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Agent L^6 injection at the Nekrasovsky oil field

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Abstract. At the Nekrasovskoye oil field, the technology of increasing the displacement coefficient by pumping agent L^6 into the Bashkir layer was tested for the first time. Before conducting field tests, laboratory studies were carried out using core material, oil and produced water from this deposit, and the optimal composition was selected. Preliminary results are given in this article.

1. Introduction

One of the main problems in oil production is the low efficiency of the reservoir pressure maintenance system in carbonate deposits containing highly viscous oils, due to the strong heterogeneity of the reservoir, the complex structure and deterioration of reservoir properties during the development process, often the reason for the low productivity of the deposits is the weak effect of water flooding or its complete absence [1–5]. An intensive decrease in reservoir pressure and extremely low rates of production necessitate a constant search for a technical and technological solution to increase the efficiency of the development of such deposits. One way to solve the problem is to increase the coefficient of oil displacement from the reservoir [6, 7].

The main agent in the reservoir pressure maintenance system is water. The properties of water to a large extent determine the nature of the physicochemical processes in the strata when organizing water flooding.

Knowing the basics of energy processes that occur in water structures when exposed to external physical factors, allows to determine the most effective ways to control the state of water and create technologies for managing its properties. The development of a method for controlling the properties of injection agents opens up wide possibilities for changing the properties of all reservoir systems by activating various liquid-phase complexes. Possessing innovative filtration management tools in reservoirs, it is possible to achieve a significant increase in oil recovery and high energy efficiency of the process.

There are substances and particles that can change the properties of liquids, for example, ligands. The most important property of a ligand is its ability to complexation and destruction of the compound as a whole. Ligands are atoms, ions or molecules bonded to other atoms through donor-acceptor interactions. The term is used in the chemistry of complex compounds, denoting particles attached to one or more central (complex-forming) metal atoms [8–12]. Ligands with a dentency of more than two can form chelate complexes - these are complexes in which the atom of the main substance is included in one or more cycles with the ligand molecule. In the case of the formation of a chelate complex, a "chelate" effect often arises - an increase in the stability of the solution through its restructuring. In this regard, there was a proposal to use this effect to create a modified displacing agent to increase the coefficient of oil displacement from the porous-fractured space of the reservoir.

2. Materials and methods

For research, we chose the base reagent L^6, which is a solution of restructured water with ligands of natural origin, stabilizing its structure. On the basis of the basic reagent, a working solution of the reagent is prepared for the optimal concentration of its components, the degree of potentiation and introduction of ligands, the nomenclature and quantitative proportions of which are determined by the characteristics of the reservoir of a particular field.

The basic reagent was obtained in the course of the implementation of the Government Decision of August 28, 1992 No. 715 by the team of authors led by Yu. I. Krasnov. It was applied in various fields and proven to be universal.

The physical principle of producing restructured water is based on vortex technologies, during the implementation of which engineering solutions have been found that allow controlling the parameters of vortex formations in a wide range, up to the separation of the molecular structures of a liquid into electron-proton component fractions. As a result, the ratio of ortho-parahydrogen and the electromagnetic characteristics of dipoles in the resulting restructured water product change, which leads to increased biological and physicochemical activity of restructured water [13–15].

The base reagent is a stably stable structure with a guaranteed shelf life of at least 1 (one) year. The working concentration reagent for use in a particular oil field is stable for 3 (three) months.

Storage conditions:
- in low light;
- temperature: 12–40 ° C,
- lack of nearby man-made fields.

The regulations for the use of the reagent and the conduct of experimental-industrial works in the oil field can be drawn up no more than two weeks after receiving the initial data on:
- the structure and composition of the reservoir;
- physico-chemical properties of oil and produced water;
- pressure and temperature in the oil reservoir.

For research, the technique of preliminary laboratory testing was chosen, and then the reagent was tested in industrial conditions.

3. Results and Discussion

The beginning of pilot testing was preceded by laboratory studies on core material to determine the effect of the displacing agent on K_{dis}. Studies of the effect of the agent on various types of reservoirs of carbonate and terrigenous rocks, including the Bazhenov Formation, as well as those containing from highly viscous to light oils, showed an increase in K_{dis} by up to 16 percentage points compared with the injection of formation water.

Particular attention was paid to the study of the pore space of the reservoir, laboratory studies of core material were performed with testing of various options for structured water.

