Technology advancement of maintaining reservoir pressure in oil carbonate fields

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Abstract. In the work, based on a comprehensive analysis of geological and field information and the dynamics of technological indicators of field development, the effectiveness of the applied waterflooding system was evaluated and the results obtained were compared with the theoretical foundations of the method.

The study used a set of well-known geological technological methods used in oil and gas production: mathematical modeling to establish the dependence of the oil displacement ratio by water on the permeability of the reservoir and the average annual water cut of well production from the volume of injected water; hydrodynamic calculations in determining the oil recovery factor in natural conditions; mathematical statistics to determine the accumulated oil production over the entire development period and its recovery factor; experimental studies in determining the coefficient of oil displacement by water.

It is shown that: productive horizons confined to a single reef complex significantly differ in the degree of geological heterogeneity; due to the isolation of the aquifer, the natural mode of operation of productive horizons is closed elastic with a transition to the mode of dissolved gas; the dynamics of the growth of water cut and oil production indicate an insignificant role of fracturing in the process of its extraction; a development system with areal water injection under the oil-water contact and a dense grid of production wells, where a phased transfer of sampling intervals was carried out, made it possible to more than double the oil recovery factor; the effect of waterflooding was obtained due to the achieved high values of sweep efficiency and waterflooding sweep efficiency.

1 Introduction

For many years water flooding has been the main method of influencing oil reservoirs in order to achieve high rates of extraction and recovery of technological oil reserves [1-4]. In these years, leading scientific centers of many countries have conducted research aimed at improving the methodological basis for maintaining reservoir pressure by applying various types of waterflooding [5, 6]. As a result of the research a number of important scientific and practical results have been obtained, including: criteria for choosing the type of water flooding depending on the geological and physical conditions of oil deposits have been developed, classifications of water flooding types based on the scheme of placement of production and injection wells and the intensity of water injection and fluid withdrawal have been proposed, hydrodynamic models of the process implementation in the late stages of development have been created, algorithms for conducting computational experiments and for predicting the technology have been developed [7-9].

Currently, about 90% of produced oil is recovered from fields developed using various types of waterflooding. The results of development of these fields show that waterflooding is a high-potential method of increasing the oil recovery factor (ORF). At favorable geological and physical deposits developed by waterflooding the recovery factor reaches 0.65-0.75, and at fields with hard-to-recover reserves it does not exceed 0.30-0.35. The category of objects with hard-to-recover reserves includes fields with high-viscosity oil, subgaseous oil rims, with reservoirs of low (less than 0.05 μm²) permeability and pore-crack type [10-13].

It should be noted that the improvement and theoretical justification of effective types of waterflooding in fields with hard-to-recover oil reserves are carried out by various methods, including the use of geological and hydrodynamic modeling methods [4-7]. At the same time, insufficient attention is currently paid to the generalization of the results of long-term application of waterflooding in various geological and physical conditions of oil deposits. The practice of oil...
2 Materials and methods

\[ \Delta \eta = \eta_{z} - \eta_{bz} \]

where \( \Delta \eta \) is the EOR achieved with waterflooding; \( \eta_{z} \) is the EOR achieved without waterflooding; \( \eta_{bz} \) is the EOR achieved without waterflooding in the natural regime.

Using the formula (5) separately assesses the impact on the oil recovery factor: physical and hydrodynamic characteristics and physical and chemical properties of reservoirs, reservoir oil and displacing fluid (through the flooding coefficient of displacement and the waterflooding system). Using the formula (6) separately assesses the impact of the transition to the gas mode in waterflooding coverage.

3 Results and Discussion

The main indicators of oil recovery factors for the conditions of waterflooding: cumulative oil production for the accumulative oil and liquid withdrawals; c, d – coefficients determined by the least squares method.

\[ \Delta \eta = \eta_{z} - \eta_{bz} \]

where \( \Delta \eta \) is the increase (increment) in the ultimate oil recovery factor.
The oil deposit in XV+XV+П horizons is massive, the initial water-oil contact was at the absolute mark "-2217 m". The size of the deposit is 2.6 x 2.05 km, height 114 m (Figure 1).

Commercial oil-bearing capacity of Upper Jurassic carbonate sediments in the North Urtabulak area was established in 1973 by testing of XV-П horizon in well No.1. In 1975 oil bearing capacity of limestones of XV-П horizon was revealed by testing of exploitation well No.9.

