydrocarbons, oil is classified as paraffin, naphthenic, or aromatic. With the age of oil, the content of paraffin in its composition increases (**Ismailova et al., 2024**). The high content of paraffin in oil, as is known, complicates the processes of its extraction, transportation, processing, and reduces the oil recovery factor. During the extraction of highly paraffinic oil, paraffin deposits on the walls of pipes. Paraffin deposits up to 30 mm thick may form in the main pipelines. The properties of oil in reservoir conditions differ significantly from those of degassed oil due to high pressures, temperatures, and dissolved gas content. This needs to be considered when choosing oil production technology and equipment for harvesting in the fields. During the development of deposits, the ratio of the components of the multiphase mixture changes. For example, the water content in oil may increase from the beginning to the end of development, which also negatively affects the oil recovery factor.

Reservoir properties also have an impact on the efficiency of oil recovery. For example, porosity is a key factor: the lower it is, the smaller the volume of the pore space will contain oil, and the more heat will be spent on heating the rock, and not on the oil itself. Based on experience, the optimal porosity of the formation subjected to thermal action ranges from 10% to 30%. This value provides the best oil recovery factor. Reservoirs with intense fracturing are usually not suitable for continuous steam exposure to oil extraction, since steam penetrates through cracks into producing wells, which significantly reduces the efficiency of area coverage (**Bliznjuk et al., 2022; Deryaev, 2023c**). Thermal treatment works are most often carried out in highly permeable reservoirs, except in cases of creating a front for low-temperature oxidation of oil. High values of hydroconductivity contribute to the rapid penetration of the coolant into the formation and its movement through it, which significantly reduces heat loss to the upper and lower boundaries of the formation (**Prokopov et al., 1993; 1989**).

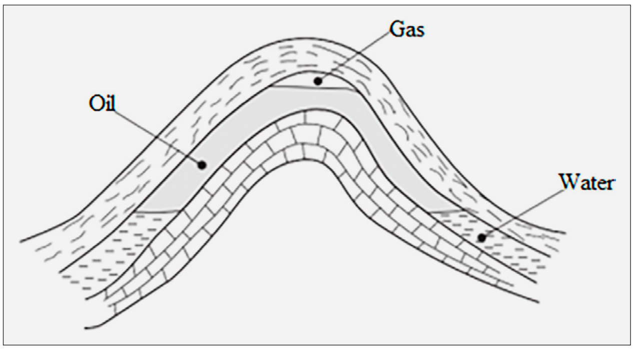


Figure 1. Collector formed as a result of folding

When applying the flooding process, porosity, fracturing, and permeability of oil reservoir rocks increase the value of oil recovery factor.

The increase in oil recovery factor, in this case, depends not only on the properties of the rocks of the oil reservoir from porosity, permeability, fracture modulus, and orientation of cracks, which are not constant, due to the heterogeneity and unevenness of the properties of the oil reservoir, but also depends on the methods of oil development, on the technical characteristics and parameters of development systems, the location of injection and production wells, supply pressure (water, steam) into the oil reservoir (in view of which steam breaks into producing wells occur), supply directions (water, steam) relative to the structure of the oil reservoir. Various tectonic fractures play a key role in the filtration of liquids in dense algal limestones. When planning the drilling directions of horizontal and inclined boreholes, and during the process of flooding the deposit, it is necessary to consider information about the prevailing directions of fracturing. If wells are drilled perpendicular to the direction of crack propagation in a reservoir with low permeability and porosity, they will cross crack systems, which will lead to an increase in their productivity. When the direction of the cracks does not coincide with the front of the water movement during the flooding period, this will increase the efficiency of oil displacement to the producing wells. This will contribute to the improvement of oil recovery factor (**Panchal et al., 2022**).

Hui et al. (2020) analysed changes in the productivity of horizontal production wells laid parallel and perpendicular to the direction of fracturing was carried out. The effect of the azimuthal distribution of natural cracks on the velocity of movement of the injected water front from injection wells to production wells was studied. The results showed that a high level of flooding is observed in producing wells located in the zone of natural cracks, especially in the northwest and southeast relative to injection points. In addition to these factors, the shape of collectors can have a significant impact on the oil recovery factor. **Figure 1** shows the reservoir, which was formed as a result of the folding of rock layers. The contour of the domed collector is round, and the anticline one is long and narrow. Oil and gas move or migrate

