Production of reserves of oil- water zones of low-viscosity oil deposits

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Abstract

The authors state that during the production there is the process of transition of deposits to the category of bottom water-drive reservoirs due to frontal displacement by the injected water. As a result, the nature of water flooding becomes similar to the primary areas of bottom water-drive reservoirs. It is shown that for water-drive areas, the development is characterized by unfavorably high input values of water flooding and its intensive growth in the range of oil recovery factor from 0.1 to 0.3 fractions of units. The nature of the displacement curves of areas with water-oil zones (WOZ) is identical and differs only by the amount of water flooding of oil reserves in a deposit or area, which allows drawing a conclusion about a similar mechanism of oil displacement, which is characteristic of oil reservoir. It is shown that the main feature that characterizes the development of areas and deposits with water-oil zones is the increase in water flooding at the first stage of production.

1. Introduction

The improvement of deposit development under the conditions of long-term operation and high current oil recovery is an urgent task [1–10]. The scientific and practical interest is presented by the generalization of oilfield data, technological indicators of development objects of Devonian terrigenous strata (DTS) of Tuimazinskoye deposit, having a high oil recovery factor (more than 0.6), substantiation of technological solutions to increase the degree of development of mobile reserves. It is connected with:

- with a long development period (since 1945);
- pioneering the introduction of edge and intracontour water flooding (since 1949);
- a unique degree of extraction from initial recoverable reserves (IRR) (99%);
- high rates of reserves selection;
- high specific production per 1 well drilled.

Many scientific works written by well-known authors are devoted to the topic of the development of oil reserves of water-drive deposits in reservoirs of terrigenous type. Such researchers as V.N. Shchelkacheva, A.P. Krylova, I. G. Permyakova, M.M. Sattarova, K.S. Baimukhametova, E.V. Lozin and others made a great contribution to the improvement of the production, including Tuimazinskoye oil field. The work [1] reflects the data of studies devoted to the development of reserves of water-oil zones of sandstones and the factors affecting the completeness of production and development time.
2. Materials and methods
In Devonian terrigenous strata of the Tuimazinskoye field, the sandstones of the Dard-vor (DIV), Dmul (DII), Dpash (DI) formations are industrially oil-bearing. The oil reserves in DTS are characterized by the following features. The largest is the Dpash reservoir, the initial oil reserves of which amounted to 59.1% of the total reserves of the field. Figure 1 shows the distribution of initial recoverable reserves (IRR) and residual recoverable reserves (RRR) of ABC1 category by DTS objects of Tuimazinskoye field.

The main share of IRR of Tuimazinskoye oil field was occupied by terrigenous deposits of Pashian horizon - 66% of IRR of the field as a whole, which, along with high filtration-volumetric characteristics, determined the advance introduction of terrigenous deposits of Devonian deposits into production.

![Figure 1. Distribution of IRR and RRR of ABC1 category by DTS objects of Tuimazinskoye field](image)

The indicators of production of Dpash, Dmul and Dard-vor formations are presented in Table 1. The state of development of Dpash formation can be characterized by the following indicators. A high oil recovery factor was achieved - 0.601 with a design value of 0.608 fraction units, the current annual rate of recovery from RRR is 5.6%, recovery from IRR is 98.8% with water flooding of 94%. RRR is 2.8 million tons. According to Table 1, DTS objects are characterized by high current water flooding and significant residual reserves.

| Indicators | Dpash | Dmul | Dard-vor |
|------------|-------|------|----------|
| Original oil, thousand tones | 385661 | 117404 | 2393 |
| IRR, thousand tones | 234427 | 60032 | 1309 |
| RRR, thousand tones | 2803 | 703 | 75 |
| Approved oil recovery index (OIR), fr.unit | 0.608 | 0.511 | 0.547 |
| Cumulative oil production, thousand t/year | 167 | 18 | 10 |
| Current water flooding, % | 94.0 | 95.3 | 95.1 |
| Current oil recovery index, fr.unit | 0.601 | 0.505 | 0.516 |
| IRR recovery, % | 98.8 | 98.8 | 94.3 |
| Original oil recovery rate, % | 5.6 | 2.5 | 11.8 |
| Ratio, year | 17 | 39 | 8 |

Residual recoverable oil reserves of Devonian terrigenous strata of Tuimazinskoye field are classified as difficult to recover due to low porosity and permeability properties (reservoir properties) of the bedrock parts of DI, DII and DIV formations, in contrast to the high reservoir properties of the main units of these reservoirs (porosity 22%, permeability up to 750 mD , effective seam thickness of 8–16 m).

Even with a uniform production system, which led to high current oil recovery due to high rates of oil production using edge and intracontour water flooding and forcing fluid recovery, the development
of reserves from the near-roof parts of DTS formations remains a problem that needs to be solved. Another problem is also the lag in the production of the top units with the worst reservoir properties, developed by one filter together with the main unit.

