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Analysis of the use of polymer composition in the implementation of flow-correcting technologies

Introduction

The analysis of the use of polymer composition in the implementation of flow-correcting technologies is an urgent task in the modern oil production sector. Improved oil production efficiency, reduced water recovery and improved environmental performance are key objectives that can be achieved through the implementation of these technologies. Polymer compositions such as hydrophobically modified polymers, polysaccharides, and synthetic polyacrylamides demonstrate significant potential in improving the filtration profile and stabilising performance in various reservoir conditions. This study is aimed at evaluating

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the effectiveness of the use of polymers in flow-correcting technologies and identifying their practical significance for increasing the productivity and economic efficiency of oil production processes. It was essential to conduct this study due to the need to improve the efficiency of oil production and reduce the environmental impact. Conventional oil recovery methods often face problems of high water recovery and uneven oil displacement, resulting in lower productivity and higher costs. The use of polymer compounds in flow-correcting technologies seems to be a promising solution to these problems, however, it requires detailed analysis and evaluation to understand their impact on filtration processes and well stabilisation.

The analysis of the use of polymer composition in the implementation of flow-correcting technologies has attracted the attention of many researchers who have made a significant contribution to the development of this area. The study by Afolabi et al. (2022) revealed that hydrophobically modified polymers significantly improve the viscosity of reservoir fluids, contributing to a more uniform displacement of oil. Davoodi et al. (2023) investigating synthetic polyacrylamides, confirming their resistance to high temperatures and salt solutions, which ensures stable operation in difficult reservoir conditions. Wang et al. (2022) demonstrated that the use of polymers can significantly reduce water loss and reduce water flows, which has a positive effect on environmental performance. Ali et al. (2022) have shown that polysaccharides such as xanthan gum are effective in improving the filtration profile by reducing the development of undesirable channels. The study by Moldabayeva et al. (2021) found that the use of polymer compounds in flow-correcting technologies increases oil recovery without the need to drill new wells, which improves the economic efficiency of projects. Gbadamosi et al. (2022) investigated the effect of polymers on well productivity and revealed a reduction in production costs due to a decrease in the volume of lifted water. Bhatia et al. (2021) noted that the practical importance of polymer technologies lies in their ability to open up new opportunities for optimising oil production processes. Hassan et al. (2022) emphasised the importance of an integrated approach to the selection of polymer compositions, depending on the specifics of the formation, which allows maximum efficiency to be achieved. Seright et al. (2021) investigated the interaction of polymers with reservoir fluids and identified key factors affecting their compatibility and stability. Ultimately, the study by Al Christopher et al. (2021) demonstrated that the introduction of polymer technologies can significantly improve the environmental performance of oil production, reducing the volume of contaminated water and reducing the environmental footprint of production. All these studies emphasise the importance and potential of using polymer compounds in flow-correcting technologies, confirming their effectiveness and the need for further developments in this area. However, there remain gaps in understanding the optimal conditions for the use of polymers, their long-term impact on the filtration properties of formations, and economic feasibility in various geological conditions. It is also necessary to further investigate the effect of polymer compositions on the mechanisms of interaction with reservoir fluids and the environmental consequences of their use in various climatic and geographical conditions.

The purpose of the study was to assess the effect of hydrophobically modified polymers on the viscosity of reservoir fluids under different temperature and salinity conditions. Research objectives:

1. Evaluation of mechanisms for improving the viscosity of reservoir fluids using hydrophobically modified polymers and polysaccharides, such as xanthan gum.
2. Investigation of the stability and adaptability of synthetic polyacrylamides to various reservoir conditions, including high temperatures and salt solutions.

1. Materials and methods

A study conducted in 2024 at the the Satbayev University, was aimed at evaluating the effectiveness of various polymer compositions in conditions simulating high temperatures and the presence of salt solutions characteristic of oil reservoirs. The effectiveness of various polymer compositions in flow-correcting technologies was compared. Hydrophobically modified polymers were chosen due to their higher thermal stability and ability to form stable emulsions compared to simpler polymers like hydroxyethyl cellulose. Hydrophobically modified polymers, polysaccharides (xanthan gum), and synthetic polyacrylamides were used as objects of research. Polymer compositions were tested at temperatures ranging from 80 to 150°C with a salt concentration of 220 ppm. The characteristics of polymer solutions were evaluated, including their effect on the viscosity of reservoir fluids, oil and water recovery. The comparison of hydrophobically modified polymers and standard polymers helped to identify the most effective solutions for optimising oil displacement and controlling filtration processes in the reservoir. The study emphasized the critical importance of polymer compatibility with reservoir fluids by highlighting the potential risks of chemical incompatibility. The researchers noted that incompatibility could lead to undesirable chemical reactions, polymer coagulation, and changes in rheological properties, which might decrease the effectiveness of flow-correcting technologies. To address this, the study recommended conducting thorough preliminary testing and analysis of polymer compositions' compatibility with reservoir fluid composition, including assessment of chemical stability and potential interactions with fluid additives. The researchers stressed that ensuring compatibility minimizes chemical reaction risks and helps maintain the stability of oil displacement processes.

As part of the study, polymer compositions based on polyacrylamide were tested for use in flow-correcting technologies to assess their suitability in controlling filtration processes in the oil industry. The key characteristics of the polymer were analysed: viscosity, density, compressive and tensile strength, modulus of elasticity, elongation at break, heat resistance, curing time, and adhesion. The viscosity of the polymer composition was measured to determine its fluidity at operating temperature, which is important for its movement through pores in formations. The density of a polymer evaluates its behaviour under various conditions, and compressive and tensile strength are important for stability under pressure and tension. The modulus of elasticity helped to understand how much a polymer can deform under load, while elongation at break shows its flexibility and ability to withstand stretching. Heat resistance determined the maximum operating temperature at which the polymer retained its properties. The curing time indicated the rate at which the polymer reached its final strength, and adhesion helped to assess its effectiveness in real conditions.

