ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 407A, No. 3, pp. 385–387. © Pleiades Publishing, Inc., 2006.
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GEOLOGY

Influence of Technological Factors on Oil Recovery from Oil Rims

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Presented by Academician A.N. Dmitrievskii July 7, 2005

Received July 20, 2005

DOI: 10.1134/S1028334X06030093

Russia's oil resources that open onto oil rims make up approximately one-third of the total reserves. They are characterized as hardly recoverable deposits. The coefficient of oil recovery (COR) is an integral indicator of the efficiency of oil recovery from a productive bed. The COR in oil rims is usually characterized by low values (20% or less). A significant number of researches dedicated to the systems of oil rim development and methods of increasing the efficiency of oil recovery from the rims has been performed in Russia and abroad. One of the latest overviews is presented in [1]. Problems related to oil rims can be divided into two groups: a system of influencing the bed as a whole and technology of exploitation of producing and injection wells. In our work, we focus the majority of attention on the second group of problems.

The term oil rim usually refers to an oil-saturated layer with a thickness of less or more than 10 m. After the introduction of horizontal wells into practice, undoubted preference is given to producing wells. Injection wells can be either vertical or horizontal [2]. Our investigations are based precisely on these types of wells. The dependence of COR in an oil rim on the density of the well grid is obvious [3]. Therefore, this factor is not discussed here.

The dependence of indicators of oil recovery on the following technological factors is of theoretical and practical interest: (1) mutual disposition of producing and injection wells; (2) type and parameters of the injection well; (3) hydrofracturing of the bed (HFB) in producing and/or injection wells; (4) intervals of influence of a working substance on the oil rim; and (5) technological exploitation regimes of producing and injection wells.

We chose the following indicators as the most important: the COR; initial oil yield, q_{ioy}; water–oil factor (WOF); coefficient of gas recovery, (CGR); and relative development period (RDP) over 50 yr. All these indicators directly influence the economic parameters of oil rim development.

The element of an oil-and-gas field with a size of $380 \times 400 \times 45$ m is considered as the object of investigation. The thickness of each of the gas-, oil-, and water-elements is equal to 15 m.

This development element was investigated in the isotropic (in terms of permeability) variant within the productive area. The lateral permeability is 100 mD. It is assumed that permeability along the *OZ* axis is 10 mD. Two types of anisotropic bed were investigated. In the first case, permeability is 50 mD along the *OX* axis, 200 mD along the *OY* axis, and 10 mD along the *OZ* axis. In the second case, permeability along axes *OX*, *OY,* and *OZ* is 200, 50, and 10 mD, respectively.

The coefficients of porosity and gas- and oil saturation are 0.12, 0.90, and 0.70, respectively. The initial formation pressure and bed temperature are 450 kg/m^2 and 97°C, respectively. The viscosity and density of oil, gas, and water in the formation conditions are 0.27, 0.035, and 0.55 cP, 650, 322, and 1190 kg/m^2, respectively. The gas content is 500 m^3/t. The volume coefficient of oil is 1.4. The relative phase permeability for oil, gas, and water was specified at 30% based on threshold water saturation and at 15% and 20%, respectively, based on residual gas- and oil saturation.

The 3D element of the oil-and-gas field was approximated by a grid with $19 \times 10 \times 18$ elementary cells. The average lateral size of the cells was 20×20 m; the vertical size, 2.5 m. Modeling of wells and HFB with the corresponding local decrease of the mesh size to 1 cm was performed for a more adequate account of the real filtration processes. In the modeling of HFB cracks, the permeability of their filler was assumed equal to 10 mD.

