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PILOT EXPERIMENTAL WORKS ON INJECTION OF HOT WATER WITH SURFACTANTS INTO BOBRIKOVIAN DEPOSITS OF BERKET-KLYUCHEVSKY FIELD

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The problem of developing and introducing new methods of enhancing oil recovery is especially important for heavy oil fields, the share of which in the structure of reserves is steadily growing. Conventional methods of oil recovery and stimulation of well productivity applied on heavy oil fields are often ineffective, in this regard, the increase in the efficiency of geological and technical measures at such objects is becoming increasingly dependent on the concentration of intensifying factors of influence on the reservoir and the proper choice of technology in accordance with geological and geophysical conditions.

The authors have developed and introduced into production the resource-saving technology of complex stimulation on the productive layer, which includes a combination of physical, chemical, thermal and hydrodynamic factors of stimulation. A rational combination of these factors made it possible to increase the efficiency of developing a heavy oil deposit – to stabilize the decline and increase oil production.

Technologically, the implemented development method consists in injecting hot water into the injection wells with a calculated content of surfactants. Associated gas of this section of the field, previously burned on the flare, is used as fuel for heating water. The introduction of the technology allowed to completely solve the problem of utilization of associated gas at the site: the flare was extinguished, as a result of which the emissions and technogenic load on the environment were also reduced.

Keywords: heavy oil, decline of production, thermal methods, surfactants, hydrodynamic simulation

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At present, the direction of creation and introduction into production of new methods and technologies of oil reservoir stimulation with the purpose of obtaining high technical and economic indices of field development becomes more and more urgent. Current conventional methods of oil recovery and stimulation of well productivity do not always give the desired result. In this regard, the increase in the efficiency of geological and technical measures becomes increasingly dependent on the intensifying factors of reservoir stimulation and the correct choice of technology in accordance with the geological and physical conditions.

In 2013, the implementation of a project to introduce a complex reservoir stimulation, which includes a combination of physico-chemical, thermal and hydrodynamic factors, was launched on the deposits of heavy oil from the Bobrikovian horizon of the Berket-Klyuchevsky oil field of CJSC Okhtin-Oil. The rational combination of these factors of stimulation made it possible to increase the development efficiency of this heavy oil deposit – to stabilize the decline and increase oil production. Technologically, the implemented development method consists of injecting hot water into the injection wells with a calculated content of surfactants.

The Berket-Klyuchevsky field in the regional tectonic plan is confined to the southern part of the Ulyanovsk terrace in the western slope of the South Tatar arch. The territory of the deposit is divided into two subregional troughs, which have a north-north-western strike. Small deflections of the north-eastern and north-north-eastern strike can also be traced, which distinguish structural uplifts in groups of independent local zones, with paleographic conditions peculiar to them only.

A characteristic feature of the oil deposits of the Berket-Klyuchevsky field is the presence of the Visean incisions, which determine the capacitive characteristics of the oil reservoirs. On the Anisov uplift, the Visean incision, confined to the vaulted part of the paleo-uplift, cuts the dome structure from the north-west to

the southeast. The erosion-karst process proceeded in a hypsometrically high part of the ancient local form of the Turnaian stage and is characterized by the deposition of terrigenous rocks with increased porosity and permeability. The thickness of the complex with filling sediments reaches 30 meters; the maximum depth of the erosion incision into the underlying Tournaisian deposits is 20 meters. The position of the incision is determined from drilling and seismic data.

The oil-saturated thicknesses within the deposit range from 2.2 m (well No. 3105) to 19.2 m (well No. 3102). The average value of the porosity is 0.23, the oil saturation parameter is 0.87, the permeability is $1.135 * 10^{-3}$ mkm^2, i.e.the development object has high-capacity and high-permeability properties. The viscosity of the reservoir oil ranges from 52 to 72 mPa * s, density – 0.9 t/m^3.

Development of a reservoir of high-viscosity oil from the Bobrikov horizon of the Anisovy Raion was started in 2004 by one well No. 2138, the dynamics of the development indicators are shown in Figure 1.