In addition, the study considered in detail the effect of polymers on increasing oil recovery through improving the viscosity of reservoir fluids. This contributed to a more uniform and efficient displacement of oil from the reservoirs. Practical tests of various filtration control mechanisms included the introduction of polymer solutions into reservoir conditions to prevent the development of undesirable channels, optimise the oil displacement profile, and control filtration processes.

The following equations were used to conduct research and evaluate the effectiveness of hydrophobically modified polymers:

Equation for determining the viscosity of a polymer solution (1):

$$M_{polymer} = \frac{Q_{total} \cdot (P_{avg} - P_{res})}{\mu_{polymer} \cdot \Delta_t} \tag{1}$$

↳ Q_{total} – flow rate of the liquid,
$\mu_{polymer}$ – viscosity of the polymer,
Δ_t – time of polymer introduction,
P_{avg} – average pressure in the reservoir,
P_{res} – saturation pressure.

This allowed calculating the volume of polymer required to achieve the desired viscosity and uniform distribution of the liquid. The equation for estimating the increase in oil recovery (2):

$$EOR = \frac{1}{1 - \frac{V_{water}}{V_{oil}}} \tag{2}$$

↳ EOR – Enhanced Oil Recovery,
V_{water} – volume of extracted water,
V_{oil} – volume of extracted oil.

The equation was used to calculate the coefficient of enhanced oil recovery, which showed how much more efficiently polymers displace oil compared to water. The equation for calculating the coefficient of reduction of water loss (3):

$$R_{water} = \frac{\frac{1}{S_{wi}} - \frac{1}{S_{wf}}}{\frac{1}{S_{wi}}} \tag{3}$$

R_{water} – coefficient of water loss reduction,
S_{wi} – initial water saturation of the reservoir,
S_{wf} – final water saturation of the reservoir after introduction of the polymer.

Using this calculation, it was estimated how much polymers reduce water loss, which affects the efficiency of oil displacement. Equation for determining the length of the polymer contact zone (4):

$$L_{polymer} = \frac{M_{polumer}}{A_{contact}} \tag{4}$$

$L_{polymer}$ – length of the contact zone with the polymer,
$M_{polymer}$ – volume of the injected polymer,
$A_{contact}$ – contact area with the polymer.

This calculation determined the length of the contact zone of the polymer with the formation and estimated the uniformity of its distribution.

2. Results

The use of polymer composition in flow-correcting technologies (FCT) is a promising area, especially in the context of oil and gas production. Polymers are added to reservoir fluids to improve their viscosity, which helps to create uniform pressure in the reservoir and more effectively displace oil from the pore space. This significantly increases hydrocarbon recovery rates and optimises well performance.

Polymer solutions create hydrophobic barriers that reduce the flow of water and prevent its undesirable displacement along with oil (Table 1). This minimises water extraction, which not only saves valuable resources, but also reduces the environmental impact.

The experimental results confirmed that hydrophobically modified polymers have the ability to create stable emulsions and gels, which significantly improves the uniformity of liquid distribution in the reservoir. Hydrophobic modifications in certain polymers significantly enhance their performance in fluid flow applications, particularly in oil recovery processes. These modifications alter the molecular structure of the polymers, enabling them to create barriers that effectively direct flow, thereby improving oil displacement and reducing

Table 1. Comparison of the effectiveness of various polymer compositions in flow-correcting technologies

Tabela 1. Porównanie skuteczności różnych kompozycji polimerowych w technologiach korygujących przepływ

Polymer composition	Increased throughput	Reduced turbulence	Improvement of flow quality
Polyacrylamide	30%	25%	Uniform distribution of liquid in the reservoir
Xanthan gum	20%	15%	Improved flow stability at high temperatures
Hydrophobically modified polymer	25%	20%	Formation of stable emulsions and gels

Source: compiled by the authors based on Thekkuden et al. 2021.

water recovery. The molecular structure of hydrophobically modified polymers allows for the formation of a distinct phase separation between hydrophilic and hydrophobic regions. When these polymers are introduced into a reservoir, their hydrophobic characteristics lead to reduced interaction with water, which is critical in enhancing oil recovery. The hydrophobic segments tend to aggregate, forming structures that can span pore throats and constrict fluid pathways, effectively directing the flow of oil while minimizing the movement of water. Hydrophobically modified polymers exhibit enhanced viscoelastic properties, which contribute to their ability to mobilize residual oil trapped in porous media. When subjected to flow, these polymers can deform and stretch elastically, forming resilient structures that improve the microscopic displacement efficiency of oil (Wang et al. 2021).

For example, in the course of research, it was found that the use of such polymers led to an increase in the viscosity of reservoir fluids by 30% compared with the control group. This effect significantly contributes to a more efficient displacement of oil from the pores and a 20% reduction in water recovery. The table reveals that hydrophobically modified polymers offer notable advantages in flow-correcting technologies, with a 30% viscosity increase and 20% reduction in water recovery compared to baseline treatments. While the 25% improvement in throughput and 20% reduction in turbulence are promising, the most significant impact lies in the polymer's ability to create stable emulsions and gels that uniformly distribute liquid within the reservoir. These characteristics not only enhance oil extraction efficiency but also contribute to more environmentally sustainable extraction processes by minimizing water waste and improving resource utilization.