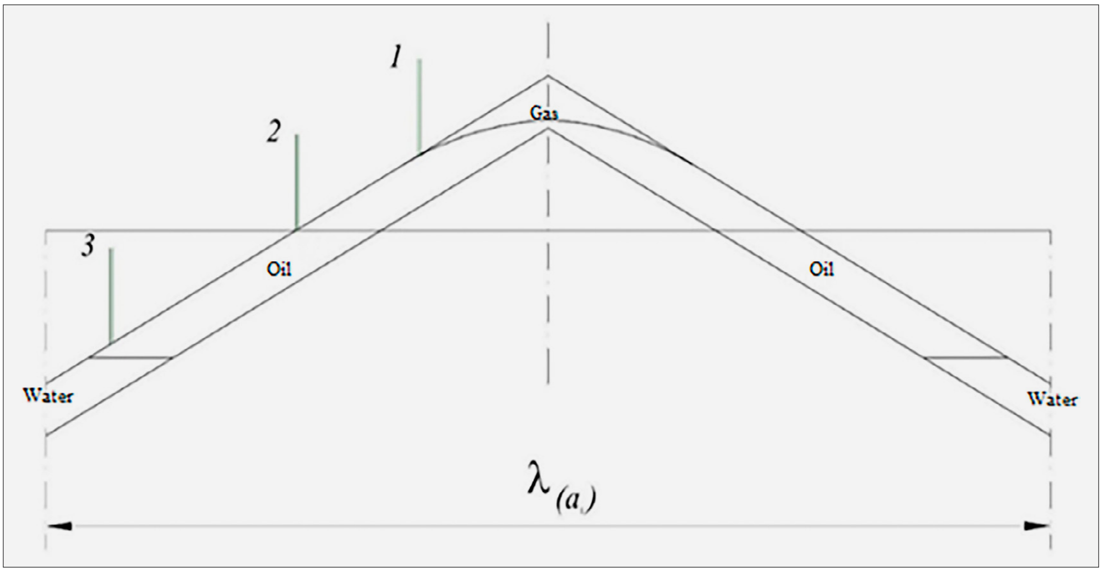


Figure 2. Substantiation of the variability of oil recovery factor in different development methods and their different location relative to the fold wing

upwards through porous rocks, where they are clogged by a sealed overlapping rock and take the form of a formation (**Winanda and Adisasmito, 2022**).

The case of simultaneous operation of three production wells located evenly along the left wing of the fold during the water-pressure operation of the deposit is shown in **Figure 2**. Initially, the highest oil production rate will correspond to well 3, since the water pressure and gravitational pressure of the oil are higher than well 3. After reaching the level of injected waters of well 3 and its subsequent conservation, the highest flow rate by analogy will correspond to well 2. And after reaching the injected water level of well 2 and its subsequent conservation, only well 1 works. The applied water pressure mode of operation and the location of production wells ensure minimal oil losses or the maximum oil recovery index in the left wing, and in the right-wing oil remains in the subsurface if there is a gap between the wings. In the case of simultaneous operation of three production wells, similar reasoning can be carried out in the gas-pressure mode of operation of the deposit.

In the case of simultaneous operation of two production wells 1 and 2 and the absence of well 3 during the water-pressure operation of the deposit, it is also possible to obtain the maximum oil recovery factor. It should also consider the possibility of a gap between the left and right wings of the oil deposit. Next, the study considers the case of simultaneous operation of two production wells 1 and 2 in the gas-pressure mode of operation of the deposit and the absence of well 3. Here, after reaching the level of injected gases at the level of well 2 and its subsequent conservation, the oil remaining in the wing will actually be attributed to losses, which can reach significant values depending on the location of well 2.

In the case of simultaneous operation of wells 1 and 2 during flooding, the oil recovery factor will be higher than in the previous case. There will also be a higher oil recovery factor when wells 1 and 3 are operating in the absence of well 2. In the case of simultaneous operation of two production wells 2 and 3 with a water-pressure mode of operation of the deposit and the absence of well 1, there is a decrease in oil recovery factor, since the oil above well 2 will remain in the subsurface. And with the gas-pressure operation of the deposit, the oil recovery factor will be significantly higher. In case of operation of only one production well 1 in the upper part of the fold wing under the water-pressure mode of the deposit exploitation the oil recovery factor will be high enough, and under the gas-pressure mode of the deposit exploitation the oil recovery factor will be low, practically all oil reserves lying in the fold wing below the well are completely written off as operational losses.

In the case of operation of one production well 2 in the central part of the fold wing during the water-pressure operation of the deposit, the oil recovery factor will not be high, since oil will remain above well 2. Similarly, in the gas-pressure mode, there will be a low oil recovery factor, since there will be oil losses below well 2. With the location of one production well in the central part of the wing, the use of a combined development method using flooding and gas-pressure operation of the deposit allows for a higher oil recovery factor. When only one well 3 is operating in the lower part of the fold wing in the water-pressure mode of operation of the deposit, the oil recovery factor value will not be significant, and in the gas-pressure mode it will be quite high. Everywhere it should be borne in mind that when the wings break, there will be oil losses in the right wing. Next, the influence of various forms of collectors on the oil recovery factor is considered, while the above arguments are acceptable, in practice, for various forms of collectors. Thus, in disturbed reservoirs, the influence on the oil recovery factor of the shape of their occurrence is similar, since it is similar to the wing of occurrence in **Figure 1** (also see **Figure 3**) (**Abdel-Aal et al., 2018**).