Intensive drilling of the deposit was carried out between 2008 and 2012. The initial oil rates were from 10 t/day to 25 t/day, however, within a year and a half the production rates decreased by 1.5-2 times. Decrease in production rates was accompanied by a drop in reservoir pressure. The low activity of marginal waters is primarily associated with the incision form of the "lace" type deposit. A further drop in reservoir pressure was accompanied by the release of dissolved gas into a separate phase, a decrease in the filtration characteristics of the bottomhole well zone. The greatest decrease was noted in wells Nos. 3115, 3104, 3201, located in the dome part of the deposit.

By the middle of 2012, these wells practically stopped producing; the gas content in the wells has significantly decreased.

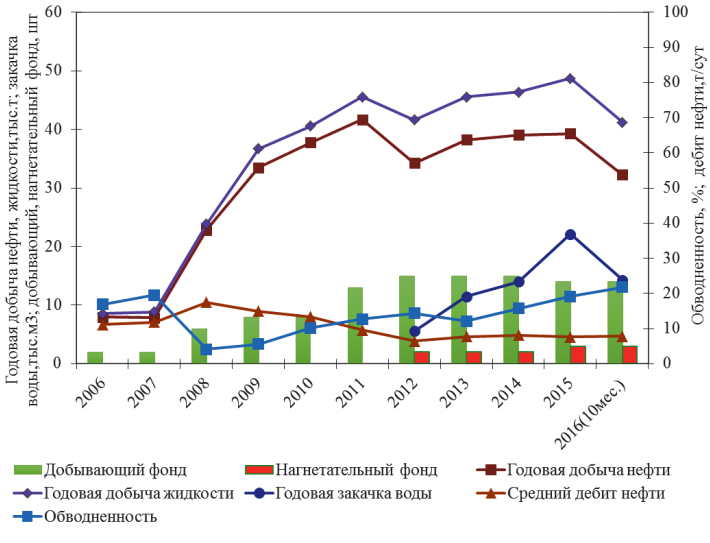

Fig. 1. Dynamics of technological indicators of the development of the Bobrikovian horizon of the Anisov uplift of the Berket-Klyuchevsky field

To stabilize the decline in production of CJSC Okhtin-Oil, a decision was taken to introduce a complex stimulation on the reservoir, which includes a combination of physical, chemical, thermal and hydrodynamic factors of stimulation. To select an effective option of complex stimulation on the reservoir, the following technological parameters are considered:

- Three temperature regimes of water injection (annual average 10 °C, heated to 30 °C and up to 50 °C);
- use of two kinds of surfactants with 0.05% concentration;
- injecting water with a temperature of 50 °C without the use of surfactants.

Laboratory studies were carried out using core samples from well No. 3118 and formation fluids from the Bobrikovian horizon of the Anisov uplift of the Berket-Klyuchevsky field. The best displacement rates were achieved using water heated to 50 °C with the addition of 0.05% Neonol AF9-6 surfactant. The increase in the displacement rate compared to the use of cold water (10 °C) without the addition of surfactants in the laboratory was 11%.

The team of authors together with the TatNIPIneft Institute, based on the data of laboratory studies and injection parameters implemented in field conditions, based on geological and hydrodynamic modeling, carried out studies of the effectiveness of technological options for the hot water injection with the addition of surfactants. In total, nine options for the deposit development were considered (Zaripov et al, 2014). The forecast oil recovery factor and additional production from the injection of hot water together with the use of surfactants for the main options for the implementation of activities are shown in Figure 2.

Based on the results of geological and hydrodynamic modeling, the urgency of improving the reservoir pressure maintenance system is justified by injecting water with a bottom temperature of 50 °C with the addition of surfactants.

