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GEOLOGY

The Development of High-Viscous Oil Resources of Petroleum Fields

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Oil-and-gas (hereafter, petroleum) fields are in the category of hardly recoverable deposits. If the oil viscosity exceeds 150 cP, the difficulty of the development of such fields increases significantly. At present, there are practically no alternative for various thermic methods of impact on the bed simulation [1]. In this paper, we substantiate the possibility of developing petroleum fields with high-viscous oil (HVO) on the basis of simpler low-cost technologies.

The unique petroleum field in Cenomanian rocks of the Russkoe oil field is one of the most representative objects. Regardless of different approaches to the recovery of oil resources on the basis of thermic methods, the development of this field has not yet been started. In addition to the high viscosity of oil (approximately 180 cP), other factors also complicate the development of this field.

The presence of a permafrost section (up to 400 m thick) in this field is a serious challenge. This requires construction of expensive thermally isolated producing and injection wells in the case of realization of thermic methods for recovery. The oil field is located near the Polar Circle, in a region with a low level of infrastructure development. The productive bed is characterized by insufficient stability of the productive reservoir and other features. In such conditions, the further orientation on expensive and technically complex development technology is apparently unjustified.

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

We carried out investigations using the characteristic elements of the Cenomanian bed in the Russkoe oil field. In this work, we present the results of investigations for an element of the bed represented by a parallelepiped 200 m × 200 m × 172.8 m in size. The element was spread from the upper to the lower boundary of the productive oil bed. The oil-saturated portion accounts for 86.6 m of the total thickness of 172.8 m, and the rest (46.2 m) corresponds to aquifer.

The element of the bed consists of 17 layers with different flow-capacity properties. The permeability of oil- and water-saturated layers changes along the lateral from 50 mD to 1045 mD. In the direction perpendicular to the bedding, the permeability varies from 10 to 244 mD. The porosity 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 85.85 bar and 19.5°C, respectively. Under the formation conditions, the viscosity and density are equal to 0.01334 cP and 73.14 kg/m^3, respectively, for gas; 180 cP and 902 kg/m^3, respectively, for oil; and 1 cP and 1016 kg/m^3, respectively, for formation water. Relative permeabilities for gas, oil, and water were specified from the following conditions: residual gas 0.15; residual water saturation 0.235; residual oil saturation in the oil–water 0.32; and residual oil saturation in the oil–gas system with residual water 0.15.

In the producing wells, a permanent pressure drawdown of 15 bar is maintained. Water is injected on the condition of equal volumes of injected and recovered water and oil. Forecasting calculations are completed at 95% water cut the recovered production, an unprofitable oil yield equal to 1 t/day, or a gas factor equal to 5000 m^3/day.

We searched for effective technological solutions on the basis of numerical simulations. This means that the element was approximated by a grid of 13 × 13 × 17 grid cells. In each of the experiments, the corresponding filtration problem was solved numerically in 3D three-phase (gas–oil–water) statement. We tested a total of more than 40 variants. It is not possible to describe all of them. Therefore, let us only dwell on the most significant results.

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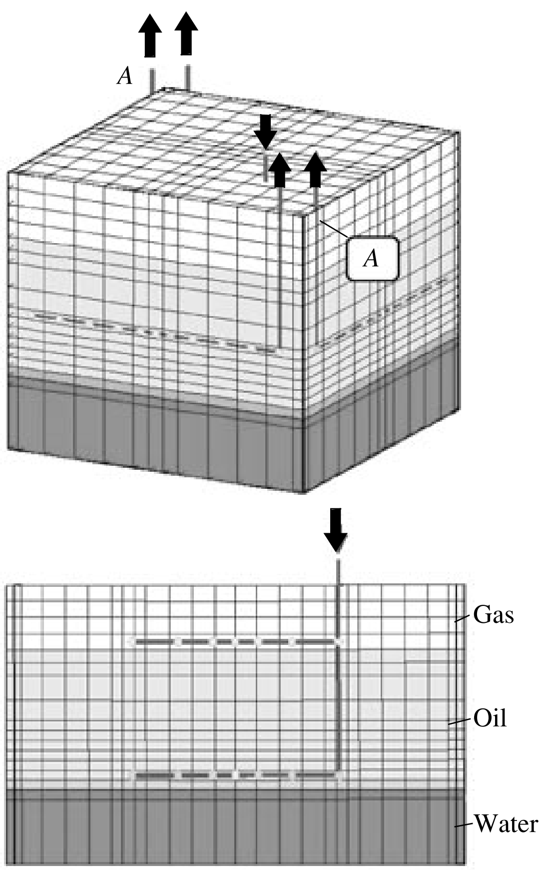
Comparison of the results in different variants of investigation

Variant	Duration of development, yr	Recovered amount of oil, kt	Recovered amount of water, kt	Water–oil factor	Oil recovery factor (ORF)	Final mean formation pressure, bar	ORF by the 20th year
1	127	48.77	442.19	9.07	0.1041	85.65	0.0224
2	33	61.59	463.42	7.52	0.1314	85.75	0.0910
3	103	109.79	771.93	7.03	0.2343	84.38	0.0565
4	172	174.41	155.07	0.89	0.3721	86.87	0.0664
5	120	217.24	597.33	2.75	0.4635	91.13	0.1547
6	93	203.62	828.65	4.07	0.4345	92.16	0.1833
7	95	195.87	783.08	4.00	0.4179	84.50	0.2350

It will be shown later that the traditional technology of developing a productive bed with water flooding has no perspectives for the Russkoe petroleum field. However, introduction of different know-how into this technology makes it effective and attractive owing to its transformation into the technology of nontraditional alternative water flooding.