Laboratory studies of the process of displacing reservoir oil with structured water from a bulk model 47 cm long with a cross-sectional area of 4.908 cm^2 were carried out. In the experiments we used solutions of a concentration of 10-4%, 10-2%, 1%, obtained by diluting the structured water concentrate (agent L^6) in produced water. For a comparative experiment, when displacing oil from a similar bulk model, the formation water of the Nekrasovsky field was used.

According to the results of the experiments, it was found:

1. The displacement coefficient before water breakthrough during pumping 1.0 of the pore volume of structured water was 65.4%, while in formation water this value is 59.1%, i.e. an increase in anhydrous oil recovery amounted to 6.3 percentage points.

2. The final coefficient of oil displacement when pumping 5 pore volumes of a structured water solution was 90.2%.

The positive results of laboratory tests gave rise to work in the field. As a result of the preparatory work, a variant of structured water, called L^6, was chosen. A procedure was developed for the preparation and technology of reagent injection into the reservoir pressure maintenance system of the experimental site.

On the carbonate deposits of the Erepkinsky and Menchinsky uplifts, pilot field tests were conducted to pump water into the reservoir pressure maintenance system with the addition of agent L^6.

The oil field is located in the inner side zone of the Aksubaevo-Melekess depression of the Republic of Tatarstan. According to the geological structure, it belongs to the category of complex ones, with a high degree of anisotropy along the section and along strike, and according to oil reserves it is difficult to recover. Porosity according to core and well log data varies from 0.5 to 21%, averaging 12%, permeability - from 0.002 to 0.250 μm^2. Oil is classified as highly viscous, sulphurous, and heavy. The average content of paraffin is 2.62%, asphaltenes 9.17%, resins 18.8% and sulfur 4.07%. The viscosity of reservoir oil varies from 204.78 to 450 mPa · s. The main object of development is the Erepkinskaya deposit of highly viscous oil in the Bashkirian stage, which is controlled by the brahiantiklinal uplift of the same name. The rise has a size of 1.5 × 2.5 km, an amplitude of about 40 m.

The deposit was put into active development in 2007, 27 wells were drilled at the field, including 23 producing and 3 injection ones. The accumulated oil production from the reservoir is 179 thousand tons. The oil production rate of the wells upon depositing reached 15 tons/day and within three months decreased by 3-4 times. As the drilling and production increases, reservoir pressure decreased from the initial 100 to 50 atm. In order to prevent a sharp decline in production in March 2008, a water flooding system was established (reservoir pressure maintenance). Parameters of the existing reservoir pressure maintenance system: formation (commercial) water is used as the flooding liquid, the discharge pressure is 35–40 atm, the accumulated water injection is 93 thousand m^3.

The launch of the reservoir pressure maintenance system made it possible to stabilize oil production at the level of 15 thousand tons per year. The current water cut of production does not exceed 15%, the average daily oil production rate per well is 2.1 tons/day. Prior to pilot testing, the selection compensation was 52%.

In the period from November 5 to November 17, 2017, at the Yerepkoye uplift of the field, agent L^6 was pumped into the reservoir through injection well No. 1278. 315 m^3 of water was added to the reservoir pressure maintenance system with the addition of 0.06 m^3 of agent L^6. The initial discharge pressure during injection fluctuated from 43 to 51 atm, then after injection of 38 m^3 of agent L^6, the current discharge pressure was set at 45 atm and at the final stage of injection it decreased to 30 atm. When selling the injected volume of agent L^6 with produced water in a volume of 76 m^3, a steady pressure of 30 atm was recorded. On the third day after L^6 injection, the wellhead pressure of injection well No. 1278 decreased to 0 atm, and the injection rate increased to 90 m^3 / day. Between November 2017 and October 2018, 22.9 thousand m^3 of water was pumped. A steady increase in the wellhead pressure of injection from 0 to 25 atm was noted, with a throttle response of the same 90 m^3 / day. As of 01.10.2018, cumulative oil production from the reservoir amounted to 179.2 thousand tons of oil, cumulative injection - 115.6 thousand m^3, 60% selection compensation (+8% for 10 months), while a gradual increase in the production volume in the field is noted and an increase of 3.3 t / day of oil, or 7% of the total production from the Bashkirian deposits. For an objective evaluation of the results of pilot testing, it is necessary to bring the compensation compensation by injection to the level of 80%.