Since September 2013, well No.3118 has been switched to hot water injection at the following

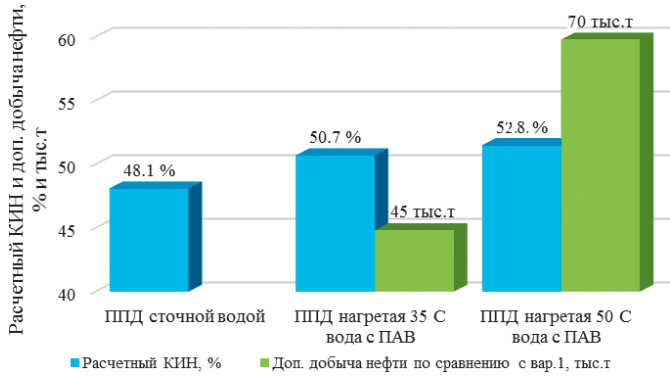

Fig. 2. Comparison of the calculated indicators of the implementation options for the reservoir pressure maintenance system at the end of the development

No. well	Qliq, m^3/day		Qoil, t/day		Pbot., atm		Increase in oil production rates t/day	Change of $P_{bot.}$, atm	Additional oil production, t	
	on 01.09.13	on 01.11.16	on 01.09.13	on 01.11.16	on 01.09.13	on 01.11.16			since the beginning of the year	since the beginning of the experiment
2138	5,5	6,5	4,7	5,6	26,4	28,8	0,9	2,4	235	465
3102	12,7	15,5	11,1	13,5	18,3	25,5	2,4	7,2	612	1277
3103	12,6	10,8	10,7	9,4	17,9	25,6	0	7,7	0	707
3104	10	15,9	8,3	13,4	23,9	28	5,1	4,1	1312	2752
3116	5,2	5,8	4,5	4,9	19,4	24,5	0,4	5,1	372	1859
3113	11,7	14,2	10	12,1	20,7	22,4	2,1	1,7	687	1152
3107	33,3	30,5	27,6	22,2	33,1	33,8	0	0,7	207	992
TOTAL:							**10,9**	**Cp. 4,1**	**3425**	**9204**

Table 1. Technological parameters for the reacting wells of the site in the area of injection well No. 3118

parameters: injection rate 45-50 m^3/day, water temperature at the mouth – 75 °C, while the bottomhole temperature due to heat losses was 35 °C. Simultaneously with the injection of hot water, the supply of Neonol AF9-6 surfactant with a concentration of 0.05% was started. To heat water, we used associated petroleum gas, previously burned on a flare. The introduction in April 2014 of heat-insulated tubing of the "ThermoCase" type allowed reducing heat losses and raising the water temperature at the bottom from 35 ° C to 55 °C.

In total, since the organization of the injection as of 01.11.2016, 55010 m3 of hot water have been injected into well No. 3118, of which 46654 m^3 (84.8%) of water – after carrying the tubing of the "ThermoCase" type.

Figure 3 shows the well location map as of 01.11.2016, where on the basis of hydrodynamic modeling the calculated distribution of the thermal front and the content of surfactants on the deposits of heavy oil from the Bobrikovian horizon of the Anisov uplift are shown. Technological parameters for the reacting wells of the site in the area of injection well No. 3118 are shown in Table 1. The analysis of the operation dynamics of the surrounding wells shows that the effect occurs both by the increase in oil flow rates and by the growth of bottomhole pressure. The accumulated additional oil production as of 01.11.2016 as a result of the injection of hot water with the addition of surfactants to well No. 3118 is 9204 tons of oil. The greatest effect (29.9%) was recorded in well No. 3104; wells No. 3102 (13.9%) and No. 3113 (12.5%) began to react six months after the start of the experiment.

A comparison of the position of the thermal front and content of surfactants shows that the front of oil displacement by surfactants is much faster than the propagation of the thermal front, which is associated with heat losses and a decrease in the temperature of the displacing agent as it moves away from the well. In addition, it is noted that part of the injected agent has left in the marginal part of the deposit in the west direction from the injection well No. 3118.

At present, the displacement front has reached the first line of producing wells No. 3104 and No. 3115.

