

# Application of flow-diversion technologies to increase oil recovery at the Uzen field

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**Abstract.** Polymer flooding is a highly effective method of physical and chemical intervention in productive reservoirs. The primary characteristic of polymers is their ability to thicken water, which reduces the viscosity ratio between oil and water in the formation and diminishes water breakthrough conditions caused by viscosity differences or reservoir heterogeneity. Additionally, due to their increased viscosity, polymer solutions can more effectively displace both oil and bound reservoir water from the porous medium. They interact with the porous medium's framework, including the rock and the cementing substance, leading to the adsorption of polymer molecules onto the surface of the porous medium. This adsorption blocks the channels or hinders water filtration within them. The extent of adsorption is significantly influenced by water mineralization and the rock's mineral composition, necessitating the creation of a fringe from fresh water to reduce adsorption. Despite this, the positive aspect of adsorption in water-washed formations is evident, as it decreases permeability and aligns the pickup profile, which is particularly beneficial for conditions like those in the Uzen deposit. The article presents an analysis of the effectiveness of Flooding Displacement Technology (FDT) in this context.

## 1 Introduction

Global energy demand is growing due to the development of industry and everyday life. Currently, fossil fuels, especially oil and gas, play an important role in providing energy compared to other energy sources such as solar energy and wind. This increasing demand for energy is driven by various factors, including population growth, urbanization, and industrial expansion [1]. As economies develop, the need for reliable and accessible energy sources becomes more critical to support infrastructure, transportation, and the production of goods and services.

Fossil fuels have been the backbone of global energy supply for decades due to their high energy density, ease of transportation, and established extraction and distribution infrastructure. Oil and gas are integral to numerous sectors, from powering vehicles and heating homes to serving as feedstock for chemicals and plastics [2]. Despite advancements

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in renewable energy technologies, the transition to a fully sustainable energy system remains a complex and gradual process. This is due to challenges such as the intermittent nature of renewable sources, the current limitations in energy storage solutions, and the need for substantial investments in new infrastructure.

Flow-diversion technologies are advanced methods used in the oil and gas industry to enhance oil recovery from reservoirs. These technologies aim to optimize the extraction process by diverting the flow of injected fluids or gases to improve the displacement of oil. In traditional recovery methods, the injected fluids often take the path of least resistance, bypassing significant portions of the oil-rich zones, resulting in inefficient recovery and leaving substantial amounts of oil unrecovered in the reservoir. Flow-diversion technologies address this challenge by using various mechanisms, such as chemical agents, mechanical devices, or polymer gels, to alter the flow paths within the reservoir and improve the sweep efficiency of the injected fluids.

Despite their potential, the application of flow-diversion technologies faces several challenges and limitations. One major issue is the heterogeneity of the reservoir. Variations in rock properties, permeability, and porosity can significantly impact the effectiveness of flow-diversion techniques. Designing and implementing these technologies requires a detailed understanding of the reservoir's geological characteristics, which can be time-consuming and costly. Additionally, the deployment of flow-diversion agents, such as polymers or gels, may pose environmental and operational risks. These substances need to be carefully managed to prevent damage to the reservoir and ensure they do not adversely affect the surrounding environment [3]. Furthermore, the long-term stability and performance of flow-diversion technologies can be uncertain, requiring continuous monitoring and potential adjustments during the production phase.

The economic feasibility of flow-diversion technologies is another critical factor to consider. While these technologies can significantly increase oil recovery rates, their implementation involves substantial upfront investment and operational costs. The economic viability depends on factors such as oil prices, the size and characteristics of the reservoir, and the expected increase in recovery rates. Technological advancements and innovations in flow-diversion methods are continually being explored to enhance their efficiency and cost-effectiveness [4]. For instance, the development of smart materials and nanotechnology-based agents holds promise for more precise and controllable flow diversion. Despite the challenges, the potential benefits of improved oil recovery and extended reservoir life make flow-diversion technologies a valuable area of research and development in the oil and gas industry [5, 6].