The main oil reserves in the North Urtabulak field are confined to the riffogenic complex of rocks (XV-П+XV-НП) and only a small share of them falls on the deposits of the XV-П horizon.

The XV-НП horizon lithologically does not practically differ from the XV-П horizon sediments. The difference between XV-П and XV-НП horizons is mainly clearly traced by the change in physical properties of the constituent rocks, which cause essentially different commercial and geophysical characteristics of reef and suprareef carbonates.

**Fig. 1.** Northern Urtabulak field. Structural map of the top of the XV horizon of Jurassic carbonate deposits.

The XV-П horizon is represented mainly by algal limestones, which together with oncolithic limestones constitute about 50%. Coralline-algal limestones also play a significant role up to 33%; coralline, coralline-algal, and organogenic-clastic limestones are present as single interlayers. Limestones are gray, light gray, biomorphic and coarse-grained, strong with interlayers of weakly cemented varieties. Dense varieties are often fractured, cracks filled with calcite, often impregnated with bitumen. Weak dolomitization from 3-5% to 10% is noted throughout the section. In impermeable varieties its intensity sometimes reaches 25%.

The XV-П horizon is represented by a rather monolithic thick porous limestone of reefogenic genesis. The limestones are gray, light gray, beige-firm, dark gray, sandstone-like, of different strength, massive, often friable. Algal (up to 29%), organogenic-clastic (up to 23%) and coral-algal (up to 18%) limestones are predominantly developed in the section of the XV-П horizon.

The XV-П horizon rocks are characterized by high porosity and cavernosity. The share of reservoirs in the horizon section is very high and ranges from 81% to 93%. Limestones of XV-П horizon are also characterized by rare purity, clay impurities are practically absent.

The XV-П horizon is represented by gray, dark gray, dense, clayey limestones. The main part of the section is composed of micrograined limestones with single interlayers of algal and lumpy-algal varieties. Reservoir rocks occur as single lenses and interlayers of small thickness, wedged at a small distance and not correlated by wells. The limestones in the boreholes are represented by dense lumpy varieties with increased clay content.

The North Urtabulak field was put into development in 1974 and until 1980 it was developed on natural-elastic mode. During the period of the field development in 1974-1979 on the natural mode with recovery of only 2.1% of the initial geological reserves the formation pressure in the extraction zones decreased to 2.5 MPa, i.e. by 29.3%.

Calculations of the main indicators of oil deposit development for the closed-elastic mode of dissolved gas were performed with the following initial data:...
specific pore volume of the deposit, m$^3$ - 52.4·10$^{-4}$; initial reservoir pressure of oil saturation with gas, MPa - 29.04; dynamic viscosity of oil, mPa·s - 1.31; dynamic viscosity of gas, mPa·s - 1.2·10$^{-2}$; initial oil saturation, fractions of units - 0.74; selected step of oil saturation change, fractions of units - 0.02; absolute permeability, m$^2$ - 0.1218·10$^{-12}$; effective oil saturated thickness, m - 42.8; porosity, fractions of units - 0.142; conditional radius of the feeding contour, m - 150; well radius, m - 0.1

The hydrodynamic calculations showed that development of the field in the closed elastic mode under the actual dynamics of oil production would have lasted 10 years and the oil recovery factor would have been 6.09%. At subsequent development of the deposit in the dissolved gas mode another 16.01% of geologic oil reserves would have been recovered. Thus, during the development of the North Urtabulak field without waterflooding, an oil recovery factor of 22.1% would have been achieved.

Despite a significant excess of annual water injection over fluid withdrawals, it was only in 1988 that it was possible to compensate for the accumulated production and stop the reservoir pressure decline. Therefore, from 1980 through 1987, the reservoir pressure continued to decline from an initial 29 MPa to 15.5 MPa. In subsequent years, the reservoir pressure remained at 17.0 MPa.

It is known that one of the ways to increase water flooding efficiency is considered to be the increase of injection volumes by increasing water injection pressure. Implementation of this measure with increase of annual water injection from relatively constant volume from 519 to 537 thousand m$^3$/day per year (1987-1997) by gradual annual increase up to 1254 thousand m$^3$/day resulted in increase of watercut of well products. At the same time during the period of water injection volume increase its close relation with average watercut is observed (Figure 2).

Fig. 2. Dependence of average annual water cut on annual water injection volume.