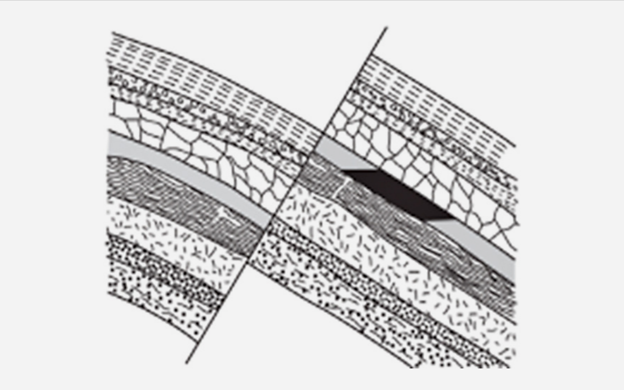


Figure 3. Geological profile of the disturbed reservoir

It is legitimate to consider the coincidence of oil recovery factor values in reservoirs with a salt dome and in domed reservoirs (see **Figure 4**) (**Abdel-Aal et al., 2018**).

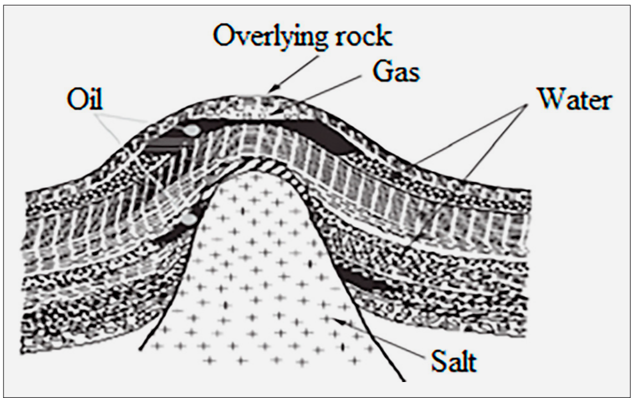


Figure 4. Section of the structure with a salt dome

Collectors with inconsistent occurrence of rocks and lenticular collectors are considered as wings of domed collectors and the values of oil recovery factor will be similar (see **Figures 5** and **6**) (**Abdel-Aal et al., 2018**).

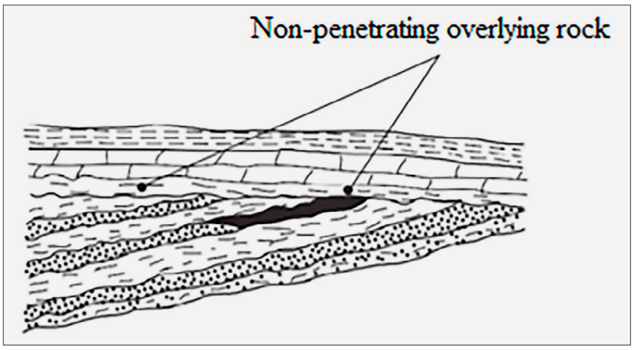


Figure 5. Reservoir formed by inconsistent occurrence of rocks

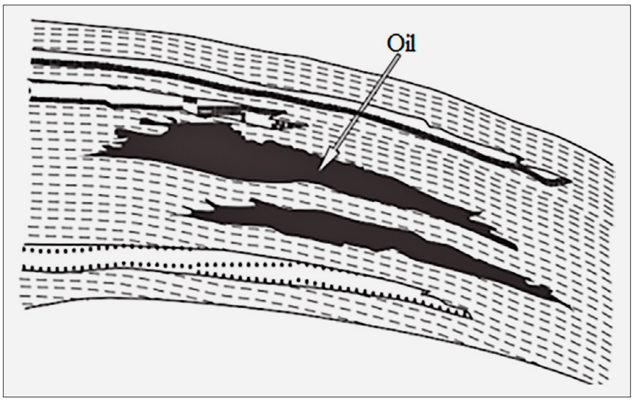


Figure 6. Lenticular collectors

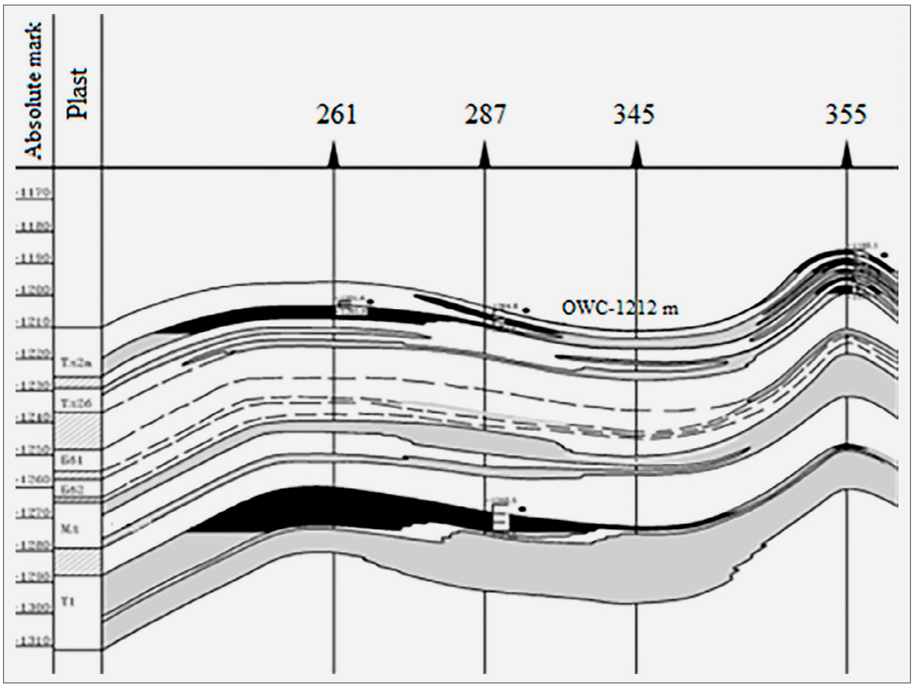
The geological profiles of the multilayer Trushnikovsky oil field, which is successfully exploited in the Lower Carboniferous and Upper Devonian deposits, are shown in **Figures 7** and **8**. The Lower carboniferous strata (Tl, T) have a connection with the formations created by the Upper Devonian reefs. Devonian sediments lie below the reefs and are associated with folded tectonic structures (**Galkin and Poplaukhina, 2021**). Based on the materials, the roof surfaces of the deposits of the Uzen Horizon 19 deposit were constructed, which clearly also represents a folded complex.