The structure of residual recoverable oil reserves in DTS is characterized by the following distribution:

- residual reserves in the near-roof part (1–2 m) of the monolithic layer of the main units are randomly dispersed over the area and residual reserves in thin low-permeable upper units are characterized by low porosity of 9–12%, small thickness of 1–3 m, lack of a system for maintaining the reservoir pressure due to the low injection capacity of the upper units;
- residual reserves in lenses, dead ends, stagnant zones and areas are not involved in production, requiring the drilling of new wells in areas with high geological risks.

The described structure of IRR creates the prerequisites for research and problem statements for the improvement of the production of reservoirs. The potential of the objects of the production of DTS should be realized at minimal cost.

Table 2 shows the distribution of the mining fund operating the upper low-power and main monolithic units of Dpash and Dmul objects. It is necessary to note that the group of wells operating the upper thin and low-permeability units is characterized by low productivity. On the contrary, the well stock operating the main unit of Dpash and Dmul formations has high water flooding and productivity, which in turn is determined by high values of permeability and thickness of the monolithic unit.

Table 2. Distribution of wells among Dpash and Dmul formations

| Wells operating the upper unit of Dpash and Dmul formations | Current fund, units | Parameters of operation | Water flooding, % |
|-----------------------------------------------------------|---------------------|-------------------------|------------------|
|                                                           | 132                 | 2.1                     | 0.7              | 62.2  |
| operating the main unit of Dpash and Dmul formations      | 184                 | 44.8                    | 2.9              | 92.4  |
| Total                                                     | 316                 | 26.9                    | 1.95             | 91.5  |

Taking into account the current state of the development of oil deposits in DTS of Tuimazinskoye field, it is necessary to study the possibilities to increase the current rate of oil reserves’ recovery.

The purposes of the research are to increase the oil recovery factor and extend the terms of profitable field production. This can be achieved in line with the identification of the features and patterns of the production of Dpash, Dmul and Dard-vor areas of fields with similar geological and physical characteristics and located in oil-water zones.

In order to analyze the nature of the production of water-drive areas, the research objects were selected according to the following criteria. These are initially water-drive deposits and areas of deposits of Tuimazinskoye field as a monolithic object with underlying water, a high rate of oil reserves extraction, drilled along a uniform grid. According to these criteria, the following deposits and areas were selected for the comparison: the deposits of Dard-Vor and Dmul formations; the areas of Dpash reservoir 7, 8, 18, 32. Table 3 presents the main characteristics of the studied deposits and areas. The deposits and areas meet the selection criteria, except for Dmul reservoir, which partially is composed of pure oil zone.
Table 3. Characteristics of the objects of deposits production of Dmul and Dard-Vor formations, the areas of Dpash formation of Tuimazinskoye field

| Reservoir, area | \( H_{\text{obs}} \), m | \( H_{\text{obs}} \), m | pattern arrangement | \( K_{\text{por}} \), \% | \( K_{\text{perm}} \), mcm\(^2\) | \( \mu_{\text{w}} \), MPa·s | Oil density, f/cm\(^3\) |
|----------------|----------------|----------------|-------------------|----------------|----------------|--------------|----------------|
| Dard-Vor formation | 12.5 | 5.4 | 27.4 | 21 | 0.310 | 3.43 | 0.849 |
| Dmul formation | 15.8 | 12.6 | 27.4 | 22 | 0.340–0.474 | 2.79 | 0.855 |
| Area 7 of Dpash formation | 29 | 2.6 | 27.4 | 21 | 0.170–0.738 | 2.57 | 0.847 |
| Area 8+18 of Dpash formation | 22 | 5.6 | 27.4 | 21 | 0.170–0.738 | 2.57 | 0.847 |
| Area 32 of Dpash formation | 19 | 4.1 | 27.4 | 21 | 0.170–0.738 | 2.57 | 0.847 |

3. Results and Discussion

Figure 2 shows the dynamics of water flooding in Dmul and Dard-Vor formations and areas of Dpash formation, depending on the oil recovery factor. Taking into account the isolation of the deposits, the low values of the oil-saturated thickness underlain by the monolithic water-saturated part of the formation, the rate of water flooding, the areas of Dpash formation and the deposit of Dard-Vor formation are distinguished by increased values of water flooding at the same oil recovery factor.

The change in water flooding of Dpash reservoir areas, Dard-Vor, Dmul reservoirs is described by the function \( B = f \) (ORF). The correlation relationship for Dpash and Dard-vor can be described by the equation \( y = 2307.1x^3 - 2253.2x^2 + 769.7x \) with a reliability of \( R^2 = 0.7434 \); for Dmul with high confidence \( R^2 = 0.9979 \) this function is described by the equation \( y = -46709x^5 + 50666x^4 - 18135x^3 + 2859.9x^2 - 115.66x \).