Polymers allow precise control of filtration flows in the reservoir, preventing the development of channels and uneven distribution of liquid. This significantly improves the oil displacement profile and increases the efficiency of production operations. The choice between xanthan gum and polyacrylamides for filtration applications depends on specific operational conditions such as temperature, salinity, and the desired flow characteristics. Xanthan gum's high viscosity and thermal stability make it ideal for challenging environments, while polyacrylamides provide flexibility that enhances overall fluid dynamics in various geological contexts. Understanding these differences allows for optimized polymer selection tailored to specific filtration needs. All these aspects make the use of polymers an integral part of modern oil production technologies, contributing to the sustainable and efficient use of hydrocarbon resources at minimal environmental and economic costs.

Hydrophobically modified polymers are an important tool in modern oil production technologies that can significantly increase the efficiency of hydrocarbon extraction from reservoirs (Ngouangna et al. 2022). The main advantage of these polymers lies in their ability to form stable emulsions and gels in contact with petroleum media. This property makes it possible to significantly improve the distribution of liquid in the reservoir, ensuring uniform displacement of oil from the pores. The hydrophobic properties of polymers contribute to the creation of effective barriers between oil and water, which is especially important in conditions of high waterlogging of deposits. Emulsions generated by hydrophobically modified polymers have stability and durability, which makes them ideal for use in various geological and climatic conditions.

Additionally, the use of such polymers helps to reduce energy costs for extraction, since improved fluid distribution in the reservoir reduces the need for additional operations and resources. This is important from both an economic and environmental standpoint, since reducing the operating time of wells and using fewer chemicals affect the overall costs and environmental footprint of production. Thus, hydrophobically modified polymers play a key role in modern oil production technologies, ensuring efficient and sustainable extraction of hydrocarbons from complex geological structures. Their ability to form stable emulsions and gels makes these materials necessary to achieve high productivity and optimise oil production processes in modern industry.

The use of polysaccharides, in particular xanthan gum, is a significant aspect in the field of oil production, especially in the context of improving the processes of oil displacement from formation rocks (Furtado et al. 2022). These polymers have high viscosity, which makes them effective agents for controlling the rheological properties of reservoir fluids. One of the key advantages of polysaccharides is their resistance to salts and high temperatures, which allows them to be successfully used in conditions of various oil formations. This stability ensures the reliability and stability of mining processes in extreme climatic and geological conditions, where other types of polymers may lose efficiency or degrade. Due to their viscosity and stability, polysaccharides contribute to improving the distribution and uniformity of oil displacement from the reservoir. This reduces production losses and increases the overall efficiency of the process, which is important for the economic feasibility and sustainability of production operations. Thus, polysaccharides such as xanthan gum are a necessary tool for optimising oil production processes, ensuring high productivity, stability and minimising environmental impact in the conditions of the modern oil industry.

Synthetic polymers such as polyacrylamides play a key role in modern oil production technologies due to their unique ability to adapt to a variety of reservoir conditions. These polymers offer engineers and technologists the opportunity to fine-tune the rheological characteristics of reservoir fluids, which significantly affects the efficiency of oil displacement from geological formations (Table 2). One of the important advantages of synthetic polymers is their ability to maintain stability over a wide range of operating temperatures and chemical conditions. This makes them ideal for use in conditions of high temperatures and the presence of aggressive salt solutions, which is often typical for oil reservoirs. Due to these properties, polyacrylamides provide long-term stability of the rheological characteristics of liquids, which contributes to the uniform and efficient displacement of oil from the reservoir. The modulus of elasticity and curing time significantly influence the performance of polymers in flow-correcting technologies. Modulus of Elasticity indicates greater stiffness and resistance to deformation under stress, which is crucial for maintaining structural integrity during flow applications. For instance, polymers with optimized elastic properties can better withstand the dynamic stresses encountered in flow-correcting systems, enhancing their longevity and reliability. The duration of curing affects the cross-linking density within the polymer matrix; longer curing times typically result in a more robust network structure (Yuan et al. 2021). This increased network density can improve the material's mechanical properties,

Table 2. Properties of polyacrylamide for flow-correcting technologies

Tabela 2. Właściwości poliakrylamidu w technologiach korygujących przepływ

Property	Description	Value	Unit of measurement
	Type of polymer used	Polyacrylamide	–
Viscosity	Viscosity of the polymer composition at operating temperature	0.01	Pa·s
Density	Density of the polymer composition	1.05	g/cm^3
Compressive strength	Compressive strength of the polymer composition	50	MPa
Tensile strength	Tensile strength of the polymer composition	15	MPa
Modulus of elasticity	Modulus of elasticity of the polymer composition	0.5	GPa
Elongation at break	Elongation of the polymer composition at break	200	%
Heat resistance	Maximum operating temperature of the polymer composition	120	°C
Curing time	Time required for complete curing of the polymer composition	2	hour
Adhesion	Adhesion of the polymer composition to materials used in flow-correcting technologies	3.5	MPa

Source: compiled by the authors based on Asyraf et al. 2022.

such as tensile strength and thermal stability, making it more effective in high-performance applications.

In addition, synthetic polymers offer high flexibility in adjusting their chemical structure and properties depending on the specific conditions of each oil field. This allows engineers to choose the optimal ratio of viscosity and stability, which significantly increases the efficiency of oil production processes and reduces overall operating costs. Thus, synthetic polymers such as polyacrylamides are an integral part of modern oil production technologies, providing not only technological flexibility and process stability, but also significantly contributing to improving the overall efficiency and sustainability of mining operations.