The purpose of polymer injection is to increase the cleaning efficiency by improving the mobility of the injected liquid. By adding polymers, the viscosity of the injected fluid is enhanced, which helps to displace the oil more effectively within the reservoir. This method reduces the fingering effect and ensures a more uniform sweep of the oil-bearing formations, leading to higher overall recovery rates and improved production efficiency. When only water is pumped into a heterogeneous reservoir (in the form of an injected liquid), pumping phenomena occur, and the injected liquid passes through a porous medium much faster than oil, due to layers with high permeability [7, 8]. At the end of this process, a significant portion of the tank's surface is no longer in contact with water. In 1964, Pai and Sandiford discovered that introducing small quantities of a water-soluble polymer could effectively reduce water's mobility. By adding this polymer, the water's movement becomes more restricted than that of the oil. As a result, the water's reduced mobility allows it to push the oil in a piston-like manner. This discovery highlighted an innovative method to enhance the displacement of oil by water [9, 10].

A surfactant or surfactant can reduce the gap between oil and water by spreading along the liquid-liquid interface. When flooding with surfactants, the main goal is to change the

wettability from petroleum to aqueous and reduce SF (surfactants), especially in the carbonate reservoir rock. Wettability has a significant impact on oil and gas production [11, 12]. This is an important aspect of fluid flow in the reservoir rock. When the surfactant is dissolved in water and injected into the reservoir, the interfacial tension (IFT) between water and oil decreases [13, 14]. As the interfacial tension decreases, the number of capillaries increases. The residual oil saturation strongly depends on the number of capillaries ( $N_c$ ), with an increase in which the oil saturation decreases. Consequently, injection with a surfactant due to a change in wettability and a decrease in IFT helps to produce more oil [15, 16].

The Uzen oilfield is in the steppe of Southern Mangyshlak and administratively belongs to a part of the Karakiyansky district of the Mangystau region of the Republic of Kazakhstan. City Zhanaozen is located next to the oilfield, where Ozenmunaigas JSC is based. It operates the development of the Uzen and Karamandybas oilfields and is a city-forming enterprise [17, 18].

The thickness of the productive thickness of the 13 – 18 horizons is more than 400 meters. In the productive thickness, with detailed correlation, six horizons are distinguished, which are well traced and sustained in area. The total thicknesses of the five horizons 13, 15, 16, 17 and 18 are almost the same and vary from 40 to 55 meters, and only the 14th horizon has a greater thickness, which varies from 65 to 75 meters. The horizons are divided by clay bundles, the thickness of which is 5-10 meters.

One of the reasons for the change in the paraffin content in degassed oil of the field may be the deposition of high-melting paraffins (ceresins) in the formation [19, 20], the temperature of the beginning of crystallization of which, as studies have shown [21, 22], in some areas of deposits exceeds reservoir temperatures.

As part of the control over changes in the properties of the reservoir fluid, laboratory studies [23, 24] should be carried out to obtain initial data:

- determination of the formation temperature (boundary conditions) of the solid phase in reservoir oil (crystallization of paraffins);
- determination of the qualitative composition of paraffins;
- development of methods to combat the loss of paraffins;
- filtration studies in order to determine the temperature of precipitation of the solid phase in the rock [25, 26];
- creation of a composite model of reservoir fluid to predict changes in properties taking into account current reservoir conditions [27, 28].

The beginning of active injection of water for the purpose of MTR (reservoir pressure maintenance) led to flooding of deposits, and, as a result, deterioration of the physico-chemical and rheological properties of the reservoir fluid.

To obtain high-quality research results, it is necessary to take deep oil samples in accordance with the sampling methodology:

- water content is not higher than 30%;
- constant flow of reservoir oil to the bottom of the well;
- the pressure at the sampling point is not lower than the approved saturation pressure values in the document [29, 30].

## 2 Engineering background

The primary approach to managing the formation of highly watered deposits involves using flow diversion technologies. These technologies redirect water flow to prevent accumulation in deposits, reducing associated risks like instability and collapse. Additionally, they improve resource extraction efficiency by maintaining optimal conditions [31]. These technologies efficiently redirect water flow, preventing its

accumulation in deposits. This redirection helps mitigate risks linked to water saturation, such as instability and potential collapse. Additionally, they play a crucial role in enhancing resource extraction efficiency. By controlling water flow, these technologies ensure that optimal working conditions are maintained. Consequently, they support the overall stability and productivity of the extraction process [32].

