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GEOLOGY

Possibility of the Development of a High-Viscous Oil Reservoir by Water Flooding

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Fields of oil with a viscosity of 150 cP or more are in the category of high-viscous oil (hereafter, HVO) fields. The corresponding oil resources are qualified as hard-to-recover. The modern theory and practice of the development of HVO fields is based on the application of various thermic methods of influencing the corresponding filtration processes [1]. Thermic methods are most important in the world among the known methods for increasing the oil recovery factor (ORF).

Several unique fields with HVO were discovered in Cenomanian rocks in West Siberia in the last century. The oil fields have not yet been put in commercial operation. Let us consider one of the fields N. The latest technological document (dated 2000) aimed at the realization of thermic methods of influencing the bed was not realized, owing to different complicating factors.

In world practice, water injection into HVO reservoirs is not considered an alternative that is worth attention. In this paper, we attempt to challenge this point of view.

We tested characteristic elements of the Cenomanian bed in the N petroleum field. In this work, we present the results of an investigation of an element of rock bed represented by a parallelepiped 200 m × 200 m × 132.8 m in size. The element was cut out from the roof to basement of the productive oil bed. The oil-saturated portion accounts for 86.6 m of the total thickness of 132.8 m, and the remaining 46.2 m corresponds to the aquifer.

The element of the bed consists of 13 layers with different filtration-capacity properties. The permeability coefficient of oil- and water-saturated layers changes along the lateral from 50 to 1045 mD. In the direction perpendicular to the bedding, the permeability coefficient varies from 10 to 244 mD. The porosity coefficient ranges from 0.2 to 0.32, and the thickness of the layers varies from 6 to 15.4 m.

The initial formation pressure and temperature are 87.5 bar and 19.5°C, respectively. The viscosity and density under formation conditions are equal to 180 cP and 902 kg/m^3, respectively, for oil, and 1 cP and 1016 kg/m^3, respectively, for water. Relative permeabilities for oil and water were specified from the condition that the residual water saturation is equal to 0.235 and the residual oil saturation in the oil–water system is 0.32.

In the producing wells, a permanent depression of 15 bar is maintained. Water is injected based on the condition of equal volumes of injected and recovered water and oil. Prognostic calculations are terminated at 95% water saturation of the recovered production or unprofitable oil yield equal to 1 t/day.

We searched for efficient technological solutions on the basis of numerical simulations. This means that the element was approximated by a grid of 13 × 13 × 13 elementary cells in a model with vertical producing wells and 15 × 15 × 13 elementary cells in a model with horizontal producing wells. In each of the experiments, the corresponding filtration problem was solved numerically in 3D two-phase (oil–water) formulation. We tested a total of more than 100 variants. It is not possible to describe all of them. Let us dwell on the most principal results.

The technology for developing the high-viscous oil reservoirs includes several characteristic elements. Let us analyze their essence and significance in the numerical variants with related indicators of exploitation.

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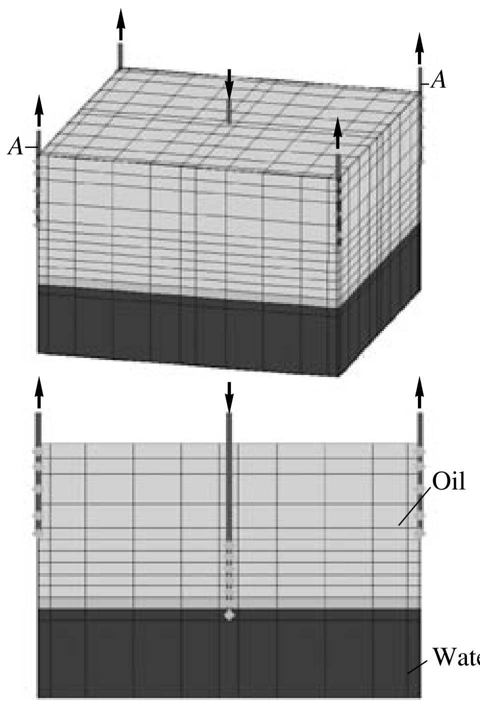

Fig. 1. 3-D image of A–A profile and grid approximation of the element of field development (Variant 2).