The convergence of laboratory research data on the displacement process on core material with the results of pilot testing is noted:

- the drop in injection pressure after pumping the L^6 solution correlates well with a significant increase in the permeability of the reservoir, due to the assumed change in the nature of the wettability of the formation from hydrophobic to hydrophilic (due to the effect of restructured L^6 water on the formation);

- a gradual increase in discharge pressure to 25 atm after a period of "zero" pressure suggests the inclusion of the process of capillary "impregnation" of the reservoir and accelerate the process of compensating injection selection;

- restoration of pressure in the reservoir pressure maintenance system to nominal (before L^6 treatment) after reaching compensation by 80% injection should significantly increase the efficiency of reservoir development and increase oil production.

In the period from September 16, 2018 to October 14, 2018, at the Menchinsky uplift, agent L^6 was pumped through injection wells No. 1351 (V = 145.5 m^3 of 0.04% agent solution, L^6 - 0.06 m^3) and No. 1369 (V = 156.5 m^3 of 0.04% solution agent, L^6 - 0.06 m^3). Before treatment, the final working pressure of injection on the 2nd day was 65 atm and the wellhead pressure (P_w) to the electric contact pressure gauge installed on the wellhead valves according to the "settings", then the injection was transferred to the next well from a pair of wells No.1351, 1369. Control and measurement of injection volumes (presented in tables and graphs) was carried out by wellhead flowmeters 'Take-off-reservoir pressure maintenance". Prior to injection of agent L^6, the average monthly injection volume of the working agent into 2 wells of the experimental section was 324 m^3 / month. After the L^6 solution was injected, the injection wells were started in the previous cyclic mode: 2 days in operation (injection), 2 days - impregnation.

After treatment with L^6 agent for 20 days, the end workers of the P_w decreased in well No.1351 to 46 atm (minus 29%). In well No.1369 it decreased to 54 atm (minus 17%), without shutdown on the 2nd day of operation according to the "settings" electric contact pressure gauge.

The dynamics of wells No.1351 are presented in table 1 and figure 1.

The dynamics of the well No.1369 are presented in table 2 and in figure 2.

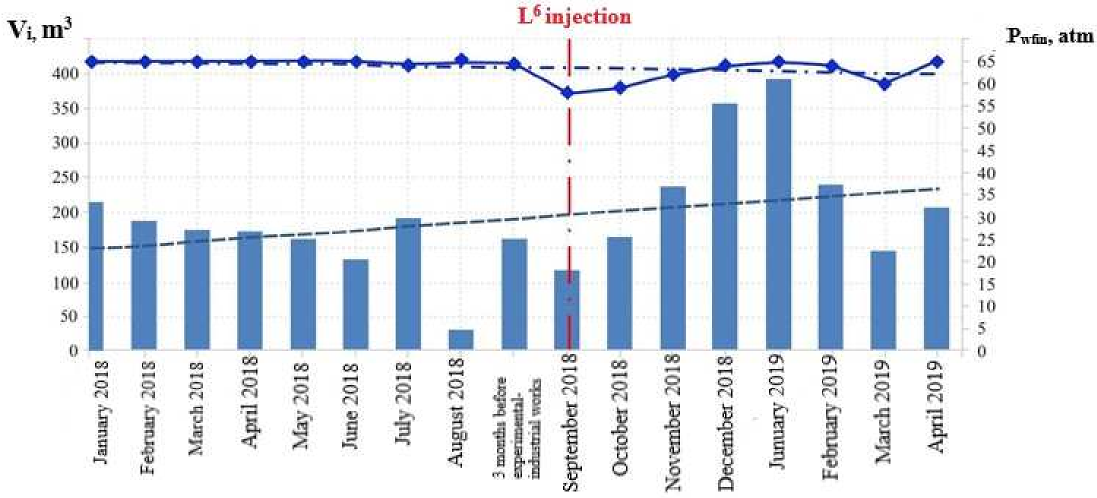

Figure 1. The dynamics of the injection well No. 1351: - injection volume per month, m^3 / month; – linear (monthly injection volume, m^3 / month); – P_{wfin}daily average, atm; – linear (P_{wfin}daily average, atm) – from January to April 2019

Since the L^6 Ru injection, the electric contact pressure gauge was switched off according to the "settings". It was decided to switch to a constant injection mode with P_w and volume control while increasing the selection by the injection. After two months of operation in the continuous pumping mode, Ru reached 65 atm and shutdowns started according to the "settings" of electric contact pressure gauge. Wells were switched to periodic download mode. The final wellhead pressures were also 65 atm.