Research indicates that polymer flooding is a cost-effective and successful enhanced oil recovery (EOR) method. It is widely used in sandstone rocks, with some success in carbonate rocks, but factors like temperature and salinity can degrade polymer performance. Modern polymers and numerical simulators are recommended for optimal results, and further laboratory and field studies are essential:

1. Polymer flooding is a cost-effective enhanced oil recovery (EOR) method with highly successful results. It offers several advantages, such as increasing oil recovery by reducing residual oil saturation and decreasing water production from oil wells. Additionally, polymer flooding requires less water compared to traditional flooding methods. This makes it an efficient and economical option for improving oil extraction [33, 34].

2. Polymer flooding is widely utilized in sandstone formations, with notable success. There is also some evidence of its effectiveness in carbonate rocks.

3. Certain factors, such as temperature, salinity, and biological activity, can degrade the polymer molecules. This degradation results in a loss of viscosity and reduced adsorption of the polymer. Consequently, the efficiency of polymer flooding is affected under these conditions [35, 36].

4. HPAM and xanthan are water-soluble polymers suitable for reservoirs with low salinity and low temperatures. However, they are not effective under harsher conditions. For such environments, modern polymers like TCP, sulfonate polymers (AMPS, nVP), and SMG from acrylamide-based polymers have been designed. Additionally, schizophyllane, derived from a biopolymer, is also used to address these challenges [37].

5. Numerical simulators like STARS from CMG, UTCHEM, and ECLIPSE are widely employed in the industry for predicting polymer injection outcomes. These simulators are essential tools for both laboratory experiments and field conditions, providing valuable insights into the behavior and effectiveness of polymer flooding strategies [38, 39].

6. The combination of polymers with alkali and surfactants has shown promising results in enhancing the oil recovery coefficient. This synergy has been documented in various laboratory studies, field applications, and simulation reports. These findings underscore the potential of integrating multiple techniques to optimize oil recovery efficiency in different operational contexts.

7. Conducting laboratory and field studies is crucial to achieving optimal polymer flooding. These studies help refine techniques, assess effectiveness in real-world conditions, and optimize the application of polymers for enhanced oil recovery.

Achieving optimal polymer flooding involves minimizing costs, achieving high viscosity with low polymer concentrations, using high molecular weight polymers with small particle sizes, and ensuring compatibility with various rock types and harsh environmental conditions (HTHS).

Combined flooding with a surfactant with preformed gel particles with polypropylene glycol (PPG), designed to simultaneously increase the efficiency of purification and displacement, has become a promising method of increasing oil recovery.

Extensive laboratory experiments have explored the fundamental mechanisms, while feasibility has been assessed in field applications [40]. Yet, no existing model adequately addresses the integrated ORF (oil recovery factor) process. [41, 42]. low diversion technology (FDT) enhances oil recovery by blocking highly permeable zones with gel substances, redistributing water injection across the deposit to develop previously untouched reservoir areas. [43, 44].

### **3 Modelling and methodology of the oil recovery at the Uzen field**

The application of flow diversion technologies at the Uzen field involves a meticulously designed methodology aimed at optimizing oil recovery. Initially, a comprehensive geological survey is conducted to identify the specific zones where water saturation is highest. This involves the use of advanced geophysical tools and techniques to map the subsurface and understand the distribution of both oil and water. Based on this data, engineers can develop a targeted plan for the placement of flow diversion devices, such as downhole flow controllers and water shutoff valves, which are strategically installed to redirect water flow away from oil-rich areas.

In modeling the effectiveness of these technologies, sophisticated simulation software is employed to predict the behavior of the reservoir under various scenarios. These models take into account a range of factors including reservoir heterogeneity, fluid properties, and existing production data. By simulating different flow diversion strategies, engineers can assess their potential impact on oil recovery rates and identify the most effective approaches. The models are continuously refined with real-time data from the field, allowing for dynamic adjustments to the diversion plan as needed.

