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CREATION OF EFFECTIVE TECHNOLOGIES FOR MANAGING HYDRODYNAMIC FLOWS AT FIELD DEVELOPMENT SITES IN WESTERN SIBERIA

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A B S T R A C T

The scientific article highlights the results of theoretical and laboratory studies of a complex of compositions and technologies for controlling the inflow of fluids developed for geological and field conditions of terrigenous productive strata of deposits in Western Siberia. The results of experimental and industrial work on the introduction of technological compositions for controlling hydrodynamic flows in the oil fields of the Kogalym region are presented.

Keywords: oil; waterlogging; oil recovery; flow-deflecting technologies; chemical reagents; oil displacement; increased reservoir coverage.

Introduction

To date, most of the long-term developed fields in Western Siberia require improvement of the development system in order to actively involve the remaining oil reserves of non-drained reservoir zones in the development [1-7]. The priority direction for ensuring high rates of oil reserves extraction with maximum coverage of the productive reservoir by impact both in thickness and area is the regulation of the flooding system [8-15]. The effectiveness of the flooding system and the dynamics of optimal reserve production, in turn, are closely related to geological factors such as fragmentation, sandiness, heterogeneity of the operational facility, the structure of reserves and reservoir productivity, and the physico-chemical properties of reservoir fluids [16-22].

The main principles of regulating the uneven selection of oil by flooding are: extraction of oil from stagnant and remote zones, by increasing the efficiency of producing low-permeability layers, changing the direction of filtration flows and increasing the coefficient of reservoir coverage by exposure, as well as carrying out measures to pre-displace oil [23-28]. For these purposes, the most widely used physical, hydrodynamic and physico-chemical MOONS [29-34]. At the same time, with an increase in the water saturation of productive formations at a late stage of development, hydrodynamic (non-stationary flooding, changes in filtration flows, drilling of second trunks and multi-barrel wells, etc.) and physical methods (hydraulic fracturing, various types of wave action) they become less effective [34-40].

In this regard, the issues of improving the applied approaches, the active application of effective methods of regulating the reservoir production process by determining the productivity of well intervals with hydrocarbon and water phases in dynamics, identifying factors affecting the nature of the interval, as well as monitoring corrective measures to increase reservoir production with lateral and vertical heterogeneity, are becoming relevant.

One of the urgent tasks is to create effective technologies for controlling hydrodynamic flows. The problems of achieving this goal are caused by the adverse consequences of the mass application of hydraulic fracturing. Artificially created hydraulic fracturing cracks in the bottom-hole zone, as oil reserves are developed, eventually lead to an intensive influx of pumped water into the supply circuit of producing wells.

When developing deposits with horizontal wells (GW), followed by multistage hydraulic fracturing (MGRP), an important task is to study wells to obtain the most complete information on the inflows of productive intervals. It is known that the application of traditional research methods in HS and the quality of interpretation is complicated by the multiphase flow, changes in the fluid flow velocity in the trunk, the presence of ascending and descending sections of the trajectory of the horizontal section of the trunk and the presence of a number of other factors. A significant disadvantage is the possibility of obtaining downhole data only during the passage of a complex of field geophysical surveys (GS) along the wellbore. It is not possible to track the degree of influence of barrel intervals or MGRP stages on the total flow rate, due to factors such as changes in pump operation, depression, and the operation of the PPD system. It is also problematic to promptly identify flooded intervals and perform repair and insulation work [41-43].

An alternative solution to downhole logging studies is various tracer methods of studying tributaries to obtain

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data on the operation of horizontal shaft intervals. The main advantage of such technologies is the ability to obtain data over a long period of time with a significant reduction in the required resources, which opens up new opportunities for managing the operation of the well and reservoir, leading to an increase in accumulated production.

The main methodological approaches to regulating the development process based on integrated geological and field analysis and dynamic tracer monitoring are considered in scientific publications [42-43], where the authors show that the results of marker monitoring of horizontal wells allow, in combination with analytical studies, to make effective corrective decisions to regulate the development system of complex reservoirs. As a result of the proposed geological and technical measures, a positive technological effect was obtained, expressed in stable dynamics of development indicators, reduction of waterlogging due to blocking of highly permeable intervals washed with water, and an increase in oil production along the site due to increased reservoir coverage in the section during flooding.

Hydrodynamic flow control technologies for the conditions of Western Siberia.

In relation to the geological and physical conditions of deposits in Western Siberia, the authors conducted a series of theoretical and laboratory studies of a complex of compositions of complex selective action in reservoir conditions and technologies for controlling the inflow of fluids. The effectiveness of compositions of different nature for leveling the intake profile of injection wells has been studied and compared.