Variant 1 (the basic one) envisages the application of a five-spot areal water-injection system based on the vertical producing and injection wells. The system of development is similar to that shown in Fig. 1. Unlike Fig. 1, the producing wells open the oil-saturated zone 6 m above the water/oil contact (WOC). In the injection well, the bed is completed from the roof to 6 m below the WOC. The table presents results of calculations for this and subsequent variants. It is evident that the basic variant confirms low efficiency of the traditional water injection system, because it provides an ORF of only 0.1351.

Variant 2. Previous investigations related to the cycling process in gas-condensate pool demonstrated the following [2]. Vertical separation of the opening (perforation) intervals in the producing and injection wells notably enhances the sweep efficiency. Therefore, we tested the efficiency of such a mode of water injection into the element of an HVO field in variant 2. The corresponding development system is shown in Fig. 1. The table demonstrates a high efficiency of this method for the development of HVO pools. For example, the ORF increases from 0.1351 to 0.2602 relative to the basic variant. This is accompanied by a notable decrease in the water–oil factor (WOF) from 10.31 to 6.67.

Variant 3. Injection of polymer solutions, a method very often applied in the practice of development of layered heterogeneous beds, has made it possible to smooth out the water saturation profile in injection wells and increase the ORF by 10–15% [3].

In the traditional water saturation method, injection of polymer solutions influences the process of oil replacement along the lateral direction. In variant 3, we investigated the efficiency of the process of oil replacement by thickened water in the direction perpendicular to the bedding (Fig. 1). The viscosity of the working substance in this case is 20 cP.

As is evident from table, the ORF increases from 0.2602 to 0.3519; i.e., the increment is 35%. Injection of polymer-saturated (thickened) water leads to a further decrease in WOF from 6.67 to 0.34. This is a significant result, since even low-viscous oil fields are currently developed in our country under conditions of higher water saturation of the recovered product.

Comparison of the results in different variants of investigation

Variant	Duration of development, yr	Recovered amount of oil, kt	Recovered amount of water, kt	Water–oil factor	ORF	Final mean formation pressure, bar	ORF by the 20th year
Vertical wells							
1	45	63.32	652.75	10.31	0.1351	87.05	0.0697
2	175	121.95	813.08	6.67	0.2602	86.79	0.0374
3	246	164.91	55.48	0.34	0.3519	86.75	0.0359
4	219	173.08	86.64	0.50	0.3693	95.88	0.0367
Horizontal wells							
5	74	126.23	844.55	6.69	0.2693	84.8	0.0900
6	112	165.56	40.87	0.25	0.3532	84.5	0.0716
7	103	172.36	68.48	0.40	0.3678	90.42	0.0741
8	101	174.01	84.79	0.49	0.3713	91.49	0.0785
9	101	225.07	767.41	3.41	0.4802	108.83	0.1818
10	73	229.28	804.03	3.51	0.4892	100.37	0.3096

Variant 4. In this variant, we investigated the expediency of the development method based on overcompensation of oil tapping by the thickened water. In all other respects, this variant repeats the previous one. The overcompensation technique practiced in some oil fields of our country is currently considered a negative method [4]. However, this method probably deserves attention in the case of HVO fields, since it fosters oil output. According to the table, the overcompensation method reduces the period of oil field development by 37 yr relative to the previous variant. Moreover, despite the expectations, the ORF also slightly increases from 0.3519 to 0.3693.

The subsequent variants investigate the expediency of applying horizontal wells in the development of HVO fields.