Table 1. Dynamics of indicators of injection well No.1351 of the Menchinsky uplift of the Nekrasovskoye field

Month year	Average daily injection volume m^3 / day	P_{wfin}daily average, atm	Volume of injection per month, m^3 / month	Increase in injection, m^3 / month	The increase in injection, %	Note
January 2018	13.4	65	214			periodic injection mode 1/1
February 2018	13.2	65	185			2/2 periodic injection mode
March 2018	12.3	65	172			2/2 periodic injection mode
April 2018	8.9	65	169			2/2 periodic injection mode
May 2018	13.2	65	159			2/2 periodic injection mode
June 2018	14.3	65	129			2/2 periodic injection mode
July 2018	12.6	64	189			periodic injection mode
August 2018	9.1	65	28			periodic injection mode
Average for 3 months. before experimental-industrial works	**13.4**	**65**	**159**			
September 2018	16.4	58	115	-44	-28	periodic injection mode
October 2018	17.9	59	161	2	1	periodic injection mode
November 2018	15.6	62	234	75	47	periodic injection mode
December 2018	13.6	64	354	195	123	in continuous download mode
January 2019	12.6	65	390	231	145	in continuous injection mode
February 2019	15.8	64	237	78	49	from 1 to 7.02.19, in 2/2 mode, then periodic 1/1
March 2019	14.1	60	141	-18	-11	from March 8 to March 25, 19, bleeding and cleaning of BHZ by swabbing
April 2019	12.8	65	204	45	28	2/2 periodic injection mode
Average after injection L^6	**15**	**62**	**230**	**71**	**44**	

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Table 2. Dynamics of indicators of injection well No.1369 of the Menchinsky uplift of the Nekrasovskoye field

Month year	The average daily injection volume, m^3 / day	P_{wfin}daily average, atm	Volume of injection per month, m^3 / month	Increase in injection, m^3 / month	The increase in injection, %	Note
January 2018	15.0	65	225			periodic injection mode
February 2018	14.0	65	197			periodic injection mode
March 2018	15.4	65	201			periodic injection mode
April 2018	12.9	65	142			periodic injection mode
May 2018	9.3	65	167			periodic injection mode
June 2018	10.5	66	116			periodic injection mode
July 2018	12.5	65	213			periodic injection mode
August 2018	14.6	65	95			periodic injection mode
Average 3 months before experimental-industrial works	**12.5**	**65**	**165**			
September 2018	17.3	57	115	-50	-30	periodic injection mode
October 2018	15.3	60	122	-43	-26	periodic injection mode
November 2018	15.8	62.8	237	72	43	periodic injection mode
December 2018	9.4	64.0	245	80	48	in continuous injection mode
January 2019	14.8	65.0	459	294	178	in continuous injection mode
February 2019	24.5	65	318	153	92	from 1 to 7.02.19, in 2/2 mode, then periodic 1/1
March 2019	17.9	58	125	-40	-24	from March 8 to March 25, 19, bleeding and cleaning of BHZ by swabbing
April 2019	13.8	65	235	70	42	2/2 periodic injection mode
Average after injection L^6	**16**	**62**	**232**	**67**	**40**	