The selection of reagents was carried out on the basis of a comparative analysis of the effectiveness of the following formulations:

1. based on an emulsion of the «water in oil» type of colloidal structure (reagent BFAN-1);
2. compositions based on polyacrylic acid precipitated by calcium chloride with reinforcing additives of inorganic nature (Geopan-MS reagent);
3. thermogel-forming composition (RUNWAY-1), as well as surfactant – polymer compositions based on a new generation of surfactants (reagent R-30).

During the research, the rheology of working solutions, filtration parameters (phase permeability, residual resistance factor For in water-saturated models and models with residual oil saturation) were studied. The various compositions are compared in terms of efficiency in terms of the increase in the oil displacement coefficient [44-45]. Figures 1, 2 show graphs of the dynamics of pressure gradient changes during filtration of reagents into low-permeable and high-permeable water-saturated models of a porous medium and oil displacement coefficients. The following is a brief description of the applied hydrodynamic flow control technologies.

The surfactant–based technology, a polymer composition, is designed to enhance oil recovery and has a complex effect. The polymer blocks the washed channels with water, and

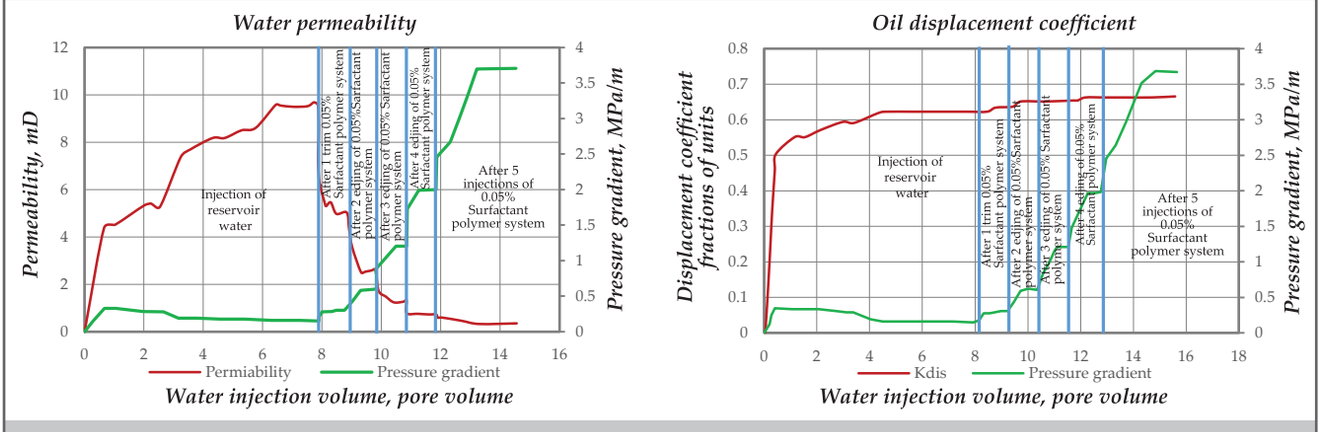

Fig. 1. Graphs of the dynamics of pressure gradient changes during filtration of reagent P30 into low-permeable and high-permeable water-saturated models of a porous medium