Variant 5. In this variant, horizontal producing wells are located near the bed roof along the sides of the element, while the injection horizontal well is located along the diagonal over above the WOC. According to table, variant 5 has the following advantages relative to the comparable variant 2: (a) a significant reduction of the period of bed element development (from 175 to 74 yr); (b) a slight increase in ORF (from 0.2602 to 0.2693); and (c) increase of the ORF from 0.0374 to 0.09 by the 20th year, which is important from the point of view of the NPV criterion.

Variant 6. This variant differs from variant 5 in the following respect. Thickened water with a viscosity of 20 cP is injected into the bed. The table shows that this method of influencing the development process is well justified: the ORF increases from 0.2693 to 0.3532, and the WOF dramatically decreases from 6.09 to 0.25. However, these characteristics are reached at the expense of a nearly twofold increase in the development period from 74 to 112 yr.

Figure 2 shows an interesting trend: the dependence of ORF on the viscosity of the dense water. One can see that the influence of high viscosity on ORF slows down beyond 20 cP. This is important from the point of view of the expense of thickened water.

Variant 7. The objective of this variant, relative to the previous ones, is to consider the possibility of reduction of the development period with an overcompensation of production by solution injection. As in the case of vertical wells, this method has several advantages. The probability of the negative impact of human-fault fissuring is low in the case of Cenomanian rocks due to their significant permeability and low consolidation of reservoir rocks.

According to table, the development period decreases by 9 yr, and the ORF increases from 0.3532 to 0.3678.

Variant 8. In this variant, we studied the expediency of replacement of the horizontal injection well (as in variant 7) by a vertical well completed as in variant 2. As is evident from the table, the replacement is justified, and, moreover, variant 8 is cheaper than the horizontal variant.

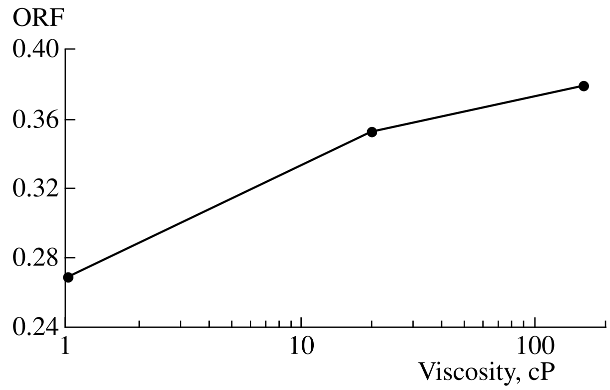

Fig. 2. ORF vs. viscosity of thickened water.

Variant 9. Similarly to the previous variant, variant 9 is based on the application of a vertical injection well. Here, the idea of two-stage drilling [5] is realized in the section rather than the productive area. Producing horizontal wells of the first drilling stage are located in the sixth layer. Drilling of lateral horizontal shafts from these wells near the roof of the bed is envisaged by the tenth year of exploitation. This variant surpasses all the previous ones with respect to many important parameters. The table shows that the ORF value is maximal (0.4802) and drops to 0.1818 by the 20th year of development, which is an important advantage of this variant (favorable impact on the NPV criterion).

Variant 10. If measures are taken to prevent sand production in the case of weakly consolidated reservoir rocks, it is possible to intensify the recovery of HVO. Therefore, in contrast to the previous approach, variant 10 is based on depression in producing wells equal to 30 bar. According to table, the ORF value is slightly higher in this case, but the WOF is stable. The development period decreases notably, and the ORF increases by the 20th year of the element exploitation.

The distinctive feature of the variants using polymer solutions consists in the admission of their continuous injection. Permanent increase of the oil price stimulates this kind of research. Polymer costs reduce in the case of injection of a polymer solution fringe.

Thus, the results of investigations testify to the possibility of enhancement of the development efficiency using the nontraditional method of water injection into HVO pools. Optimal volume of a polymer solution fringe is determined by technical and economic calculations.

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