Technological feature of water shutoff operations

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Abstract. At present, the use of a water flooding pattern in the development of oilfields at the late stage causes the premature water influx. Therefore, in recent years, the problem of eliminating water influx has become urgent. The productive horizons of the studied deposits are merged into a single object and exhibit a sharp heterogeneity in combination with a dense well pattern. This leads to the natural water influx and, as a result, to high water cut oil reserves. In conditions of a high level of water cut, a significant number of wells are idle and require geological and technological measures for recommencing, demulsification of the produced oil and disposal of the produced water. Therefore, oil companies suffer significant losses. The aim behind this paper is to analyze and evaluate the existing water shutoff techniques for the Vereisk and Bashkir carbonate sediments in the field studied.

1. Introduction

The current state of oil production requires the increased rate and improved quality of oil recovery [1]. The use of an intensive water flooding pattern in the development of heterogeneous productive horizons and an intensive increase in the rate of oil production lead to premature oil withdrawal from the reservoirs, and the initially single oil-saturated field is split into several individual areas. As a result, the structure of oil reserves becomes worse and difficult to recover. In many fields, the development of reserves is uneven due to a large dissection and heterogeneity of the reservoirs, which also affect the process of splitting a single oil-saturated field [2].

Due to the fact that oil reserves in low-permeability layers are a huge reserve for increasing the rate of oil production, and there is a need for additional development of reserves in these layers, the study of oil production in layer-by-layer reservoirs with heterogeneous permeability is becoming more relevant than ever [3, 4].

The need for energy resources increases interest in the techniques to improve oil production, which prompts additional studies to find and apply the most effective techniques for enhanced oil recovery. The current state of the development of many fields requires enhanced oil recovery techniques to more effectively affect the residual oil, which is distributed in the water cut zones of the reservoir, and low-permeability layers with a high oil saturation factor [5].

In order to solve the urgent problem of high water cut in production wells, numerous researchers propose to use water shutoff technologies aimed at increasing filtration resistance in high-permeability zones of the reservoir in order to involve previously non-draining reserves in the process of development.

Practice shows that at the late stage of development that employs water flooding pattern, there is a
premature water influx as the reserves are depleted. Water often breaks into production wells due to the reservoir heterogeneity in area and thickness, displacement instability, wrong well location, the presence of a large number of high-permeability cracks and channels, and uncontrolled spreading of the front of oil displacement by water [6, 9].

For more accurate prediction of effective water flooding, it is necessary to take into account all physical and geological factors, which include macro- and micro-heterogeneity, fracturing level, viscosity of reservoir oil and water, wetting ability of the fluid, and the state of water-oil contact and saturation of the reservoir with oil [12].

2. Materials and methods

The obtained results reported in this paper are substantiated by the use of methods for assessing the involved oil reserves using the characteristics of displacement caused by water shutoff operations.

3. Results and discussion

The studied deposits are anticlinal and exhibit intensely developed fracturing with the presence of both vertical and sub-vertical (at an angle of 60–80 degrees) fractures. Almost every part of the reservoir is represented by matrix blocks between large fractures, which are the main channels for fluid motion. They are consistently associated with medium-sized and small fractures. All deposits are characterized by a gradual decrease in oil-saturated thickness from the central part to the periphery. Some areas exhibit both the Bashkir and Serpukhov sediments.

Oil recovery in carbonate-fractured reservoirs is hindered by the low filtration properties of the matrix and by vertical fractures, along which mainly reservoir water flows [7].

The productive sediments of the studied deposits are carbonate reservoirs of the Vereisk, Bashkir and Serpukhov ages with zonal and layer-by-layer heterogeneity, both in section and in area.

In terms of the structure, the investigated deposits are classified as layer-uplifted and massive. The mode is elastic water-pressure. The thickness of the bridge between the deposits is represented by the formation member of clays and highly clayey limestones and varies within 1–26 m, on average 6.1 m. However, it is unevenly distributed along the strike, fractured and cavernous, which does not provide a reliable separation between the two reservoirs [8–10].

The entire well stock as of January 1, 2017 included 974 wells, including 786 wells of the production stock, of which 695 were production wells and 91 were idle wells (11.6% of the production stock). The main reasons for idle wells are the increased water influx and poor technical condition of wells [9].

The analysis of the lithological and physical characteristics of the deposits and areas showed that the reservoir structure has a significant impact on the choice of wells for pilot works aimed at introducing new technologies and geological and technical measures. Therefore, it is necessary to pay attention to the areas with constant filtration-volumetric properties and to the areas with a compacted carbonate interlayer between oil and water in the bottom part of the Serpukhov stage, which to some extent affects the rate of watering flooding.

The studied deposits are at the final stage of development. In 2017, 382 thousand tons of oil were produced with water cut of 88%.