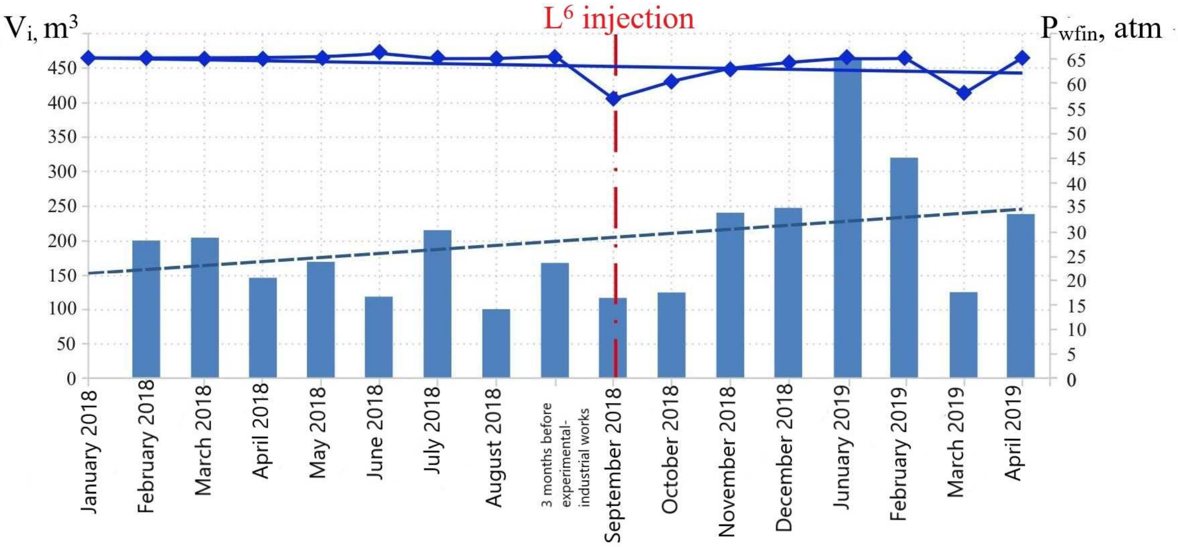

Figure 2. The dynamics of the injection well No. 1369: - injection volume per month, m^3 / month; - linear (volume of injection per month, m^3 / month); – P_{wfin}daily average, atm; - linear(P_{wfin}daily average, atm) – from January to April 2019

We assumed that during the shutdown of injection, oil is displaced from the formation into injection well No.1369 because of the periodic "clogging" of oil of the "Takeoff-reservoir pressure maintenance" meter at the wellhead No.1369. Since the meter was not clogged with oil well No.1351, then leaking from a water well No.668 is not possible (well No. 668 - the total water intake for wells No.1351 and No.1369). In March, the wells were stopped for bleeding and cleaning BHZ by self-flow, followed by swabbing. From March 8, 2019 to March 26, 2019, the wells were idle due to bleeding and cleaning of BHZ with inappropriately swabbing. When bleeding and swabbing from well No.1369, an abundant film of oil was obtained, but no traces of oil were found in well No.1351. Further, the wells were launched in a continuous mode and within 10 days Roux reached 62 atm. Then, from 04/05/2019, the wells were switched to a cyclic mode of operation: "2 days. work / 2 days. impregnation "with alternate injection.

As of 01.04.2018, cumulative oil production from the reservoir amounted to 61.484 thousand tons of oil, cumulative injection - 15.066 thousand m^3, selection compensation - 22.1% (+2.1% for 7 months). For an objective assessment of experimental-industrial works, it is necessary to bring the compensation compensation by injection to the level of 80%. The development indicators of the Menchinsky uplift section before and after experimental-industrial works are presented in table 3.

The effect of the use of agent L^6 is obvious in the form of a decrease in wellhead injection pressure and an increase in well injectivity. It is worth noting that the specific energy consumption measured at water intake well No.668 with a Mercury 230 ART-02 PQRSIN meter per 1 m^3 of water injected before treatment with L^6 was 16.5 kWh; after processing with L^6, the specific energy consumption decreased to 14.0 kWh (minus 15.2%) This decrease in specific energy consumption was recorded during the first 4 months after injection of L^6 solution.

During the period of wastewater injection without additives from January 2018 to August 2019, the increase in compensation for injection by the month was on average 0.16%, after the injection of L^6 from October 2018 to May 2019, the average monthly increase in compensation for injection was increased to 0.36%. Now that the effect of the L^6 solution is over, the compensation compensation has slowed to 0.16% per month.

Table 3. Development indicators of the Menchinsky uplift of the Nekrasovskoye field before and after L[6] injection

Date	Accumulated oil production, thousand tons	Accumulated fluid production in the area, thousand m^3	Accumulated injection, thousand m^3	Accumulated injection, thousand m^3	Compensation from the beginning of development, %	IOIP, thousand tons	ROIP, thousand tons	ROIP selection, %	Current oil recovery, %
01.09.2018	54.207	59.614	4.627	11.918	20.0	2420	298	18.22	2.24
01.04.2019	61.484	68.239	1.501	15.066	22.1	2420	298	20.67	2.54

4. Conclusion

Conducted laboratory and pilot field studies revealed that restructured water increases the oil displacement coefficient and, accordingly, the oil recovery coefficient, both current and final, also increases the energy efficiency of maintaining reservoir pressure. The technology of using agent L[6] is feasible both in laboratory and in field conditions.

It is proposed, as a promising technology to increase the K_{dis} at the developed fields, to carry out a modification of the reservoir pressure maintenance agent, which consists in adding structured L[6] water to the reservoir pressure maintenance system when water is injected into the reservoir.

It is recommended to continue pilot testing in order to refine (adapt) the technology for various objects.

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