In the area of wells 28, 41 and 131, when analysing the productive horizon of roof 19, the Humurun dome was found to be 4.2 km long and 1.5 km wide, with an amplitude of about 30 m along the isohypsis, reaching a depth 1,240 m (see **Figure 9**). According to 3D seismic data, two discontinuous faults can be distinguished on the Humurun dome, oriented in a submeridional direction, with an amplitude from 10 to 15 m. One of the violations is visible on the eastern periclinal, and the second on the western (**Khassanov and Sikhayev, 2020**).

Evidently, the oil fields, including the Uzen field, are a folded complex. In this regard, producing wells are drilled and fall into different parts of the wing, and therefore, the flow rate of these wells for oil will be uniquely different. And as a result, low oil recovery factor values are obtained for producing wells. There are studies in the literature on various causes affecting oil recovery factor, especially those related to the viscosity of oil. In this regard, the influence of reservoir folding on oil recovery factor is considered below. Traditionally, the development of oil fields is carried out using a relatively rare grid of wells of 25-30 ha/well or more, which is approximately 250×1,000 m or 300×1,000 m, or other variations thereof. The design documents provide that a certain proportion of reserves should be extracted from each well (**Current oil production, 2011**).

Figure 10 shows the classical scheme of a brachianticlinal oil deposit. According to the data of exploration wells drilled along a grid of (250×1,000) or (300×1,000) m, and between two production wells 4 there are two wings of a fold with an oil layer.

Upon receipt of additional exploration data, by further thickening the grids of exploration wells, a more



Note*: OWC – oil-water contact.*

Figure 7. Geological profile of the Lower carboniferous deposits of the Trushnikovsky deposit (Perm Krai)

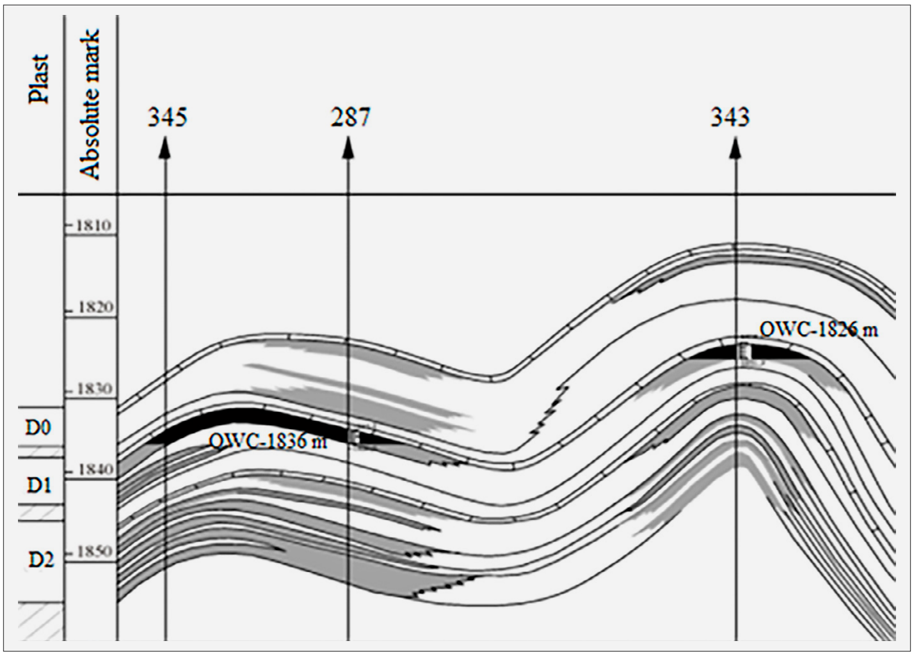


Figure 8. Geological profile of the Devonian deposits of the Trushnikovsky deposit (Perm Krai)

refined location of the producing wells 4 relative to the oil reservoir is obtained. As can be seen, if there is a high folding, the loss of oil in the subsurface will be very significant, since part of the oil field does not fall within the range of producing wells. If the folding turns out to be even higher, for example, as shown in **Figure 10**, then oil losses will be more significant.