Due to the late stage of the area development, the majority of wells are of low production rate, which is explained by the high water cut and low liquid flow rate of the wells. An increase in the water influx and poor technical condition are the main reasons for the idle stock. The escape of the injected water along the fractures into the water-bearing part of the reservoir explains the absence of the injection effect. Figure 2 illustrates the dynamics of the main technological indicators of development for deposits [10–12].
Due to the structural features of the reservoirs of the considered field objects, which are mainly carbonate rocks, fluid in the reservoirs flows along high-permeability fractures-channels, and bottom water (massive type deposits) breaks through them to the wells. A large number of reservoir areas remain unaffected by the drainage process. In these areas, intensive fluid withdrawals are not applicable and displacement of oil by water is ineffective. In the considered deposits, a high water cut is observed even with a decrease in the volume of water injection [3, 7].

At present, there are a sufficient number of EOR techniques, in particular, chemical water shutoff techniques. The major techniques for limiting water influx in the studied deposits are WSSH, HSP, SNPCH-9633.

The WSSH technology is designed for deep isolation of water cut areas of different permeability around the bore of horizontal and slanted wells. The technological process is carried out in several cycles by injecting a composition of an aqueous solution of polyacrylamide with a cross linker and a clayey suspension, which form an elastically stationary screen overlapping the watering area [4, 9].
The composition of the polymer composition allows controlling the viscosity of the working solution, which makes it possible to deliver it to the required distance around the axis of the horizontal wellbore. A sufficiently long gelation time blocks the channels of incoming water at the approaches to the horizontal wellbore. In addition, gel is stable as temperature changes and it is resistant to biodegradation in the oil reservoir.

At the time of injection, the water cut averaged 97.2%. The use of this technology in horizontal wells led to a decrease in the water cut to 50–55% followed by its recovery to 80–90%. The use of the considered technology for horizontal wells with ultra-high water influx should be continued [3].

The SNPCH-9633 injection technology to limit water inflows has been used for the considered deposits since the beginning of the nineties.

The SNPCH-9633 reagent is composed of surfactants in a hydrocarbon solvent. On contact with water or acid, the reagent forms highly viscous emulsions. These emulsions are resistant to water washout, but at the same time they are destroyed when in contact with oil. In this regard, they increase filtration resistance in water-saturated areas, that is, selective water isolation [10,11].

Injection of the SNPCH-9633 reagent to limit water inflows to production wells actually reduces the water influx by 40–50% in the initial period after the technology is implemented. The most effective is the operation period of the treated well, which is 5–10 months from the onset of the reagent injection, at which the average daily increase in oil production attains 4.5–6 tons/day for most of the treated wells [11].

In the future, the effect remains for up to 2 years, but its efficiency is significantly reduced and the water influx returns to the initial level observed before the injection.

The HSP technology is used to isolate water inflow that enters the wellbore from the bottom of an oil-saturated reservoir or from a nearby water-saturated reservoir. In addition, this technology limits the water influx injected into the reservoir to maintain reservoir pressure.

The use of this technology implies the injection into the polymer composition formation and gelation inducers. To fix the gel-forming composition, various plugging compositions are used, which consist of cement or carbide-formaldehyde resin.

When implementing this technology, high-strength gels based on polymers and cross linkers are formed in its bottomhole area, which plug the water-saturated intervals of the formation. As a result, the water inflow into the oil well decreases [1].

### Table 1. Efficiency of enhanced oil recovery (EOR) techniques for additional oil production

| EOR technique                          | Number of treatments | Additional oil production, thousand tons |
|---------------------------------------|----------------------|----------------------------------------|
| Water shutoff of slanted and horizontal wells (WSSH) | 189 | 85.7 |
| Reagent SNPCH-9633                   | 190                  | 72.2                                   |
| High-strength polymer (HSP)           | 77                   | 19.2                                   |

### Table 2. Indicators of efficiency of EOR techniques used in the studied deposits

| EOR technique | Efficiency, tons/day | Success,% | Duration of the effect, month |
|---------------|----------------------|-----------|------------------------------|
| WSSH          | 2.5                  | 96.3      | 17                           |
| SNPCH-9633    | 1.8                  | 92.3      | 9                            |
| HSP           | 2.1                  | 94.1      | 10                           |
4. Conclusion

The techniques used to isolate the water inflow were analyzed. The use of a water flooding pattern in the development of oilfields at the late stage causes the premature water influx as the reserves are depleted. Based on the analysis of the causes of water breakthrough and isolation techniques, it was revealed that the most effective solution is the use of physicochemical techniques to affect the reservoir layers by treating them with various gel-forming compositions that increase the filtration resistance of channels washed with water. It was also revealed that one of the factors that can complicate water shutoff operations is the low production index of wells. Due to a decrease in the inflow after the injection of water shutoff compositions and a decrease in bottom-hole pressure, it is impossible to carry out retreatment after reducing the effect of water shutoff operations. In particular, a comprehensive treatment was considered, which includes water shutoff operations with subsequent stimulation of the reservoir layers.

The analysis of the efficiency of techniques for water shutoff operations in the studied deposits showed that WSSH is the most effective technique. SNPCH-9633 and HSP techniques showed lower efficiency and a lower increase in additional oil production. The drawbacks of these techniques include high cost and a significant decrease in bottom-hole pressure after treatments. A significant number of wells associated with the studied deposits operate with low bottom-hole pressure and high water cut, therefore, it is necessary to use complex technologies that include the water influx isolation with subsequent stimulation.

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