The technology for developing the HVO reservoirs includes several characteristic features. Let us analyze their essence and importance in the numerical variants with respect to the whole development strategy of HVO reserves.



3D image of profile A–A and grid approximation of the element of field development (variant 3).

Variant 1, or the basic model. The authors of [2] substantiated the effective technology for oil recovery on the basis of water flooding and exploitation of producing wells at the critical gas rate applied to oil rim with low-viscous oil. Therefore, we examine this approach to the development of oil rim of HVO. In the development element examined, the horizontal producing and injection wells are parallel to each other. They are located in the 5th grid layer from the water/oil contact (WOC). The results of calculation for this and subsequent variants are given in the table.

It is evident that the traditional development method has low efficiency. First of all, this is related to the oil recovery factor (ORF). The final ORF value is only 0.1041.

Variant 2. The efficiency of the vertical spacing of the bottomholes between producing and injection wells as applied to cycling process in a massive gas-condensate reservoir is shown in [3]. This notably enhances the sweep efficiency in the case of heterogeneous layered formation, e.g., the productive bed in the Cenomanian pool. Thus, unlike in variant 1, the sector element in variant 2 is distinguished by the location of the horizontal injection well above the WOC. Horizontal producers are located along the four sides of the element, as in Fig. 1.

The table shows that this method of overcoming of the negative factor (stratal nonuniformity) enhances the ORF value from 0.1041 to 0.1314 (or by 26%). However, such an increment of the ORF still does not make the water flooding technology attractive.

Variant 3. Application of barrier water flooding is efficient in the boundary oil rims [4]. In the case of the oil rim with bottom water, no specialists in the world were oriented to such a possibility of separation from the gas cap. Nevertheless, in contrast to variant 2, variant 3 is supplemented with a horizontal injection well above the gas–oil contact (GOC). The figure shows a schematic system of development.

Data in the table testify to the efficiency of such approach, because the ORF increases almost twice, from 0.1314 to 0.2343. Moreover, the water–oil factor (WOF) decreases from 9.07 in the basic variant to 7.03 in variant 3. The progress is explained by low differences between the oil–water densities and phase permeabilities. Moreover, the stratal nonuniformity of reservoir properties facilitated the vertical displacement of oil.

Variant 4. Application of polymer solutions has been rather efficient for the lateral replacement of oil by water. They make it possible to smooth out the water injectivity profile and increase the ORF by 10–15% [5]. In addition to the conditions accepted in variant 3, variant 4 simulates the continuous injection of polymer-saturated (thickened) water with a viscosity of 20 cP.

According to the table, variant 4 provides a further increase in the ORF from 0.2343 to 0.3721 (by 59%). This testifies to a high efficiency of the use of polymers for vertical oil displacement.

Variant 5. Measures preventing sand production make it possible to increase pressure drawdown in producing wells. In variant 5, unlike other variants, drawdown is specified at 30 bar. In addition, overcompensation of production by solution injection is accepted here.

According to the table, variant 5 has the following advantages: the ORF value is maximal (0.4635); the current ORF by the 20th year is equal to 0.1547, which would have a positive investment impact for the studied type of oil fields; and the development period decreases by 52 yr.

Let us note the following comment concerning the unpopular overcompensation of production by solution injection. In the Cenomanian petroleum fields, the risk of technogenic fracturing due to overcompensation is absent, because the rocks are highly permeable and weakly cemented.

Variant 6. In this variant, we consider a possibility of using one vertical injection well instead of two horizontal ones, with simultaneous competing intervals above the GOC and near the WOC.

From the point of view of the ORF, this variant is slightly inferior to variant 5. However, this variant makes it possible to reduce the development period by 27 yr and increase the ORF value by the 20th year from 0.1547 to 0.1833.

Variant 7. In addition to the conditions specified in variant 6, variant 7 estimates the efficiency of two-stage (infill) drilling. At the first stage, the producing horizontal wells are located in the seventh layer. At the second stage (the 10th year of the element exploitation), additional lateral horizontal wells are drilled in the third layer. Here, the numbers of layers are counted from top to bottom relative to the GOC.

Intensification of the HVO recovery in variant 7 has a positive impact. By the 20th year, the ORF value increases to 0.2350. This is very important from the point of view of the recoupment of capital investment. However, the final ORF slightly decreases in this scenario.

Of course, subsequent technicoeconomic calculations will be crucial in all variants considered in this paper, particularly in the case of the polymer rim volume. The objective of this work was to substantiate an alternative approach for the development of HVO resources in petroleum fields based on the proposed nontraditional approach to water flooding.

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