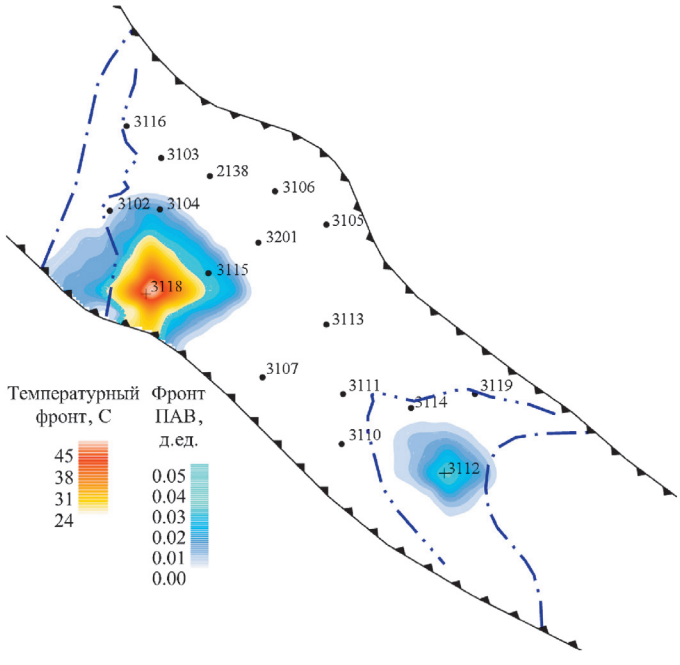

Fig. 3. Map of the thermal front position and the content of surfactants on the heavy oil deposit from the Bobrikovian horizon of the Anisov uplift of the Berket-Klyuchevsky field

At the same time, in the process of its advancement, the change in indicators of producing wells was noted. In the well No. 3104 (Fig. 4a), at the initial stage of injection point creation, well productivity was restored – the oil production rate increased from 0.9 t/day and was established at the level of 4 t/day. After increasing the temperature in the stimulation zone and approaching the surfactant front, a further increase in the oil production rate was observed ~ 1.5-1.7 times. In the well No. 3115, the displacement front was traversed much earlier, which is associated with high dispersion of this zone at the date of introduction of the reservoir pressure maintenance system, as a result, water cut has a growth tendency (Fig. 4b). At present, well No. 3115 continues to be operated with an oil production rate of about 2 tons per day with a rise in bottomhole pressure from 2.7 to 4.5 MPa, which indicates the continuation of the effect associated with the effect of temperature.