Subsequent step-by-step decrease in the volume of annual water injection in 2012-2017 to 849 thousand m$^3$ led to a decrease in the average watercut by 6%. This fact confirms theoretical provisions that for each specific field based on its geological and physical conditions there is a limit-the optimal volume of water injection, which does not lead to premature watering of well production.

Current oil and liquid withdrawal rates are 1.15% and 5.45% of initial recoverable reserves, respectively. The achieved oil recovery rate is 44.45%. Current and total fluid withdrawals are offset by water injection at 150% and 152%, respectively.

To intensify oil flow, wells are flushed with surfactants, thermo-acid and foam acid treatments. The greatest effect was achieved from thermo-acid treatment of bottom-hole zone with increase of initial average oil flow rate by 6 tons/day (or 1998-1999 1999-2000 2000-2006 2007-2009 2010-2011 2012-2017).
To estimate the value of the oil recovery factor under the realized system of development of the North Urtabulak field, the dependence of $Q_{zh} \cdot Q_{n}$ on $Q_{zh}$ (Figure 3) was plotted according to the actual data and the accumulated oil production for the whole period of its operation was determined, which amounted to 9198 thousand tons, which is 50.68% of the geological reserves.

Fig. 3. Characteristics of oil displacement by water of North Urtabulak field.

It follows from the calculated values that due to the waterflooding system implemented in the field, an increase in the oil recovery factor by 28.58% was achieved, i.e. almost twofold increase was obtained.

In order to develop recommendations to improve the efficiency of development of the North Urtabulak field in the late stage, the components of the KIN coefficient were calculated. To determine the coefficient of oil displacement by water the results of experimental studies were used.

The results of experimental studies to determine the coefficient of oil displacement by water were processed on the reservoir model made from cores extracted from XV-NR horizon in exploration wells of North Urtabulak field.

As a result of processing the materials of laboratory studies, the dependence of oil displacement coefficient with water on the average permeability of the formation ($k$) was obtained in the form:

$$K_{vyt} = a + bk - r k^2,$$

(6)

where $a$, $b$ and $r$ are coefficients numerically equal to $a = 0.4864$, $b = 0.8651$, $r = 0.5568$.

At average permeability of productive horizons 0.121 μm$^2$ the coefficient of displacement for the fields is 0.5822.

Under the condition of wells shutdown at 99% water cut of the produced product the water flooding coverage coefficient is 0.950, and the displacement coverage coefficient at the grid density of 3.3 hectares per well, placed on a uniform triangular shape is 0.9163.

4 Conclusions

Thus, the values of displacement coefficients, displacement coverage and waterflood coverage for the conditions of the North Urtabulak field are 0.5822, 0.9163 and 0.950, respectively. From the obtained values of the parameters determining the oil recovery factor, a very important conclusion follows that the achieved values of $K_{ohv,ext}$ and $K_{ohv,zav}$ are close to the limit values achieved in practice. This conclusion is confirmed by the actual results of field development. As is known, high waterflooding efficiency is largely determined by uniform displacement of oil by injected water over the section and area without premature breakthroughs to the bottoms of production wells. Therefore, in order to increase the oil recovery rate at the North Urtabulak field more than 50.68%, it is necessary to implement methods that increase the oil displacement factor with water.

Currently, a large number of methods have been proposed to increase the oil displacement ratio by water, naturally leading to an increase in the final oil recovery factor. Detailed analysis and conditions of their effective use are given in many works. They differ in purpose, method of action, and used working agent, potentialities and critical factors. Based on the potential and purpose of methods for the North Urtabulak field, with low-viscosity oil, developed with the use of waterflooding, the most promising methods include the use of carbon dioxide, water-gas mixtures and micellar solutions. The most suitable method for the geological and physical conditions and the current state of development of...
the North Urtabulak field is gas-water mixture stimulation. Among other things, this method is universal in terms of application criteria.

For water-gas stimulation in the North Urtabulak field it is recommended to use gas produced associated with oil and currently flared. Obtaining and injection of water-gas slurry into formations will be carried out with the help of special equipment, for example, pump-buster unit or screw pumps.

The realization of this proposal will allow to increase the coefficient of oil displacement method 0.11 and increase the oil recovery factor by 5.6%.

It is necessary to emphasize the relevance of using a mixture of produced water and gas as working agents for impact on the reservoir from the point of view of ensuring the protection of subsoil and the environment.

References


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