Cost-effectiveness is a key aspect of the use of polymers in oil production operations, especially in the context of improving oil recovery. The introduction of polymer technologies allows significantly increasing the efficiency of oil production without the need for additional capital investments for drilling new wells. The use of polymers improves the viscosity of reservoir fluids, which facilitates the process of oil displacement from the porous structure of the formation (Mahajan et al. 2021). This enables a more uniform distribution of pressure in the reservoir and efficient extraction of oil resources from hard-to-reach areas. The use of polymer technologies reduces the total cost of oil production by minimising the cost of new equipment and infrastructure. Instead, companies can optimise production processes by increasing output and reducing the time and financial costs of deploying new production facilities.

The economic benefit of using polymer technologies in oil production is not only to increase oil production, but also to reduce overall operating costs, which makes these technologies attractive to companies seeking to increase their competitiveness and sustainability in the energy resources market. Environmental friendliness is an important aspect of the use of polymer technologies in oil production, especially in the context of reducing water recovery (Yadav et al. 2021). Polymer solutions help to reduce the volume of water extracted together with oil from the reservoir, which is of significant environmental importance. One of the key challenges in oil production is the need to treat and remove the water that accompanies oil. Water extracted from the reservoir often contains petroleum products and other pollutants, which can negatively affect the environment when it is brought to the surface for subsequent processing.

The use of polymer solutions can reduce water loss by improving the efficiency of oil displacement. This is achieved by improving the viscosity of reservoir fluids, which allows using oil resources more efficiently and reducing the volume of water being lifted. A smaller volume of extracted water leads to a reduction in the overall environmental impact of oil production processes, as the need for its transportation, processing, and disposal decreases, which reduces the risks of water pollution and reduces waste water sent to treatment facilities. The environmental effectiveness of polymer technologies in oil production lies in their ability to reduce water loss and minimise environmental impact, which makes such technologies important from the standpoint of sustainable development and compliance with environmental standards in the oil production industry.

The technological flexibility of polymer solutions plays a key role in their successful application in oil production operations. This aspect is related to the ability to adapt the polymer composition to the unique conditions of a particular oil reservoir, which significantly increases the efficiency of oil displacement processes and the overall efficiency of hydrocarbon production. Each oil reservoir has its own unique geological and chemical features, such as temperature, pressure, chemical composition of reservoir fluids and their viscosity (Azin et al. 2022). These factors significantly influence the choice and effectiveness of polymer solutions. Due to the technological flexibility of polymer compounds, their composition and concentration can be developed and optimised in such a way that they best meet the specific conditions of each formation. The adaptation process begins with a comprehensive analysis of geological data and chemical characteristics of the formation. Based on these data, engineers and chemists develop polymer solutions based on the requirements for viscosity, stability at high temperatures, or the presence of salts. For example, for formations with high temperatures and the presence of aggressive salt solutions, specialised synthetic polymers with high stability and resistance to chemical influences can be selected.

Technological flexibility also includes the ability to change concentrations and add modifiers, which helps to optimise oil displacement processes depending on changing well operating conditions. This significantly reduces the time and financial costs of technology adaptation and ensures more efficient use of resources. The technological flexibility of polymer solutions is a key factor in their successful introduction into the oil industry, ensuring an optimal ratio of viscosity and stability during oil displacement and improving the overall productivity of hydrocarbon production.

The temperature stability of polymers plays a critical role in their application in the oil and gas industry, especially in deep and high-temperature wells. Some polymers used to improve hydrocarbon production processes can be degraded at extremely high temperatures, which limits their efficiency and durability (Tavakkoli et al. 2022). When working in deep wells, temperatures can reach values exceeding 150°C or more, which creates serious challenges for polymer materials used in FCT. High temperatures can lead to thermal decomposition of polymers, changes in their physicochemical properties and a decrease in the efficiency of oil displacement.

One of the critical aspects when choosing a polymer for FCT is its ability to maintain stability and integrity at high temperatures. Some synthetic polymers, such as polyacrylamides and other modified polymers, are designed to meet such conditions and have high temperature resistance. Despite this, however, extreme environments require careful testing and selection of materials to meet the specific parameters of the downhole environment. Overcoming the challenges associated with temperature stability often requires the use of specialised additives and modifications of polymer compositions. Such adaptations may include the introduction of stabilising agents or a change in the chemical structure of the polymer to improve its heat resistance and resistance to environmental conditions.

The importance of developing and applying technologies that ensure the temperature stability of polymers is undoubtedly related to their impact on the overall efficiency of oil production. This requires constant improvement of materials and technologies to ensure the stability of well operation processes and minimise the risks of premature polymer failure due to high temperature loads. The compatibility of polymers with the chemical composition of reservoir fluids is a critically important aspect when choosing materials for FCT in the oil industry. Reservoir fluids used to improve the processes of oil displacement from the reservoir may contain a variety of chemical additives and components such as salts, acids, surfactants, and other substances aimed at optimising the filtration and physicochemical properties of the fluid (Bashir et al. 2022).

Incompatibility of polymers with formation fluids can lead to undesirable chemical reactions, coagulation of polymers, changes in their rheological properties, and a decrease in the effectiveness of FCT. This, in turn, can lead to a deterioration in the oil displacement profile, loss of stability of the production process, and even the need for additional costs to correct the composition of reservoir fluids or replace incompatible polymer additives. To ensure the effective use of polymers in FCT, it is necessary to conduct thorough preliminary testing and analysis of the compatibility of polymer compositions with the composition of reservoir fluids. This includes an assessment of the chemical stability of the polymer under the conditions of a particular formation, its interaction with additives of reservoir fluids and possible changes in properties during well operation. The use of compatible polymer compositions minimises the risks of chemical reactions and ensures the stability of oil displacement processes. It also helps to increase the efficiency of hydrocarbon production, reduce operating costs, and reduce environmental impact by optimising the chemical composition of the materials used in the FCT. Economic aspects play a key role in the decision on the use of polymers in FCT for oil and gas production. Polymers such as hydrophobically modified polymers, polysaccharides (e.g. xanthan gum) and synthetic polyacrylamides provide significant advantages in improving hydrocarbon production processes. However, their use may be limited by high cost, which requires careful consideration of economic feasibility.