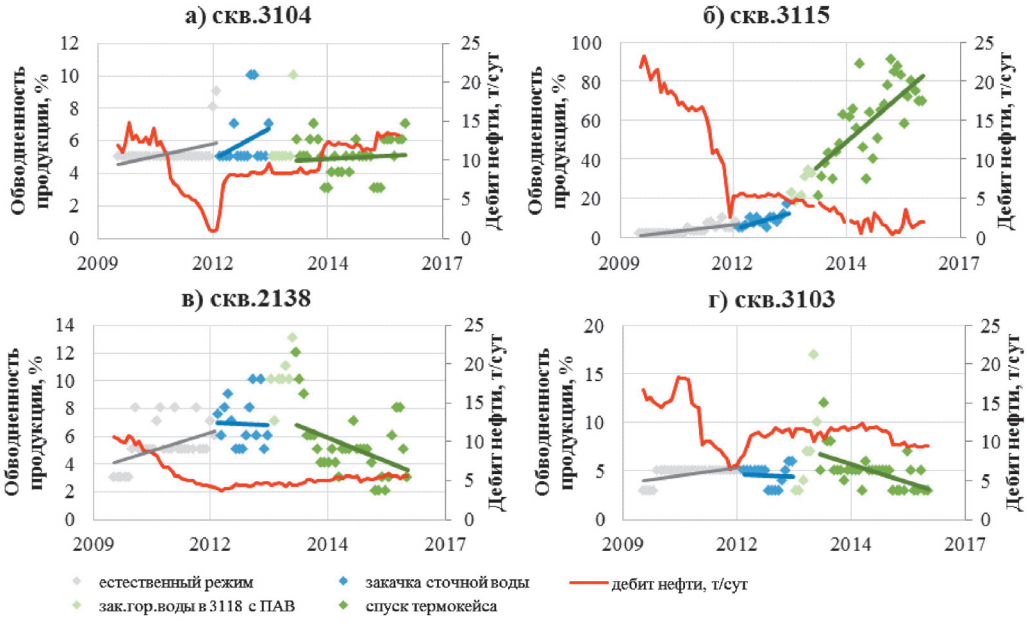

Fig. 4. Comparison of the dynamics of the water cut in the first (a, b) and second line (r, d) of producing wells from the source of injection

On the second line of production wells No. 2138 and No. 3103, as the stimulation is implemented, the water cut of the production is reduced to the initial level (Fig. 4c, d), which confirms the positive effect of the implementation of the reservoir pressure maintenance by injecting hot water with the addition of surfactants.

The efficiency of the introduction of the complex stimulation method on the Bobrikovian horizon of the Anisov uplift of the Berket-Klyuchevsky field by organizing the reservoir pressure maintenance and injecting hot water with the addition of surfactants confirms the presented dynamics in production rate and bottomhole pressure in Figures 5 and 6, respectively. With the continuation of the development of the deposit in natural mode (Fig. 5), the decline in the rate of oil extraction from the initial recoverable reserves was predicted to decrease by 10 times on the fall curve.

The decline in the rate of oil extraction from the initially recovered reserves in the natural mode was accompanied by a decrease in bottomhole pressure in production wells (Fig. 6). The introduction of the reservoir pressure maintenance system with the injection of waste water allowed reducing the rate of decline and its improvement by switching to the injection of hot water with the addition of surfactants – allowed increasing the bottomhole pressures in production wells while stabilizing the level of fluid extraction through the deposit.

To analyze the impact of introducing stimulation technology on the displacement process and the final oil recovery of the reservoir, the displacement characteristics are constructed. Considering the behavior of the displacement characteristics before and after the beginning of the impact, the reservoirs are determined for each development stage (Fig. 7, Table 2). The direction of the kinks indicates that the implemented measures led to an increase in the efficiency of the development of heavy oil deposit from the Anisov uplift.

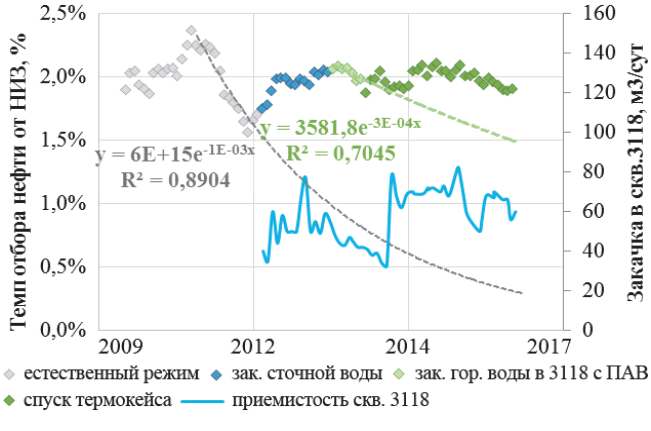

Fig. 5. Rate of oil extraction from initial recoverable reserves at different stages of reservoir development