The forecast of development indicators was continued up to the satisfaction of one of the following limi-

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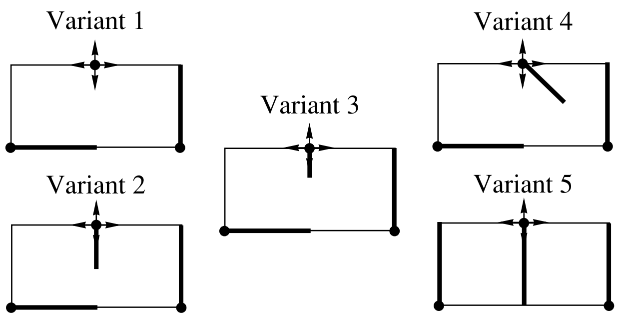

Fig. 1. Types and locations of injection wells.

tations: 98% water flooding of production and a minimal permissible oil yield of the well of 1 m^3/day.

A total of 642 variants were investigated. The corresponding gas-hydrodynamic calculations were performed in a 3D three phase (gas–oil–water) formulation. The theory and practice of the development of oil rims with gas-underlying and water-overlying zones indicate that application of areal grid systems of wells is preferential.

A schematic plan view of the investigated producing and injection wells is shown in Fig. 1. Since the scheme is symmetric, the figure shows only half of the area of the development element. This means that injection wells of different types are optionally located in the center of the element. In the case of horizontal injection wells, their length and layout are varied. Producing horizontal wells are located at the edges of the development element.

Figure 2 shows a 3D scheme of one-half of the development system with one grid of wells. According to the results of previous investigations, the horizontal producing wells were located 3.75 m above the water–oil contact. The intervals of working-substance injection varied from oil-saturated to gas-saturated zones of the bed in the case of maintaining the formation pressure by water injection. If gas was considered as the working substance, the latter was injected into the gas cap.

The possibility of other technological factors seems obvious. We should mention only the technological regimes of exploitation of the producing and injection wells. The variants, in which depression in the producing and repression in the injection wells were the same and equal to 1 bar, were investigated. In the further investigations, this indicator was assumed equal to 2, 3, and up to 20 bar.

Let us illustrate the results of calculations on the example of one series of variants. They are related to the case, when variants are ranked relative to the COR value in the function of depression/repression in the bed. As this takes place, pressure is maintained by means of flooding and the injection well is positioned according to variant 5 (Fig. 1). In this model, the bed is anisotropic ($k_x = 50$ mD, $k_y = 200$ mD, and $k_z = 10$ mD).

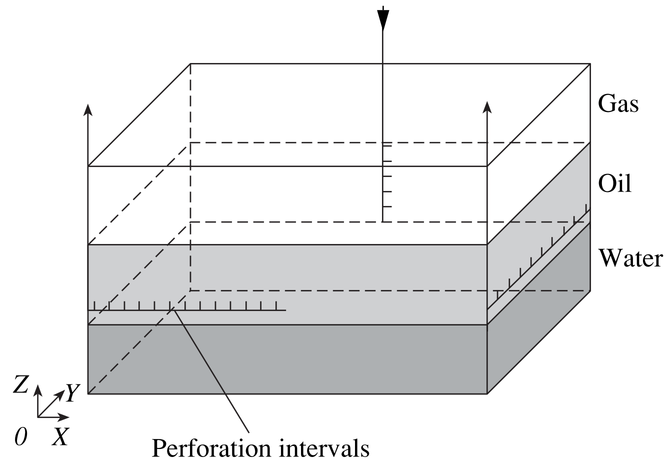

Fig. 2. 3D scheme of the development system for the oil rim element in variant 1.

Consideration of the results shown in Fig. 3 demonstrates the following.

The technological regime of the exploitation of wells is an important factor influencing all indicators of oil production both in the positive and negative aspects.