The implementation phase involves the precise installation of the chosen flow diversion technologies, followed by rigorous monitoring and adjustment. Advanced sensors and monitoring systems are deployed to track the performance of the diversion devices and the overall behavior of the reservoir. This data is used to make ongoing adjustments to the flow diversion strategy, ensuring maximum efficiency and effectiveness. The goal is to reduce water cut and enhance oil recovery, thereby extending the productive life of the Uzen field and improving the overall profitability of the operation.

### **4 Numerical model**

The problem of uniformity of formation production in the presence of complicating geophysical conditions (fragmentation, heterogeneity in permeability, the presence of highly permeable and watered zones) is successfully solved by influencing the formation with gel-forming polymer compositions capable of penetrating deep into highly permeable zones over considerable distances and effectively regulating the distribution of flows [45, 46]. The main purpose of injection of polymer compositions is to equalize the heterogeneity of productive layers by reducing the mobility of the displacing agent in highly conductive interlayers.[47, 48]

The use of cross-linked polymer compositions ensures the creation of flow diversion screens that lead to [49, 50]:

- containment of injected water breakthrough into producing wells;
- stabilization or decrease of the water content of the surrounding production wells products, hydrodynamically connected with injection wells;
- involvement in the development of hard-to-recover oil reserves from areas with reduced permeability;
- increase of oil production.

The essence of the technology [51] consists in the addition of an insignificant amount (hundredths of a percent) of a crosslinking agent to the polymer solution injected into the reservoir, under the influence of which the polymer macromolecules are structured in a porous medium to form a gel [52, 53].

## 5 Results and discussion

In 2021, 320 injection wells were processed at the field on an industrial scale using polymer compositions [54, 55]. An analysis of 1.252 observation producing wells was carried out, 948 of which have obtained effect – the specific increase in oil production averaged 1.2 tons/day, additional oil production resulted in 245 thousand tons, pick-up decreased on average from 191 to 175 m<sup>3</sup>/day (decrease in pick-up by 17 m<sup>3</sup>/day) [56, 57]. Deviation of water content by 2% (Table 1).

**Table 1.** Results of the effectiveness of the technology under.

Burn the umbrella	Number of injection wells	$Q_{red}$ , m <sup>3</sup> /day		Number of producing wells		Additional mining				Water cut, %		
		before	after	number of observation wells	incl. effective	total		specific		before	after	deviation
						$Q_{liquids}$ , m <sup>3</sup>	$Q_{oils}$ , t	$Q_{liquids}$ , m <sup>3</sup> /day	$Q_{oils}$ , t/day			
13	94	185	177	354	260	79353.2	73193.2	1.8	1.6	89	86	3
14	111	183	180	455	355	-5305.8	97157.3	1.6	1.6	89	86	3
15	51	197	186	194	150	19200.4	33166.6	1.5	1.4	88	86	2
16	18	173	168	62	47	-5163.4	10159	0.7	1.6	92	88	4
17	21	205	201	90	68	-3713.2	18325.6	0.4	1.6	88	84	3
18	14	203	194	57	41	6432.3	13091.7	1.6	1.5	85	83	2
19	2	139	156	5	3	-4049.1	-25.0	-4.5	-0.1	85	85	0
20	2	195	183	9	5	44.7	-284.7	0.2	-0.3	77	79	-2
21	6	172	90	22	15	-4341.8	365.9	-3.4	0.2	72	73	1
22	1	259	211	4	4	-572.5	477.6	-2.9	2.4	91	88	3
Total	320	191	175	1252	948	81884.8	245627.2	-0.3	1.2	86	84	2

During the analyzed period, not all wells reached their planned targets, and the achievements were due to technological and geological reasons. The analysis of the FDT failure in the cells under consideration shows that there is a negative effect for technological and geological reasons. The main reasons for the negative effect are losses due to a drop in fluid flow rates, the absence of a decrease in waterlogging, and a decrease in injection in injection wells with defective operation [58, 59].