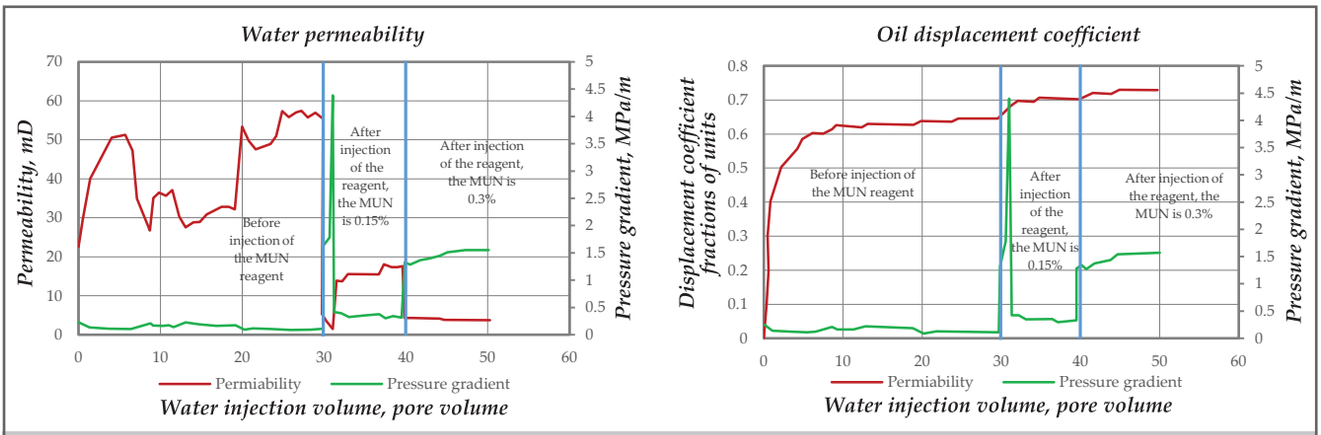

Fig. 2. Graphs of the dynamics of changes in the pressure gradient during filtration of the reagent into low-permeable and high-permeable water-saturated models of a porous medium and oil displacement coefficients

the surfactant (reagent P-30) effectively washes oil from the surface of pores and capillaries. The composition uses a new generation of surfactants that reduce the oil-water interfacial tension by 2 orders of magnitude more than the well-known neonols and sulfanols [44-45]. Anionactive surfactant is not precipitated by ions of polyvalent metals of reservoir water, heat-resistant and is a dry powder. Surfactant «R-30» biodegrades well, does not accumulate in soil and water, does not harm the environment. «R-30» refers to the reagents «green chemistry».

Geopan-MS technology is designed to increase the coverage of reservoirs by flooding by leveling the pickup profile during the treatment of injection wells. The essence of the technology application is the formation of a gel-like precipitate directly in the formation as a result of the interaction of polymer macromolecules with a crosslinking reagent (polyvalent metal cations). The Geopan-MS reagent is a hydrolyzed polyacrylonitrile fiber with the addition of sodium hydroxide. The reagent has a wide range of gelation in the range of 60-120 °C. Pilot industrial works (OPS) using the Geopan-MS reagent were carried out in 2018-2021 at the SE1 facility in the amount of 23 square meters with an average volume of injection of the reagent of 182 m^3 per injection well. According to the results of pilot industrial works (OPR), the average specific efficiency as of 06/01/2021 is 359 t/sqm.oper., the effect continues for 19 wells.

The «Complex-377» technology makes it possible to increase the efficiency of redistribution of filtration flows in the formation by installing filtration screens in a remote part of the formation. The technology provides for the injection of two different compositions: a polymer solution of grade A (a high-molecular anionic polymer of the polyacrylamide type with additives of surfactants) and a low-viscosity thermotropic solution of grade B (a product based on aluminum oxychloride, carbamide and modifying additives). The temperature threshold is 60-90 °C.

According to the results of the ODA at 10 wells, the total additional oil production amounted to 5212 tons, the specific effect was 521 t/sqm.oper., the duration of the effect was 8 months. The reagent was transferred to industrial implementation in 2019.

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The GELEN-13 technology is capable of forming a hydraulic screen in the bottom-hole part of injection wells, as a result of which the coverage of the productive reservoir over the entire thickness increases. The composition is a mixture of aluminum salts, urea, urotropin and heat-strengthening additives. Under reservoir conditions, under the influence of temperature, carbamide is hydrolyzed in an aqueous medium, due to which the pH increases. During the transition from an acidic medium to an alkaline one, an aluminum hydroxide gel is formed from aluminum oxide. The temperature threshold is 60-90 °C. Pilot industrial work using the GELEN-13 reagent was carried out in 2019 in the amount of 8 SLE operas. As of 06/01/2020, additional oil production due to the method amounted to 4296 tons with a specific efficiency of 537 t/sqm.oper.. The average duration of the effect was 8 months. In 3 of the 4 sites, the efficiency calculation was discontinued due to the shutdown of OPEC wells. For the fourth site, the effect was fully calculated, the specific efficiency was 966 t/sqm.oper.. The reagent was transferred to industrial implementation in 2020.

The thermogel-forming composition based on the VPP-1 reagent is designed for conditions of high-temperature low-permeability formations, aimed at increasing oil recovery of formations represented by terrigenous, carbonate reservoirs. Carrying out work on leveling the intake profile of injection wells using the VPP-1 reagent allows:

- to increase the coverage of reservoirs by flooding;
- to reduce unproductive injection in the PPD system by reducing the flow of water into the contoured zone or reducing interplastic flows;
- increase the oil flow rates of reacting producing wells.