The analysis identified critical factors affecting the low oil recovery coefficient, including geological complexities (e.g. fracturing, folding, and waterlogging), high oil viscosity, and low permeability of reservoirs. Statistical and experimental studies emphasized the significance of secondary and tertiary recovery methods such as water, gas, and chemical injection, which, while impactful, have limitations in substantially enhancing the oil recovery factor. The findings suggest that improvements in reservoir management strategies – optimized well placement, tailored extraction technologies, and advanced reservoir modelling – are essential for minimizing losses and achieving more efficient extraction. The results underline the importance of integrating geological insights with technological advancements to address the multifaceted challenges of oil recovery.

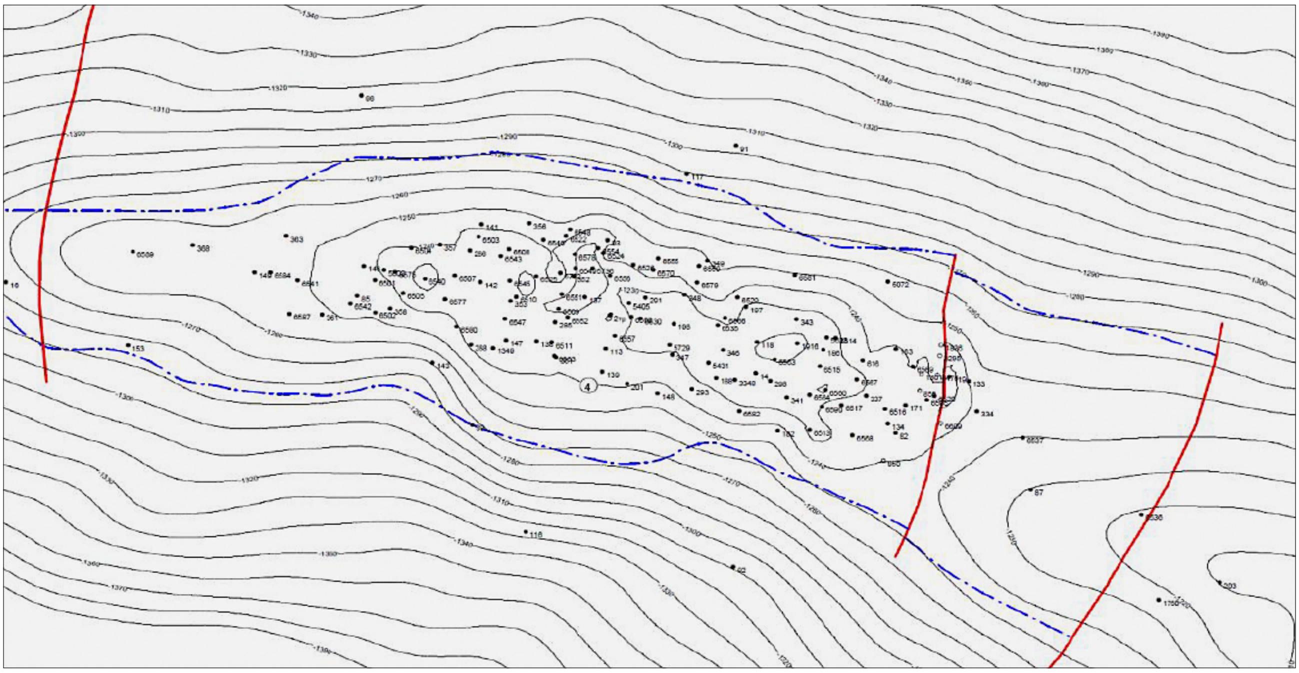
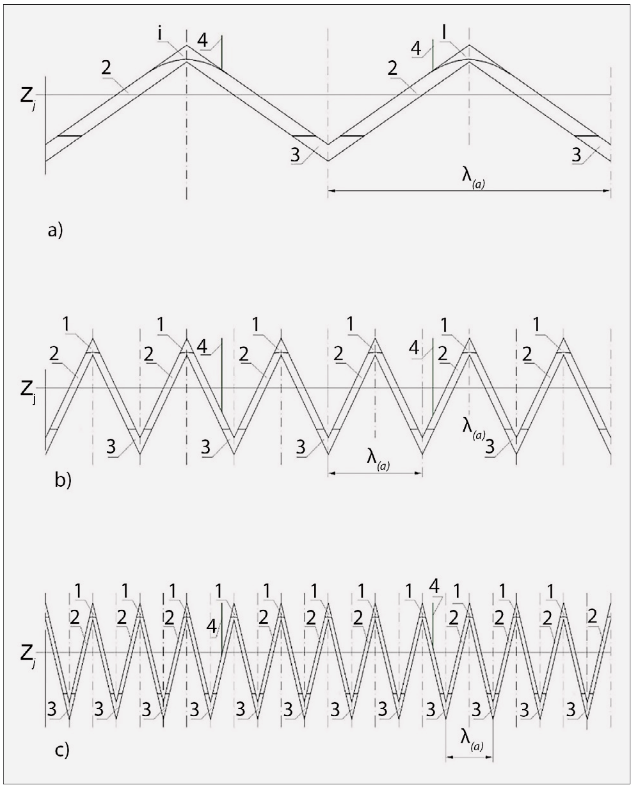


Figure 9. Fragment of the structural map along the roof of the 19th horizon. Humurun dome of the Uzen deposit.