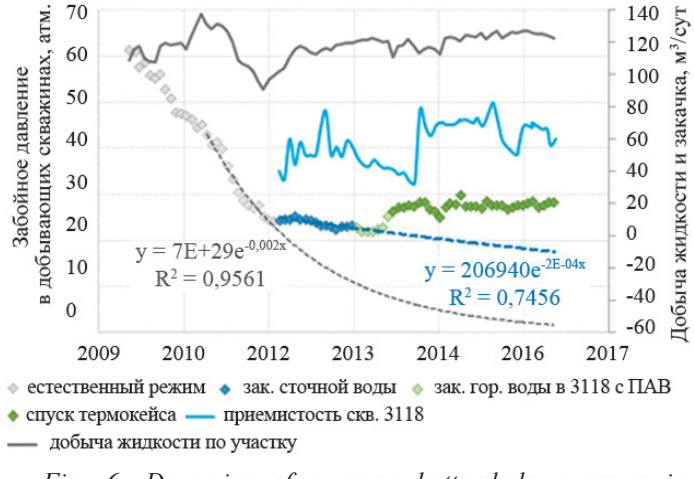

Fig. 6. Dynamics of average bottomhole pressure in production wells, fluid production and injection by site

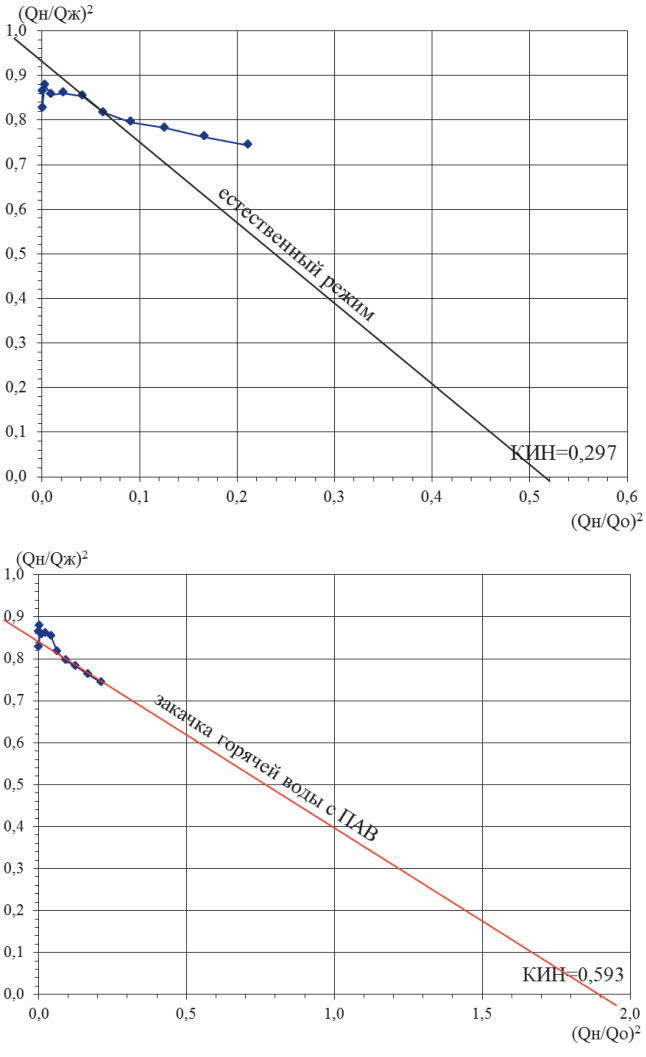

Fig. 7. Characterization of the displacement by Zakharov: a) by decline in natural mode; b) by decline at injecting hot water with the addition of surfactants

The evaluation of the technological efficiency of hot water injection with the addition of surfactants based on displacement characteristics is presented in Figure 8. Additional oil production as a result of the project was 75 thousand tons of oil. By changing the increment to the approved recoverable reserves, we can