Gel formation leads to a redistribution of filtration flows, alignment of the intake profile of injection wells, an increase in oil flow rates and a decrease in the water content of production wells, an increase in current oil recovery and final oil recovery from the reservoir. In RIR technologies, it leads to a limitation of water flow. Gels are applicable for deposits with high reservoir temperature (more than 70 °C) and high heterogeneity. Gels can be used to prevent gas from bursting into producing wells.

Technology for limiting water flow based on a thermostable composition. The BZHG-1 reagent used in the technology contains an aqueous or aqueous-saline solution of a mineral component and organic polymers. It has a high value of the recovery coefficient of phase permeability in oil and sufficient stability to be able to use it as a blocking pack during repair and insulation work.

The technology for limiting water inflow based on the BFAN-1 emulsifier is based on the production of invert emulsions in watered and highly watered areas of fields in order to reduce the water content of produced products and increase oil recovery. The introduction of a solution of the oil-soluble reagent «BFAN-2» in a hydrocarbon liquid into a washed collector makes it possible to hydrophobize the skeleton of the collector with a decrease in its phase permeability to water. In addition, when filtering the solution into the most permeable and water-washed channels and cracks, due to interaction with the residual film oil, an emulsion is formed capable of structuring in the pore space. This reduces the permeability of the washed interlayer to the injected water.

Inflow control technologies based on a complex reagent

Based on the conducted laboratory experiments for terrigenous reservoirs, a technology for regulating the inflow based on a complex reagent has been developed [46].

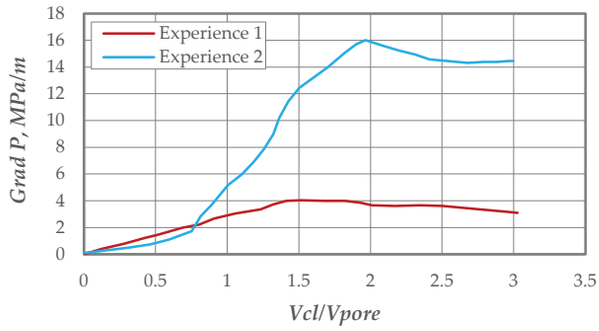

Fig. 3. Dependence of the pressure gradient on the pore volume, injected RSE reagent in experiments 1, 2

The technology is based on the idea of reducing the water saturation of the bottomhole zone of a producing well by exposure to a water-absorbing and hydrophobic solvent while selectively isolating water-saturated intervals and microcracks with a grouting component with hydrophobic properties with increased adhesion to the rock without significantly affecting the oil-saturated layers. As a result of the conducted complex of laboratory studies, the optimal component composition for the implementation of the above idea was found - a stable polymer composition in a universal solvent, called the RSE reagent. Upon contact with water in water-saturated interlayers and cracks in the bottomhole zone of wells, the reagent forms a hydrophobic polymer film on the rock surface, sharply reducing the phase permeability of water, and the universal solvent plays the role of a water absorber, reducing water saturation and increasing the phase permeability of oil, and additionally hydrophobizes the surface of low-permeability pores.

To identify the water insulation properties and evaluate the technological parameters of the RSE reagent, a series of filtration experiments was carried out on full-scale cores of the layers of group B of the Surgut arch. Filtration tests were carried out on composite full-scale models of a productive reservoir (two cores with a total length of 8-10 cm) at a temperature of 70 °C. The permeability of the cores for experiments was taken at two levels, the first level corresponding to the layers of the BS group was about 100 microns and the second level was 450 microns and higher, corresponding to highly permeable interlayers and microcracks. At each level of permeability of the root models, experiments were carried out on three saturations: water-saturated models, water-saturated models with residual oil saturation and kerosene-saturated models with bound water.

The characteristics of the core samples, the description of the model and the filtered liquid are shown in table 1. The pressure gradient first increases, reaching a maximum, and then its growth rate slows down. It is noteworthy that the pressure gradient in the case of a low-permeability model reaches a higher value than in the case of a high-permeability model (16.0 versus 4.8 MPa/m). This is observed in all models, both purely water-saturated and with residual oil saturation, as well as with initial kerosene saturation. It should also be noted that the pressure gradient during injection of the reagent reaches relatively high values, especially in low-permeability models (40.0 and 21.0 MPa/m in experiments 3 and 5, respectively). This indirectly indicates the high tamponing efficiency of the RSE reagent. Thus, the lower the permeability, the higher the tamponing capacity of the RSE reagent. Figure 3 shows typical curves of the dynamics of pressure gradient changes during filtration of the RSE reagent into low-permeable and high-permeable water-saturated models of a porous medium (experiments 1 and 2, respectively).