Note: 1 – gas layer; 2 – oil layer; 3 – water layer; 4 – production well.

Figure 10. Cross-section of a brachianticlinal oil deposit built on the basis of exploration wells using various well grids: a) a grid of wells (25-30 ha/well and more); b), c) with a reduced grid of wells clarifying the surfaces of the roof and soil of the oil reservoir.

4. Discussion

The analytical review presented above focuses on various aspects affecting the efficiency of oil extraction from fields, with an emphasis on the geological and physical properties and conditions of the reservoir. This review identifies key factors such as the folding of the occurrence, the viscosity and permeability of rocks, and the role of fracturing and reservoir waterlogging. The analysis showed that these parameters significantly affect the oil recovery factor, and their consideration is critically important for optimising production parameters. The review examines in detail the influence of various schemes of the location of producing wells and modes of operation of the deposit (water and gas pressure) on the oil recovery factor. For example, depending on the location of the wells in the upper, central or lower part of the fold wing, the oil recovery factor can vary significantly. In water pressure mode, the maximum oil recovery factor is achieved if the wells are positioned in such a way as to minimise oil losses due to its accumulation in the wings of the fold. Similarly, in the gas-pressure mode, the correct location and sequence of wells are also important to avoid operational losses of oil. It is known that combining reservoirs with significantly different physico-chemical properties of oil may be impractical. The different content of paraffin, hydrogen sulphide, and other components requires the use of various oil extraction technologies, which complicates the process of field development. In addition, the phase state of hydrocarbons (for example, the presence of a gas cap) and the formation regime (elastic-water-pressure or water-pressure) play a significant role in choosing the optimal development scheme. The inclusion of more reservoirs in one development facility complicates the technical and technological control over the movement of oil and its displacing agent. This leads to the need to develop more complex well operation schemes and apply technologies that can ensure effective management of the development process. The review shows the importance of using combined methods, such as water and gas pressure modes, to achieve higher values of oil recovery factor.

The main focus of the study by **Kang et al. (2022)** is on innovative EOR methods for low-permeability reservoirs, such as gas and surface-active displacement, nanofluids, and gel systems. **Liu and Wang (2020), and Lu et al. (2021)** argue the need for further development of pore modelling for a deeper understanding of the relationship between the contact angle and oil production at the pore level. Their research summarises the relevant mechanisms for predicting reactions to low-salt water flooding. Since the change in surface moisture is usually considered the most important among the possible mechanisms of low-salt water flooding, two aspects of forecasting reactions to low-salt water flooding are considered: forecasting changes in surface moisture and the effects of changes in surface moisture on oil production. The mechanisms and technical approach to polymer flooding using rocks and fluids from the Dachin, Dagan, and Changchin oil fields are also discussed. By comparing the results of displacement with a conventional polymer, glycerin, a polymer in the "sheet-mesh" structure and a heterogeneous weak gel with the same viscosity and concentration, the relationship between the viscosity of polymer means of displacement and their effectiveness is demonstrated, and a method for improving the effect of polymer flooding is developed. The main mechanism for increasing oil production in polymer flooding is the expansion of flushing volume when water is introduced due to polymer retention in porous media (**Iskandarov et al., 2024; Aliyeva et al., 2024**). The viscosity of polymer agents has no significant correlation with the effectiveness of polymer flooding.

The study conducted above examined in more detail the impact of geological and physical conditions and conventional EOR methods, such as water and gas pressure operating modes. Both approaches are complementary. The study described above emphasises the need to consider geological and physical conditions in the development of deposits and suggests optimal schemes for the location of wells and their operation modes. Other researchers, in turn, provide new technologies that can be implemented for EOR in difficult low-permeability conditions. The study by **Bashir et al. (2022)** noted the importance of combining surfactants with other chemicals to improve oil production results and discussed various combinations such as alkali-surfactant, polymer-surfactant. **Massarweh and Abushaikha (2021)** highlighted the key role of surfactants in increasing oil production and described the problems faced by surfactant flooding methods, such as instability and adsorption, and their impact on the economic efficiency of EOR projects. However, they also emphasised that the right choice of surfactants in accordance with the conditions of the formation and rock can help overcome these problems. **Gong et al. (2021)** presented a new look at surfactant-based EOR mechanisms, offering an alternative mechanism for the solubilisation of oil by micelles and providing additional understanding of the interaction between surfactants and oil. It may have important practical applications in optimising EOR processes and improving oil production efficiency.