Bottom-hole pressure recovery (drop) curves (PRC-PDC) are one of the well-known and widespread methods of hydrodynamic studies of wells in unsteady filtration modes. A pressure drop study was conducted in well No.6304 (PDC) [60] (Table 2).

**Table 2.** Well survey results.

No.	Parameter (6304)	The value before FDT	The value after FDT
1	Type of research	PDC	PDC
2	Perforation intervals (roof, sole), m.	1259.5 – 1287.0	1259.5 – 1287.0
3	Duration of hydrodynamic studies (HDS), h	18.6	73.88
4	The pick-up rate of the well before stopping, m <sup>3</sup> /day	127	159
5	Well model	Crack-infinite conductivity	Vertical
6	The border model	One fault	Intersecting faults
7	Conductivity, mD·m	50.5	58.1
8	Permeability, mD	4.2	4.8
9	Skin factor (general)	-4.08	-2.9
10	Bottom hole pressure, atm	213.5	233.2
11	Pick-up ratio, m <sup>3</sup> /day/atm	2.53	1.84

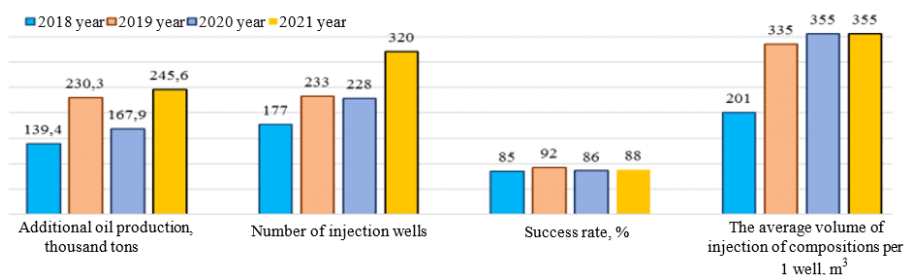
The drop-in fluid flow rates of producing wells are associated with faulty operation of underground equipment, closure of the bottom and other technological malfunctions [51, 52]. The lack of reduction in water content is mainly due to the weak correlation of perforated formations, the lack of hydrodynamic coupling, and the geological features of the impact sites. In some injection wells, there is a decrease in injection even before FDT treatment, which in turn affects site sampling and FDT efficiency.

Straitening up profile of well intake capacity and reducing the water content of producing wells can be achieved by performing water isolation works. Information on the degree of layered phase permeability of oil and water is important.

The results of hydrodynamic studies of HDS wells, namely, a decrease in the permeability or the coefficient of well pick-up, indicate the formation of a gel screen in the bottom-hole zone of the injection well formation. From the data presented above, it can be said that changes in the calculated permeability of formations in the well section occurred due to the redistribution of the injected liquid. During the analyzed period, 958 injection wells were processed at the field using polymer compositions, additional oil production amounted to 783.2 thousand tons, and the average success rate was 88%. Tables 3 and 4 and Figs. 1 and 2 below show the results of flow-bending technologies efficiency by year and by horizon.

**Table 3.** Analysis of the effectiveness of flow-deflecting technologies by year.

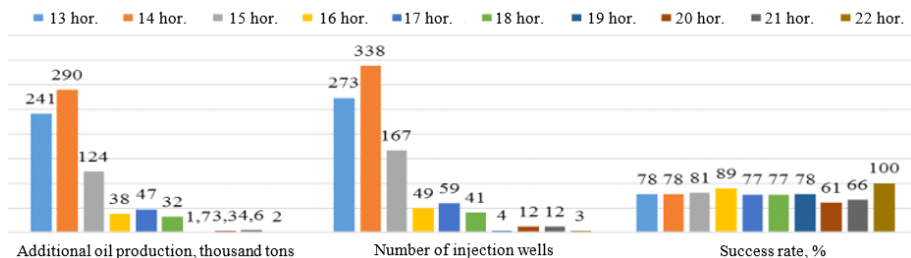
Year	Additional oil production, thousand tons	Number of injection wells	Success rate, %	The average volume of injection of compositions per 1 well, m <sup>3</sup>
2018	139.4	177	85	201
2019	230.3	233	92	335
2020	167.9	228	86	355
2021	245.6	320	88	355
In total	783.2	958	88	311,5