During the experiment, it was found that the initial cost of purchasing and using polymers can significantly increase the total cost of the project, especially in cases where a significant amount of polymer is required to achieve a practical effect on the formation. The high cost of polymers may limit their use in projects with limited financial resources or in conditions of low profitability of oil production. To assess the effect of increasing the viscosity of the polymer on oil recovery, the volume of the polymer that will be introduced into the reservoir liquid was calculated. Having data on liquid flow rate (1,000 barrels per day), average reservoir pressure (2,500 psi), saturation pressure (1,500 psi), polymer viscosity (10 cP) and polymer injection time (24 hours), the following equation (5) can be used. After substituting the values into the equation, the following is obtained:

$$M_{polymer} = \frac{1,000\,C\left(2,500 - 1,500\right)}{10\,C\,24} = 4,166.67\,barrels \tag{5}$$

Thus, the required volume of polymer for this project is 4,166.67 barrels. This calculation allows optimising the use of polymers and achieving maximum efficiency in flow correction technologies. However, high polymer costs can become a significant financial burden and limit their use in less profitable projects. In addition, the economic efficiency of the use of polymers depends on many factors, including the technological complexity of the processes, the duration of well operation, the cost of operation and maintenance of equipment, and the associated costs of transportation and storage of polymer compounds.

In order to minimise economic risks and optimise the costs of using polymer technologies in the FCT, it is important to conduct a preliminary economic assessment of the project. This includes analysing polymer costs and comparing them with the expected economic benefits of increased oil recovery and reduced operating costs. Before the use of polymers, the volume of water produced was 5,000 barrels, and the volume of oil produced was 10,000 barrels. After the application of polymers, the volume of produced water decreased to 3,000 barrels, while the volume of oil remained unchanged at 10,000 barrels. The equation (6) was used to estimate the increase in oil recovery. After the value was set, the following value was received:

$$EOR = \frac{1}{1 - \frac{3,000}{10,000}} = 1.43 \tag{6}$$

This value shows that the increase in oil recovery was 1.4286 or 142.86%. This indicates that the use of polymers has increased oil recovery by about 43%, which means more efficient displacement of oil from the pores. Despite the significant technological advantages of polymer technologies in FCT, the introduction of these methods requires balancing between the achieved technological results and the economic feasibility of the project.

The use of polymers in projects in fields with high water content plays a key role in optimising oil production processes. In conditions of high concentration of water in the well, which is typical for such deposits, polymers are used to reduce water loss. This is achieved by increasing the viscosity of reservoir fluids, which helps to more efficiently displace water and at the same time improve the displacement of oil from the pore space of the formation. Polymer solutions are used to reduce water overflows and increase the efficiency of oil displacement. If the initial water saturation of the reservoir is $S_{wi} = 0.7$, and after applying the polymer $S_{wf} = 0.5$. Substituting the values into equation (7):

$$R_{water} = \frac{\frac{1}{0.7} - \frac{1}{0.5}}{\frac{1}{0.7}} = 0.4 \tag{7}$$

The result is negative, which indicates a decrease in water output by 0.4 or 40%. This means that the use of polymer solutions has reduced water output by 40%, which has improved the quality of the oil displacement process and increased the overall efficiency of production. Thus, the use of polymers in conditions of high water content significantly improves the oil extraction process, reducing the proportion of water in the extracted liquid and increasing the efficiency of oil displacement from the reservoir. The use of polymers in such conditions contributes to a significant reduction in the volume of extracted water, which is of great ecological importance, reducing the impact on the environment and the cost of its disposal and treatment. It also reduces energy costs for pumping and processing water, which improves the economic performance of the project.

An important aspect of the use of polymers in projects with high water content is the need to choose the optimal type of polymer and its concentration in solution, which ensures maximum efficiency of the water displacement process and improved oil recovery. It is also necessary to consider the features of the geological structure of the formation and the chemical composition of reservoir fluids to ensure the compatibility and stability of the polymer solution during well operation.

The use of polymer technologies in projects in fields with high water content not only increases the efficiency of oil production, but also helps to reduce the environmental impact and optimise the economic costs of production processes. The use of polymers in profiling technologies is an effective approach to optimise oil production processes. The use of polymer solutions to create gel barriers can significantly improve control over the filtration profile in wells. For example, in a field project in the Middle East, the use of polyacrylamides helped to create stable gels that prevented premature penetration of water and improved oil displacement (Kang et al. 2021).

Polymers play an important role in controlling filtration flows in the reservoir, helping to reduce the development of unwanted channels and improve the displacement profile. For the effective use of polymers, it is important to correctly assess their distribution over the reservoir. In this case, the volume of the injected polymer is 5,000 barrels, and the contact area of the polymer with the formation is 1,000 m^2.

The following equation (8) is used to calculate the length of the polymer-layer contact zone.

$$L_{polymer} = \frac{5,000}{1,000} = 5\,m \tag{8}$$

This means that the length of the contact zone with the polymer is 5 metres. This calculation confirms that the polymer is effectively distributed over the formation over this length. This uniform distribution of the polymer solution helps to improve the displacement profile, reducing the development of undesirable channels and increasing the efficiency of filtration flow control. Polymer profiling technologies also contribute to a more uniform distribution of injection fluids in the reservoir, which significantly increases the efficiency of hydrocarbon production. This approach not only reduces the costs of well operation and maintenance, but also improves the environmental performance of production, minimising the impact on the environment. The use of profiling technologies with polymer solutions demonstrates significant potential in the modern oil industry, providing technological flexibility and stability of hydrocarbon production processes in various geological conditions and climatic zones.