Experience in the application of flow-deflecting technologies of selective action in the deposits of the Kogalym region

In the period 2021-2022, 53 injection well treatments were performed at the fields of CCI «Povhneftegaz» using reagents «Geopan-MS», «Complex-377» and «GELEN 13» (table 2). As of 06/01/2022, the effect has been completed for 7 treatments (13% of the total), for 41 treatments the effect continues (77% of the total). For 5 treatments (10% of the total), the effect was not calculated at the analysis date (late treatments).

According to the Geopan-MS reagent, as of 06/01/2021, the specific effect on treatments performed in 2021 amounted to 479 t/sqm.oper. (plan – 301 t/sqm.oper.). The effect continues for 11 of the 15 treatments performed. According to the treatments performed in 2022 (8 wells),

Table 1

Characteristics of core samples, description of the model and the filtered liquid (diameter of all cores 3 cm)

Number models	Porosity, %	Gas permeability, $mm^2 \cdot 10^{-3}$	Length, cm	Description of the model and the filtered liquid
1	22.7	120.4	4.4	Water–saturated core, filtered liquid - reservoir water model
	21.2	120.4	4.4	
2	25.6	460.6	4.1	
	25.7	449.3	4.0	
3	23.0	118.0	4.3	Water–saturated core with residual oil filtered liquid - reservoir water model
	25.1	100.0	4.6	
4	24.9	744.1	4.1	
	24.5	700.7	4.2	
5	20.8	79.0	4.6	Kerosene–saturated core with bound water, filtered liquid - kerosene
	20.9	82.0	4.4	
6	24.6	783.4	4.1	
	26.3	823.6	4.0	

the specific effect as of 06/01/2021 is 134 t/sqm.oper., the effect continues. According to the Complex-377 reagent, as of 06/01/2021, the specific effect for treatments performed in 2022 is 772 t/sqm.oper. (the plan is 381 t/sqm.oper.). The effect continues for 16 of the 19 treatments performed. According to the treatments performed in 2022 (7 wells), the specific effect as of 06/01/2021 is 149 t/sqm.oper., the effect continues for 3 treatments. For 4 treatments, the effects were not calculated at the analysis date (late treatments).

According to the GELEN-13 reagent, as of 06/01/2022, the specific effect of the 2022 treatments (4 wells) is 136 t/sqm.oper., the effect continues for 3 treatments. For one treatment, the effect was not calculated at the analysis date (late processing).

Table 2

The effectiveness of the use of «Geopan-MS» and «Complex-377» formulations at the landfills of the Kogalym district deposits

FH MOON Technologies	An object	Number of treatments, pcs.	Injection volume (average), m^3	Additional oil production, tons	Specific efficiency, t/sqm.oper.
Polygon 1					
Geopan-MS	BV8	11	177	4158*	378*
GELEN-13	BV8	2	200	351*	351*
Complex-377	BV8	17	297	9554*	735*
	Ach2	6	281	2478*	413*
Total		36	252	16541	534*
Polygon 2					
Geopan-MS	AB1-3	8	180	1123*	140*
	AB7/1	1	200	2657*	2657*
	AB8	1	200	232*	232*
	BV1	1	200	73	73
	UV1/1	1	200	23	23
Complex-377	AB7/2	2	295	2167*	1083*
	UV1/1	1	215	906*	906*
GELEN-13	AB1-3	2	155	56*	28*
Total		17	197	7237*	426*
Total		53	235	23778*	495*

* *The effect continues*

Conclusions

In order to regulate water flows to producing wells, increase oil displacement coefficients and flood coverage, in relation to the geological and physical conditions of fields in Western Siberia, the effectiveness of compositions of different nature for leveling the intake profile of injection wells was studied and compared.

Laboratory experiments were conducted to study the rheology and filtration parameters of chemical solutions. A flow control technology based on a complex reagent has been developed for terrigenous reservoirs in Western Siberia, which is a stable polymer composition in a universal solvent. Upon contact with water, in water-saturated interlayers and cracks in the bottom-hole zone of wells, the reagent forms a hydrophobic polymer film on the rock surface, sharply reducing the phase permeability of water, and the universal solvent plays the role of a water absorber, reducing water saturation and increasing the phase permeability of oil, and additionally hydrophobizes the surface of low-permeability pores.

The experience of using flow-deflecting technologies of selective action in the fields of the Kogalym region shows that the proposed technological compositions for controlling hydrodynamic flows make it possible to achieve high efficiency in the production of residual oil reserves.

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