For example, increasing depression and repression in the bed from 1 to 20 bar increases the initial oil yield of the wells from 25 to 70 m^3/day. From the point of view of utilization of the Earth's interior, this fact is characterized as positive. The high yield significantly decreases the period of oil field development (to be more exact, the period of profitable oil production). Intensification of oil recovery is characterized by a decrease in the COR, i.e., by a decrease in the efficiency of the oil rim development from 0.573 in variant 1 to 0.411 in variant 5. An increase in the depression and repression in the bed from 1 to 20 bar leads to an increase in the water–oil factor from 5 to 10. This means that production of 1 m^3 of oil would require extraction of only 5 m^3 of water in variant 1, as opposed to 10 m^3 in variant 5.

An increase in both CGR and COR values in the case of gas and gas-condensate fields is an urgent problem. However, it is known that the increase in the CGR plays a negative role during oil production in the development of petroleum fields. From this point of view, an increase in the CGR during intensification of the influence on the bed is considered a negative consequence.

Let us formulate the generalizing conclusions based on the mathematical simulations performed.

1. The above-mentioned influence of the technological regime for development of producing and injection wells also remains valid for all other series of computational variants. Today, such a conclusion becomes even

more pressing in connection with the universal drive of subsoil users to intensify oil recovery processes.

2. The maximal COR reaches 0.568 in an isotropic stratum and 0.545 in an anisotropic stratum if the stratum pressure is maintained by injecting water into the oil rim. The COR increases to 0.573 if HFB is applied to an anisotropic bed. If water is injected into the gas cap, the technological regime of the operation of wells has a smaller influence on the indicators of development, and different variants do not differ strongly. If this method of water injection is applied, the COR reaches a maximum value of 0.567 in an isotropic bed and 0.560 in an anisotropic bed. If the HFB is applied in an anisotropic bed and water is injected into the gas cap, the COR increases to 0.568.

3. Anisotropy of permeability along axes *OX* and *OY* has a notable influence on the indicators of the development of wells. The best variant is the one with the location of wells normal to the direction of the maximal permeability along the lateral. In this case, all wells are characterized by horizontal shafts and parallel location to each other as in variant 5 in Fig. 1.

4. The best indicators of development are obtained in the variants with injection of water into the gas cap and oil-saturated interval. Injection of water into the oil-saturated part of the bed leads to partial destruction of the oil rim and hence to lower coefficients of oil recovery.

5. Relative to variants with the injection of dry gas, variants with the injection of fat gas show better indicators of oil recovery, because the fat gas has better displacement properties.

6. The HFB enhances the efficiency of vertical and horizontal injection wells by four and two times, respectively. Variation in the COR of a producing well is insignificant whether or not HFB is applied.

7. The considerations presented here are not absolute. They point to the necessity of various preliminary investigations with the elements of oil field development. Prognostic calculations with a 3D large-scale model of the field is possible only after such research.

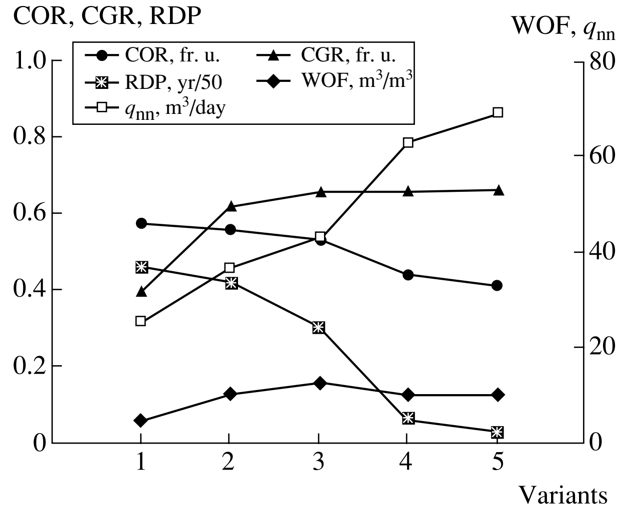

Fig. 3. Technological indicators of the development of oil rim element in the variants considered here.

ACKNOWLEDGMENTS

The authors thank Academician A.N. Dmitrievskii and E.S Zakirov for fruitful discussion of the work.

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