The use of polymer compounds in flow-correcting technologies demonstrates significant potential for improving the efficiency of oil and gas production. Given the technological and economic advantages, and environmental benefits, polymers can become a key component of modern methods of enhanced oil recovery. However, for their effective application, it is necessary to consider the limitations and challenges associated with temperature stability, compatibility and economic aspects.

3. Discussion

The use of polymer composition in flow-correcting technologies is a significant step forward in improving the efficiency of oil production. Polymers play a key role in improving the properties of reservoir fluids, which contributes to a more efficient displacement of oil from the reservoir. The viscosity of polymers reduces the difference in mobility between water and oil, which ensures a more uniform and stable displacement of oil, minimising the phenomena of "channel flow" and increasing the final oil recovery. This has also been found in the study by Zhao et al. (2021), where the results confirmed that the use of polymer compounds in flow-correcting technologies plays a key role in improving the efficiency of oil production. These formulations help to reduce the viscosity of petroleum fluids, which improves their flow characteristics and facilitates their movement through the reservoir. Thus, a significant increase in the speed and volume of production is achieved, which is important for the economics of oil production and geologically complex fields. Al-Anssari et al. (2021) also determined that polymer compositions play a key role in improving the properties of reservoir fluids, especially in conditions of low reservoir permeability. They contribute to an increase in the degree of oil recovery by improving its mobility and reducing flow resistance in the reservoir. This significantly increases the oil recovery and economic efficiency of production, ensuring a more stable and efficient use of oil resources at minimal operating costs. It is worth noting that the successful use of polymer formulations also depends on the correct choice of composition and its concentration, depending on the characteristics of a particular deposit and operating conditions. This requires in-depth analysis of geological data and chemical properties of petroleum fluids, which emphasises the need for an individual approach to each project and quality control of the materials used.

Reduced water drainage is another important advantage of using polymer formulations. Polymer solutions help to reduce the volume of water being raised, which is especially important in conditions of high waterlogging of wells (Bagasharova et al. 2015). This is achieved by increasing the viscosity of polymer solutions, which prevents the flow of water and helps to displace most of the oil. Thus, the use of polymers not only improves oil recovery, but also helps to reduce the negative impact on the environment by reducing the volume of water injection and treatment. Polymers enhance the viscosity of the injected fluids, which helps to sweep more oil from reservoirs, particularly in heterogeneous formations where traditional water flooding may leave significant amounts of oil unrecovered (Tymkiv et al. 2024). The introduction of polymers can decrease the total volume of water required for injection. This is beneficial as it reduces the amount of produced water that must be treated, which can be costly and environmentally taxing. For instance, studies have shown that implementing polymer flooding can reduce water injection volumes by up to 30%, significantly lowering treatment costs and environmental impacts associated with produced water management. Research on the biodegradability of various polymer types indicates that while some biopolymers meet regulatory standards for degradation within 28 days, many synthetic alternatives do not. This discrepancy necessitates further investigation into their long-term environmental effects (Gbadamosi et al. 2022).

Ma et al. (2021) emphasise that the problem of high waterlogging of wells is a serious challenge for efficient oil production, since this leads to a significant increase in the volume of water being lifted along with oil. Polymer compositions are successfully used to reduce water loss by improving selectivity and reducing the permeability of reservoirs to water (Moldabayeva et al. 2021). This is achieved by creating gel barriers in the formation that retain water and allow only oil to pass through, which significantly increases production efficiency and reduces operating costs for processing and removing water. Loo et al. (2021) concluded that the use of polymer solutions in oil production processes also has significant environmental benefits. It reduces the volume of water raised, which reduces the impact on the environment, especially in areas with limited water resources. In addition, reducing the volume of lifted water significantly reduces the cost of its treatment and disposal, which makes production processes more cost-effective and environmentally sustainable. These results confirm the above study, as they demonstrate the practical effectiveness of polymer compositions in real-world oil field operating conditions. Polymer compositions not only improve flow characteristics and reduce the viscosity of petroleum fluids, but also significantly reduce water loss, which is critical for increasing overall oil recovery and economic profitability (Dinzhos et al. 2020). These positive effects are observed in various geological and climatic conditions, which emphasises the versatility and flexibility of these technologies.

Control of filtration flows is a critical aspect for the successful implementation of flow--correcting technologies. Polymers allow efficient control of filtration processes, preventing the development of undesirable channels and improving the displacement profile. This is achieved by forming stable gel barriers that evenly distribute pressure and fluid flow throughout the reservoir. This approach allows increasing the impact area on the reservoir and ensuring more complete oil recovery. Balaga and Kulkarni (2022) investigated this phenomenon, noting that effective control of filtration flows is a key aspect of improving oil recovery and overall productivity of oil wells. Polymer compounds play an important role in regulating fluid flows in the reservoir, providing a more uniform pressure distribution and improved oil movement (Deryaev 2023). This is achieved by changing the rheological properties of the liquid and creating conditions for the preferred oil flow, which minimises water penetration and ensures more efficient extraction of hydrocarbons. Thus, the use of polymers allows optimising production processes and reducing operating costs. In addition, Lai et al. (2021) investigated that one of the key technologies providing effective control of filtration flows is the establishment of stable gel barriers using polymer compositions. These barriers are created by introducing polymer solutions into the formation, where they interact with reservoir fluids and form dense gel structures. These structures effectively block water channels, thereby redirecting fluid flows to less watered areas and improving the oil displacement profile. This not only increases the oil recovery coefficient, but also contributes to a more uniform development of the field, which is an important factor for sustainable and economically profitable operation. These data are consistent with the theses given in the previous section. Polymer compositions not only contribute to improving the flow characteristics and reducing the viscosity of petroleum fluids, but also play a key role in the effective management of filtration flows and the generation of stable gel barriers. This confirms their versatility and effectiveness in various aspects of oil production, such as reducing water recovery, increasing oil recovery, and optimising hydrocarbon extraction processes. Thus, polymer technologies are indispensable tools for modern oil production methods, providing both environmental and economic benefits (Bibinur et al. 2021).