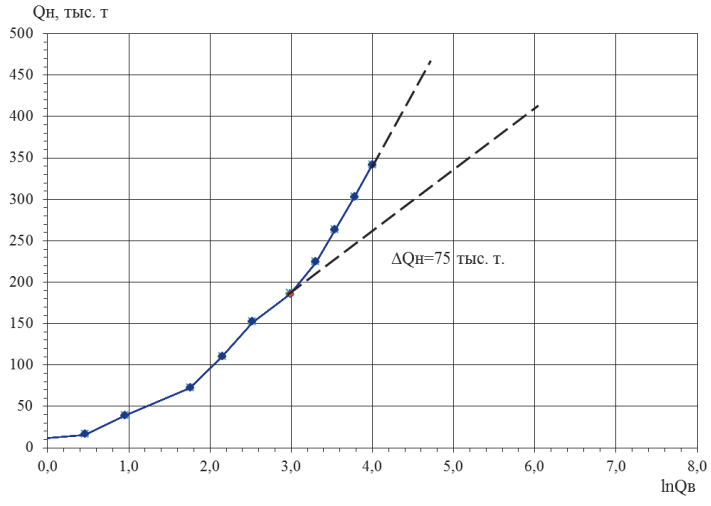

Fig. 8. Definition of additional oil production due to injection of hot water with the addition of surfactants

note the change in efficiency as the development system is transformed. Analysis of the reserves involved in the displacement characteristics shows that with the development system currently being implemented, the average recovery factor is projected at 0.565 unit fractions with an oil-water factor of 3.1 unit fractions, which is higher than the approved (0.461 unit fractions) in 1, 23 times. Relative to the results of geological and hydrodynamic modeling (0.528 unit fractions), the excess is 1.07 times.

In general, the analysis of the effectiveness of the complex stimulation system shows that the introduction of hot water injection with the addition of surfactants has prevented the decline in oil production in the deposits and has involved additional development of oil reserves in relation to the natural mode of development and development by waste water injection.

Conclusions

- The low activity of the marginal waters of the "lace" type incision deposits does not allow for a long time to develop a heavy oil deposit from the

	Displacement characteristics	Forecast of base scenario, units		From approved initially recovered reserves, units	Forecast with the injection of hot water+ surfactants, units		From approved initially recovered reserves, units
		Oil recovery factor	Water-oil ratio		Oil recovery factor	Water-oil ratio	
1	Shia-Khiggins	0,304	2,3	0,66	0,691	2,3	1,50
2	Nazarov-Sipachev	0,181	1,4	0,39	0,420	2,0	0,91
3	Pirverdyan	0,226	4,6	0,49	0,474	4,4	1,03
4	Zakharov	0,297	2,8	0,65	0,593	2,9	1,29
5	Kotzyubinsky-Muslimov	0,261	3,8	0,57	0,649	3,7	1,41
Total, units		**0,254**	**3,0**	**0,55**	**0,565**	**3,1**	**1,23**

Table 2. Resources involved in the development by displacement characteristics

Bobrikovian horizon of the Berket-Klyuchevsky oil field on a natural mode.

- The conducted laboratory studies of oil displacement by heated water with the addition of surfactants showed, and the results of hydrodynamic modeling confirmed the effectiveness of introducing an option of the reservoir pressure maintenance system by injecting hot water heated to 50 °C at the bottom, with the addition of surfactants in an amount of 0.05 %.

- Based on the analysis of the results of field research, it is shown that the effect is manifested both by the increase in oil production rates and by the growth of bottomhole pressure. As a result of the complex stimulation, the additional oil production for the period from 01.09.2013 to 01.11.2016 amounted to 9204 tons of oil.

- The organization of the injection of hot water with the addition of surfactants, the introduction of heat-insulated tubing favorably affected the deposit development – the decline was prevented, and the bottomhole pressures of production wells were increased, the production rate of the extraction reserves was increased, and the high rate of oil extraction was restored for a long time on the deposit.

- Developed and implemented technology for injecting hot water with surfactants is resource-saving; associated petroleum gas, previously burned on a torch is used for heating the water.

- With the use of displacement characteristics, active oil reserves and predicted oil recovery factors are determined at various stages of the development system implementation. Displacement characteristics show that increasing the temperature of the injected water and adding surfactants leads to an increase in oil recovery as a result of improved flooding coverage.

- According to the data of geological and hydrodynamic modeling, the achievement of the oil recovery factor is predicted at the end of the development to be 0.528 unit fractions, with displacement characteristics of 0.565 unit fractions, which is higher than the approved value of 0.461 unit fractions.

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