Figure 2 shows that the dynamics of water flooding of the initially water-drive areas and deposits
of Tuimazinskoye field, as well as the reservoir of Dmul reservoir, which has a purely oil zone and became water-drive as a result of water flooding, is identical. This identity is manifested at the stage of reaching the oil recovery factor equal to 0.38 units, i.e., the recovery of reserves of a purely oil zone and the transition of the reservoir to the category of water-drive.

In addition to DII reservoir, in DI and DIV reservoirs, the water flooding has unfavorably high initial values and intensive growth in the interval of oil recovery factor from 0.1 to 0.3 fractions of a unit. The achievement of oil recovery factor values of 0.2 fractions occurs at a water flooding of 83% and there is a risk of not reaching the planned oil recovery factor, which is the reason for forcing fluid withdrawals and, as a result, a consistently high current water flooding.

For DII reservoir, the dynamics of water flooding is flatter, which is explained by the process of production in the purely oil zone of the deposit with a lower water flooding. The graph (Figure 2) shows that in the ORF range of 0.35–0.40 fractions there is a process of transition of the reservoir to the category of water-drive due to frontal displacement by the injected water and the rise of OWC. As a result of this impact on the reservoir, the nature of the rate of water flooding becomes similar to the primary water-drive zones of DI and DIV deposits.

The displacement characteristics presented in Figures 3, 4 reflect the intensity of the production of produced water from the analyzed deposits. The deposits of Dard-Vor formation and area 8 + 18 of Dpash formation, as a result of forcing fluid withdrawals, are distinguished by higher values of the accumulated water-oil factor (WOF) with a lower value of the achieved oil recovery factor.

Figure 4 shows the displacement characteristic reflecting the dependence of cumulative oil production on the natural logarithm of cumulative fluid production. The nature of the displacement curves is identical and differs by the amount of oil reserves in the reservoir or area, which allows drawing a conclusion about the similar parameters of the oil displacement process, which is characteristic of oil-water zone (OWZ).

The dependence of the rate of recovery from IRR on oil recovery factor in Figure 3, b gives the idea of the distribution of the rate of recovery of IRR when the recovery rate is reached. At the initial stage, withdrawals from IRR are characterized by values of 3–5%, then with the increase in water flooding, the rate of withdrawal decreases and stabilizes at the level of 1–3%.

The dynamics of the changes of average daily liquid flow rate in Figure 3, c shows which areas were subjected to forced withdrawal of liquid. The increased values are characteristic of Dard-Vor reservoir and the 8 + 18 area of Dpash reservoir with withdrawals of 200-300 t / day per 1 well, which is explained by the activity of the edge area and the forced production of fluid at a high value of water flooding.

The analysis of the production indicators of the selected deposits of Dmul, Dard-vor and areas of Dpash reservoir quite confidently agrees with the next stage of production. The first stage is characterized by intensive drilling out of the project fund, increasing fluid production and increase in water cut flooding to 30%. At the second stage, there is the increase in water flooding to 50-60%, organization of injection, stabilization of the rate of withdrawal from the oil reservoir, reaching the maximum values of annual oil production during the development period. The third stage starts when the oil recovery factor reaches 0.35–0.40 units and is associated with the increase in water flooding to 85–90% and shutting of unprofitable highly flooded wells. The gradual drop-off of the production level at the fourth and final stages continues during this period.
Figure 3. Dynamics of changes in accumulated water-oil factor (a); recovery rate (b); average daily liquid flow rate (c) for Dmul, Dard-vor formations and areas of Dpash formation depending on oil recovery factor: • Dard-vor; ▲ Dpash area 7; × Dpash area 8 + 18; ▫ Dpash area 32; ■ Dmul
4. Conclusion
1. The dynamics of water flooding of initially water-drive areas and deposits of Tuimazinskoye field, as well as a deposit that has a purely oil zone and became water-drive as a result of water flooding, was analyzed. It was found that the nature of the change in water flooding is identical.

2. During the production, the process of transition of the reservoir to the category of water-drive occurs due to the frontal displacement of the injected water and the rise of OWC. As a result, the nature of water flooding becomes similar to the primary water-drive zones of deposits.

3. It was shown that for water-drive areas, the production is characterized by unfavorably high input values of water flooding and its intensive growth in the interval of oil recovery factor from 0.1 to 0.3 fraction of units.

4. The nature of the displacement curves of the areas with OWZ is identical and differs only by the amount of oil reserves recovered by the beginning of water flooding in the reservoir or area, which allows concluding about a similar mechanism of oil displacement which typical of OWZ.

5. It was shown that the main feature characterizing the production of areas and deposits with water-oil zones is the increase in water flooding at the first stage of production.

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