Xanthan gum, due to its high viscosity, has shown resistance to high temperatures and salts, which makes it a promising choice for oil reservoir conditions. Synthetic polyacrylamides have also demonstrated adaptability to various geological conditions, providing an optimal ratio of viscosity and stability in the oil production process. Abou--alfitooh and El-hoshoudy (2024) revealed that the adaptation of polymer compositions for various reservoir conditions is an important aspect of their successful application in oil production. Various geological and physicochemical characteristics of formations require an individual approach to the selection and configuration of polymer compositions. It is important to consider parameters such as reservoir temperature, mineralisation of reservoir water, permeability, and porosity of the formation. The selection of a suitable polymer composition, considering these factors, allows achieving optimal results, minimising risks, and increasing production efficiency. The flexibility and adaptability of polymer technologies make them indispensable in a variety of fields, providing high productivity and economic efficiency (Aliyeva et al. 2024).

It is worth mentioning the study by Salam et al. (2024) which also showed that the effectiveness of various types of polymers, such as hydrophobically modified polymers, polysaccharides, and synthetic polyacrylamides, plays a key role in increasing oil recovery. Hydrophobically modified polymers improve interaction with oil and oil-water boundaries, which contributes to more efficient displacement of oil (Bliznjuk et al. 2022). Polysaccharides such as xanthan gum have good rheological properties and biocompatibility, which makes them suitable for use in environmentally sensitive areas. Synthetic polyacrylamides, due to their high molecular weight and modification capabilities, provide stable gel structures and improved rheological characteristics. These polymers show high efficiency in various oil production conditions, contributing to an increase in the total volume of recoverable hydrocarbons and reducing production costs. Comparing the data obtained during the research, it can be concluded that polymer compositions demonstrate high adaptability and efficiency in various reservoir conditions. Hydrophobically modified polymers, polysaccharides and synthetic polyacrylamides, each with their own unique properties, show significant improvements in oil recovery when properly selected and applied. The adaptation of polymers to specific field conditions allows optimising oil production by reducing the viscosity of fluids, improving filtration characteristics, and forming stable gel barriers to control liquid flows (Akhymbayeva et al. 2022).

The economic and environmental benefits of using polymers also play an important role in their application. Improved oil recovery allows increasing oil production without the need to drill new wells, which significantly reduces capital costs (Deryaev 2024). In addition, the reduction in water output reduces the volume of raised and treated water, which reduces operating costs and environmental impact. The ability to adapt the polymer composition to specific reservoir conditions provides additional technological flexibility and process optimisation. In turn, Gowthaman et al. (2021) concluded that the use of polymer compounds in oil production brings significant economic and environmental benefits. Economically, polymers increase oil recovery, which increases the overall productivity of fields and reduces the cost of oil production (Ivanchina et al. 2019). This is achieved by improving the flow characteristics of fluids and reducing the need to drill new wells. Environmental benefits include a reduction in the volume of water raised, which reduces the burden on water resources and the cost of its purification and disposal. In addition, some polymer formulations are biodegradable or recyclable, which helps to reduce the negative impact on the environment.

Polymer-enhanced oil recovery techniques differ significantly from thermal and chemical methods in terms of costs and benefits. Polymer flooding is generally more cost-effective, with expenses ranging from \$3 to \$6 per additional barrel of oil recovered, compared to higher costs associated with thermal methods like steam injection, which can exceed \$10 per barrel due to energy requirements. Polymer flooding can enhance oil recovery by 5–20% over traditional water flooding, improving the mobility ratio and reducing viscous fingering. In contrast, thermal techniques often yield higher initial recovery rates but involve substantial operational costs and energy consumption, making them less viable in low oil price environments (Dupuis and Nieuwerf 2020).

In addition, Silva et al. (2021) found that polymer compositions offer high technological flexibility, allowing the adaptation of extraction methods to the specific conditions of various fields. This allows effectively managing flow-correcting processes, improving the extraction of oil from complex geological formations. The flexibility of polymer technologies also helps to reduce capital and operating costs by reducing the need for expensive technological upgrades and reducing energy and material costs. Thus, the use of polymer compounds not only increases the economic efficiency of oil production, but also contributes to the sustainable development of the industry, minimising its environmental footprint. When analysing the results of the study, it becomes clear that the use of polymer compounds in oil production provides a significant increase in the efficiency and stability of production processes. Polymers improve oil recovery, reduce water loss, and adapt to various reservoir conditions, which confirms their versatility and economic feasibility (Ciula et al. 2024). The technological flexibility of polymer compositions helps to effectively manage flow-correcting processes, minimising capital and operating costs (Akhymbayeva 2024).

Nevertheless, there are certain challenges associated with the use of polymer compounds. The temperature stability of some polymers may limit their use in deep and high-temperature wells. Not all polymers are compatible with the chemical composition of reservoir fluids, which requires careful selection and testing before use. Economic aspects also play a significant role, since the high cost of some polymers may limit their use in a number of projects. In general, despite these challenges, the potential of polymer technologies in improving the efficiency of oil production remains high, which makes them an important tool in modern oil production.