All three studies have a common goal – to improve oil production processes, but focus on different aspects and offer different approaches to achieve this goal. The studies by **Bashir et al. (2022), Massarweh and Abushaikha (2021), and Gong et al. (2021)** turn to chemical methods of oil extraction using surfactants and other chemicals, they also consider the problems and potential advantages of these methods. In contrast, the study conducted above focuses on the geological and physical properties of deposits and their impact on oil production processes. Thus, Bashir et al., Massarweh and Abushaikha, and Gong et al. propose chemical methods to optimise the parameters of oil production, while the study on the analysis of low oil recovery focuses on geological and physical aspects and optimisation of technological processes to improve oil recovery factor.

The identified factors influencing low oil recovery highlight several critical implications for future production strategies. Understanding geological complexities, such as fracturing, folding, and waterlogging, is essential for optimising well placement and extraction techniques **(Deryaev, 2023a; 2023b)**. Similarly, addressing high oil viscosity and low permeability requires the development of tailored technologies, including advanced EOR methods. These improvements not only enhance extraction efficiency but also reduce operational losses and improve economic feasibility. The economic impacts are multifaceted: although innovations in production technologies may require significant initial investment, they can lead to increased recovery rates and long-term profitability, particularly in fields with declining production. The results of the study underscore that low oil recovery factors are primarily associated with high oil viscosity, low rock permeability, and challenges such as fracturing and waterlogging. Furthermore, combining formations with varying oil viscosities into a single development facility has proven impractical due to the need for diverse extraction technologies. Secondary and tertiary recovery methods – such as the injection of water, gas, or chemicals – offer considerable potential to improve oil recovery factors. However, their effectiveness is constrained by factors including the phase state of hydrocarbons and the conditions governing field development. Therefore, it is essential to account for the complex interplay of geological and physico-chemical properties when designing strategies to enhance oil recovery.

Wei et al. (2021) evaluated five reservoir EOR methods: water flooding, modified water flooding, CO_2 flooding, alternating CO_2 flooding with water, and alternating CO_2 flooding with surfactant. The main results showed that the surfactant flooding showed the best results, effectively increasing the oil recovery coefficient to 50% and reducing waterlogging. The gas phase in the surfactant flooding method helped to extract more oil from small pores by reducing the interfacial tension, and surfactants reduced the oil-water interfacial tension and created foam, which significantly increased the efficiency of oil displacement in large pores. The study on the causes of low oil recovery focuses on a comprehensive analysis of the factors influencing low oil recovery factor, including mining and geological conditions and physico-chemical properties of oil reservoirs. While the study by Wei et al. evaluates specific EOR methods and their effectiveness using experimental data and nuclear magnetic resonance to analyse microscopic mechanisms of oil displacement. The study conducted above highlights the importance of an integrated approach and consideration of many factors such as oil viscosity, rock permeability, fracturing and waterlogging of formations. The study by J. Wei et al. identified a surfactant-based flooding method that has shown the best effectiveness among the five evaluated methods, suggesting specific EOR mechanisms. Both studies made a significant contribution to understanding and solving the problem of low oil recovery factor by offering different approaches and methods.

Shakeel et al. (2024) investigated innovative chemical EOR techniques to enhance oil recovery in water-flooded sandstone reservoirs. Their study evaluated the effectiveness of surfactant-polymer (SP) and alkali-surfactant-polymer (ASP) flooding methods, demonstrating significant improvements in residual oil mobilization. The SP method was particularly effective, achieving high recovery rates by reducing interfacial tension and improving fluid mobility. Meanwhile, ASP flooding provided additional benefits by reducing chemical adsorption and enhancing the displacement efficiency, though its complexity posed challenges for large-scale application. The findings emphasized the need for tailored chemical formulations that account for reservoir-specific properties such as mineralization and temperature. This aligns with broader research into improving recovery factors through chemical EOR methods, complementing analyses that focus on geological and physico-chemical conditions. By addressing key challenges such as high viscosity and reservoir heterogeneity, Shakeel et al.'s work highlights practical solutions for optimizing oil recovery in complex reservoirs.

Shao and Chen (2024) explored the application of molecular deposition film (MDF) technology to enhance oil recovery in low-pressure, tight oil reservoirs. Their experimental study demonstrated that MDF technology effectively alters the wettability of reservoir rocks, reducing oil adhesion and improving fluid mobility. The technique involves the deposition of a thin molecular layer that reduces interfacial tension and facilitates the displacement of oil in tight pore spaces, leading to a significant increase in the recovery factor. The authors highlighted that the method is particularly advantageous in reservoirs with low permeability, where conventional methods often face limitations. By addressing key challenges such as poor fluid flow and high capillary pressure, MDF technology shows potential as an innovative approach for improving oil recovery in tight formations. This study underscores the importance of advanced physicochemical technologies in enhancing extraction efficiency in challenging reservoir conditions.