**Fig. 1.** Analysis of the effectiveness of flow-deflecting technologies by year.

**Table 4.** Analysis of the effectiveness of flow-bending technologies over horizons.

Horizon	Additional oil production, thousand tons	Number of injection wells	Success rate, %
13	241.0	273	78
14	290.0	338	78
15	124.0	167	81
16	38.0	49	89
17	47.0	59	77
18	32.0	41	77
19	1.7	4	78
20	3.3	12	61
21	4.6	12	66
22	2.0	3	100
In total	783.6	958	78



**Fig. 2.** Analysis of the effectiveness of flow-bending technologies over horizons.

## 6 Conclusions

In summary, analysis of Flow Diversion Technology (FDT) effectiveness revealed increased oil production and reduced water content in well products through optimized filtration flow redistribution in the reservoir. This included water containing breakthrough from injection wells and integrating hard-to-recover reserves from low-permeability areas into production. During the review period, FDT contributed 783.2 thousand tons of additional oil production, achieving a specific daily increase of 1.5 tons and a success rate of 88%. To further enhance flooding system efficiency, mitigate rapid well flooding, and ensure uniform reservoir production, the proposal of employing Crosslinked Polymer Systems (CPS) technology has been made. CPS technology enhances both current and ultimate oil recovery rates by optimizing reservoir coverage during flooding, modifying flow dynamics, and strategically redistributing injected water flows across the reservoir's area and vertical sections.

Another significant benefit of CPS technology is the prevention of water breakthroughs from injection wells into producing wells. By creating a more controlled flow environment, it helps in maintaining the integrity of the production process and prevents premature water encroachment, which can hamper oil extraction and reduce overall efficiency. Additionally, the technology enables the inclusion of hard-to-recover reserves, especially from areas with reduced permeability. These areas are typically challenging to exploit using conventional methods, but the CPS technology enhances their accessibility and productivity. By improving the mobilization of these reserves, the overall recovery factor of the reservoir is increased, leading to more efficient and effective oil production. In summary, the proposed crosslinked polymer systems (CPS) technology offers a comprehensive solution to improve flooding system efficiency, control flooding rates, and ensure uniform reserve production. It achieves this by redistributing filtration flows, preventing water breakthroughs, and enabling the recovery of hard-to-reach reserves, ultimately leading to higher oil recovery rates and more efficient reservoir management.

The choice of specific polymer brands is determined by the technologies of their application, the properties of the solvent, the cost of the polymer and is clarified during the preparation of technological plans drawn up for each facility at the time of the start of work on the implementation of recommended technologies.

Depending on the reservoir parameters, different compositions and volumes of compositions are recommended for processing each injection well. At the same time, the total volume of injection of the CPS composition for each well varies in the range from 245 to 1186 m<sup>3</sup>.

According to the results of the introduction of CPS technology in 2002, the total additional oil production amounted to 32717 tons of oil (from 171 producing wells located

in the response zone), i.e. 1090.6 tons per well, while the average daily additional oil production per 1 surrounding well was 1.6 tons/day.

In 2001, pilot industrial tests of the polymer-gel composition “Temposcreen” were carried out. “Temposcreen” is a one-component system that forms hydrogels with a volumetric mesh structure and viscoelastic properties. The reagent selectively affects highly permeable watered formations, sharply reducing their permeability, ensures alignment of well pickup profiles, changes filtration flows, increasing reservoir coverage by flooding, which leads to a decrease in the water content of the produced products, an increase in oil production and an increase in oil recovery.

According to the results of the introduction of CPS technology in 2002, the total additional oil production as of 01.01.2003 amounted to 32717 tons of oil (from 171 producing wells located in the response zone), i.e. 1090.6 tons per well. When using the polymer-gel reagent “Temposcreen”, a negative effect was mainly observed: an increase in liquid extraction and an increase in water content of products.

The work was implemented with support of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant No. AP19679430).

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