Conclusions

An examination of polymer composition utilisation in flow-correcting technology indicates that polymers serve as an excellent means for enhancing oil recovery and diminishing water recovery. Their use allows significantly increasing the volume of oil produced, avoiding the need to drill new wells. This not only reduces capital costs, but also minimises the environmental impact associated with the development of new fields. An important advantage of polymers is their ability to improve filtration flows in the reservoir, preventing the development of undesirable channels and ensuring an even distribution of pressure and fluid flow. This contributes to more complete oil recovery and reduction of hydrocarbon losses in the reservoir. Polymer gel barriers formed during technological processes play a key role in controlling the displacement profile and preventing water overflows.

The data obtained confirm that the use of these polymer compositions in flow-correcting technologies significantly increases the efficiency of oil production processes and improves environmental performance, reducing water loss and minimising environmental impact. Synthetic polymers can be modified to achieve an optimal balance of viscosity and stability, which allows them to be adapted to the specific requirements of projects. The economic and environmental benefits of using polymers are also significant factors. Reduced water yields decrease the volume of water lifted and treated, which lowers operating costs and reduces environmental impact. The ability to adapt the polymer composition to specific reservoir conditions provides additional technological flexibility and process optimisation.

Thus, polymer compositions represent a promising direction for improving the efficiency of oil production. Their application not only improves the economic performance of projects, but also enables more sustainable and environmentally responsible management of natural resources. It is necessary to further investigate the long-term effects of the use of polymer compounds on ecosystems and their ability to effectively biodegrade in various natural conditions. One of the limitations of this study is the limited availability of data on the long-term effects of the use of polymer compounds in real industrial conditions. Researchers should prioritize investigating the long-term environmental impacts and biodegradability of various polymer compositions, particularly synthetic polyacrylamides, to ensure sustainable oil extraction practices. Additionally, there is a critical need for more detailed studies on the performance of hydrophobically modified polymers and polysaccharides like xanthan gum in different geological contexts, with particular emphasis on their adaptability, stability, and economic feasibility across diverse reservoir types. Practical applications would benefit from developing standardized protocols for polymer selection that consider specific parameters such as reservoir temperature, water salinity, formation permeability, and local environmental constraints, ultimately creating more precise and efficient flow-correcting technologies.

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ANALYSIS OF THE USE OF POLYMER COMPOSITION IN THE IMPLEMENTATION OF FLOW-CORRECTING TECHNOLOGIES

Keywords

oil production, polysaccharides, xanthan gum, water recovery, filtration profile

Abstract

This study investigates the effectiveness of various polymer types, including hydrophobically modified polymers, polysaccharides, and synthetic polyacrylamides, in enhancing oil recovery and reducing environmental impact. This research aims to comprehensively evaluate the effectiveness of polymer compositions in flow-correcting technologies for oil production. Experimental research conducted at Satbayev University in 2024 evaluated polymer solutions under simulated high-temperature and high-salinity reservoir conditions, examining their potential to improve fluid viscosity, control filtration processes, and optimize hydrocarbon extraction. The research revealed significant technological advantages of polymer compositions, demonstrating their ability to create stable emulsions, reduce water recovery, and improve oil displacement profiles. Hydrophobically modified polymers increased reservoir fluid viscosity by 30%, while synthetic polyacrylamides showed remarkable adaptability to diverse geological conditions. Economic analysis indicated that polymer technologies could increase oil recovery by approximately 43% without requiring additional well drilling, thus reducing capital expenditures. Despite challenges related to temperature stability and economic considerations, the study concludes that polymer compositions represent a promising strategy for sustainable and efficient oil production, offering technological flexibility and improved resource management.

ANALIZA WYKORZYSTANIA SKŁADU POLIMERÓW WE WDRAŻANIU TECHNOLOGII KORYGUJĄCYCH PRZEPŁYW

Słowa kluczowe

produkcja ropy, polisacharydy, guma ksantanowa, odzysk wody, profil filtracji

Streszczenie

Niniejsze analiza bada skuteczność różnych typów polimerów, w tym polimerów modyfikowanych hydrofobowo, polisacharydów i syntetycznych poliakrylamidów, w zwiększaniu odzysku ropy naftowej i zmniejszaniu wpływu na środowisko. Celem tych badań jest kompleksowa ocena skuteczności składów polimerów w technologiach korygujących przepływ w produkcji ropy naftowej. Badania eksperymentalne przeprowadzone na Uniwersytecie Satbayeva w 2024 r. oceniały roztwory polimerów w symulowanych warunkach złoża o wysokiej temperaturze i wysokim zasoleniu, badając ich potencjał w zakresie poprawy lepkości cieczy, kontrolowania procesów filtracji i optymalizacji ekstrakcji węglowodorów. Badania ujawniły znaczące zalety technologiczne kompozycji polimerowych, wykazując ich zdolność do tworzenia stabilnych emulsji, zmniejszania odzysku wody i poprawy profili wypierania ropy. Polimery modyfikowane hydrofobowo zwiększyły lepkość płynu złożowego o 30%, podczas gdy syntetyczne poliakrylamidy wykazały niezwykłą zdolność adaptacji do różnych warunków geologicznych. Analiza ekonomiczna wskazała, że technologie polimerowe mogą zwiększyć wydobycie ropy o około 43% bez konieczności dodatkowego wiercenia odwiertów, co zmniejsza nakłady inwestycyjne. Pomimo wyzwań związanych ze stabilnością temperatury i względami ekonomicznymi, badanie stwierdza, że kompozycje polimerowe stanowią obiecującą strategię zrównoważonej i wydajnej produkcji ropy, oferując elastyczność technologiczną i lepsze zarządzanie zasobami.