The study by **Sun et al. (2020)** and **Aljuboori et al. (2020)** focused on a specific chemical EOR method using surfactants and analysed its effectiveness and economic feasibility based on field trials. Despite the theoretical advantages of flooding using surfactants and polymers, in practice this method faces serious technical and economic problems, such as high adsorption of surfactants and high cost. The study by Sun et al. and Aljuboori et al., similar to the above study, were aimed at improving EOR methods, but focused on different aspects of the problem. The study that was conducted above provides a comprehensive analysis of the factors influencing low oil recovery factor, and offers recommendations for optimising methods of secondary and tertiary exposure. This study highlights the importance of considering the geological, physical, and chemical properties of oil reservoirs to select optimal EOR methods.

5. Conclusions

During the review, the reasons for low oil recovery from reservoirs were analysed, and almost all the studies considered in this review were aimed at establishing the relationship between the physico-chemical and geological-physical properties of rocks and oil recovery factor. However, the main emphasis is placed on low permeability and high viscosity of oil.

And as a result, the use of secondary and tertiary methods of exposure, such as injection of water, gas, and chemicals, has shown that these technologies contribute to an increase in the oil recovery coefficient, but their effectiveness is not sufficient to increase the oil recovery factor multiple times. It is also shown that increasing the degree of reservoir coverage by optimising the well grid and preventing the formation of low-pressure zones can reduce oil losses in the subsurface, but there is no significant increase in oil recovery factor.

Based on the results of a review of previously performed studies, it is possible to identify the main factors, using which will increase the oil recovery factor very significantly – this is the viscosity and adhesion of oil to the reservoir, the location of the well relative to the fold wing, permeability and resistance to extraction by gravity. In this regard, the creation of new mining technologies to increase the oil recovery factor can go in the following areas. Thus, the viscosity, adhesion of oil to the reservoir and the forces of gravity are directed against the forces of oil extraction through producing wells. Then production wells can be passed from the mine workings previously carried out below the oil accumulation. In this case, the forces of gravity contribute to the advancement of oil into the mine workings, and the extraction of oil from the mine workings exclude its adhesion to the collector.

Blasting operations can be carried out on mothballed fields, the shock wave and seismic waves of which can create new and increase existing cracks, thereby increasing permeability, and the expansion of explosive gases will increase the pressure to displace oil into producing wells. The improvement of conventional production technologies that increase oil recovery factor is possible by changing the distances between wells, taking into account folding.

Thus, an increase in oil recovery factor is primarily possible due to the rational location of production wells in the field and the maximum use of gravity forces and new methods of increasing pressure on oil.

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SAŽETAK

Analiza uzroka maloga iscrpka nafte

Cilj je ovoga analitičkog pregleda identificirati i analizirati niz čimbenika koji utječu na nizak faktor iscrpka nafte. Ovo istraživanje obuhvaća širok raspon parametara od rudarsko-geoloških uvjeta ležišta do fizičkih i mehaničkih svojstava stijena i ugljikovodika. Pažnja je također posvećena važnim aspektima kao što su geološke značajke, uključujući frakturiranje stijena, zasićenje ležišta vodom i nabiranje slojeva ležišta, što sve proizvodnju nafte može učiniti još složenijom. Prikupljeni su i analizirani statistički podatci o trenutačnim postotcima iscrpka nafte iz različitih regija i zemalja, što je pomoglo u identificiranju najčešćih problema i tipičnih postotaka iscrpka nafte. Ovaj pregled naglašava da, uz dobro poznate čimbenike, kao što su visoka viskoznost nafte i niska propusnost stijena, na faktor iscrpka nafte znatno utječu i otpor ekstrakciji uzrokovan gravitacijom i složeni tektonski uvjeti kao što su stvaranje bora i prisutnost rasjeda. Osim toga, razmatrani su i problemi vezani uz modeliranje i prikaz naftnoga ležišta, koji mogu dovesti do pogrešaka u procjeni rezervi nafte i posljedično do krive procjene faktora iscrpka nafte. U zaključku ovoga pregleda predložena su moguća područja razvoja tehnologija proizvodnje nafte koja mogu pomoći u prevladavanju identificiranih problema. Daju se prijedlozi za poboljšanje metoda povećanja iscrpka nafte, kao što su uvođenje novih tehnologija, unaprjeđenje postojećih metoda i provođenje preciznijih geoloških istraživanja.

Ključne riječi:
geološke, fizičke i fizičko-kemijske karakteristike nafte, tehnologija rada bušotine, frakturiranje, zavodnjavanje, stijene

Author’s contribution

Nikolai Buktukov (DSc) conducted the geological and reservoir condition analysis and contributed to the interpretation of the factors affecting oil recovery efficiency. **Rustem Igizbaev** (Senior Lecturer) analysed the physical and mechanical properties of rocks and hydrocarbons, focusing on their impact on oil recovery rates. **Gulnaz Moldabayeva** (DSc) investigated the geological features of the deposits, including rock fracturing, waterlogging, and structural folding. **Evgenii Gumennikov** (Senior Lecturer) gathered and analysed statistical data on current oil recovery rates, identifying key patterns and contributing to the regional comparative analysis of recovery rates. **Elmira Yesbergenova** (MSc) reviewed issues related to reservoir modelling and contributed to the discussion on methods to improve the accuracy of oil reserve estimates.
All authors have read and agreed to the published version of the manuscript.