Patterns of recovery and injection wells in deposits of high-viscosity oil with reservoir decompression zones

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Abstract. The issue of patterns of injection and recovery wells in zones of non-uniform permeability reservoirs is discussed by many researchers. The researchers aim to identify the influence of well patterns in reservoir zones with different permeability on the efficiency of oil recovery. This issue is particularly acute for systems maintaining reservoir pressure. The location of injection wells in low-permeable zones, and recovery wells - in high-permeability zones helps increase the coverage of the impact. Moreover, even in the conditions of a partially developed reservoir, transformation of the existing development system has significant potencies for increasing the ORC. One more crucial problem is the study of the effect of extensive highly permeable inclusions (faults, zones of reservoir loosening) on the effectiveness of regular development systems.

1. Introduction
Let us consider a model problem of the development of a high-viscosity oil deposit with a reservoir characterizing by homogenous permeability. The deposit contains a linear fracture intersecting the reservoir (figure 1) [2]. The simulated area of the deposit has dimensions of 1000x1000x20 m. Let us assume tectonic processes vertically shifted parts of the deposit relative to each other preserving hydrodynamic coherence. The fault line is a region of reservoir decompression with increased porosity and permeability exceeding permeability of the parent rock [3–5].

An in-line development system was implemented at the site with a maximum distance of 1000 m between the rows of wells (depending on the option under study).

Reservoir porosity is 0.21 U. In the main part, reservoir permeability is 0.2 μm², in the zones of decompression, it is 10 μm². Formation depth is 1000 m, average effective thickness is 10 m. Initial reservoir pressure is 8 MPa.
2. Methods and materials
The results are justified by the use of hydrodynamic simulators tested and recommended for use in the oil industry. For the field data processing, well-known and approved PC-based methods were used. The recommendations were field tested with a positive technological effect [6–8].

3. Results and discussion
Let us analyze how the extended zones of reservoir decompression affect the efficiency of the current development system. Several injection and recovery well pattern options were studied [9, 10].

In the first option (basic option), the rows of wells are parallel to the fault line. The distance between the rows of wells is 1000 m. The fault passes between the rows of wells. At the same time, the row of injection wells is located in the lower part of the reservoir, the row of recovery wells is located in the upper part.

In the second variant, the conditions of the first option are preserved except for the fact that the injection wells are located in the upper part of the reservoir, and the recovery wells are located in the lower part.

The third option involves location of rows of wells perpendicular to the fault line.

The fourth option differs from the previous one in the number of recovery wells. There are two rows of recovery wells in the reservoir area, one of which is located as in the first option, the second row is located in the fault zone.

The fifth option has the same pattern of rows of wells as the fourth option, however, the row of injection wells is located in the fault zone, and the row of recovery wells is located along the edges of the section under study.

In the sixth option, the rows of wells are located similar to the location in the fifth option. However, recovery wells are located in the fault zone, and two rows of injection wells are located along the edges of the section under study.

Other initial technological conditions of the wells in all the options are similar.

Analysis of current oil saturation cubes (maximum water cut of 95 %) shows that the bedside area of the reservoir is characterized by a minimum degree of oil reserves which is consistent with the known provisions on the gravitational phase separation in formation conditions. The presence of a fault significantly affects the flooding process. In some cases, relative position of the fault and the rows of
wells contributes to development of oil reserves; in other cases the presence of a fault reduces efficiency of the development system.

Let us compare the dynamics of the current technological indicators of the options (figure 2).

![Figure 2. Dynamics of technological indicators of model reservoir development for different well row pattern options relative to the fracture: a - oil flow rate, b - water cut fraction](image)

The comparison of the dynamics of the current technological indicators of the first (basic) and second options shows that location of injection wells in the upper part of the reservoir divided by the conductive fault is not optimal due to the fact that in the injection zone only the subsurface zone of the reservoir is flooded. Therefore, in the second option, oil flow rates are lower, and water cut growth is slower which results in a longer development period. The comparison of the first and third options shows that orientation of the rows of wells perpendicular to the fault lines increases a water cut coefficient, while the oil flow rate is smaller than in the the basic option.

The comparison of the first and fourth options shows that an increase in the number of recovery wells does not improve efficiency of oil reserves. In the fourth option, an additional row of three recovery wells was located in the fault zone. Since this zone is highly productive, in the initial period of development, oil uptake was high. However, this led to the screening of the impact of injection wells on the remote row of recovery wells. In the reservoir zone between the two rows of recovery wells, a sharp decrease in reservoir pressure, a decrease in pressure below oil saturation pressure of gas and...
degasification of this section were observed. After the water cut of recovery wells reached its maximum, this row of wells is turned off, the reservoir pressure begins to recover, but the flow rate remains below the baseline values.

The comparison of the first and fifth options shows that this option is characterized by higher efficiency. High permeability of the area of the decompressed reservoir allows for pumping large volumes of water, and the fracture zone acts as an extended drainage which allows water to be more evenly injected into the main reservoir.

The comparison of the first and sixth options shows that creation of an intensive water-flooding system with a small number of recovery wells located in the fault zone helps achieve maximum indicators of oil reserves in the shortest development period.

The comparison of the results shows that the sixth option has the greatest efficiency. This option is characterized by the highest ORC value and the maximum uptake rate. If an increase in the ORC relative to the basic one is only 0.004 gf, the rate of oil extraction is almost twice as high as the basic one. In addition, the volume of accumulated water uptake has a minimum value.

The fifth option is characterized by a high uptake rate and a lower ORC compared with the basic one. Therefore, this location of wells can be used only for intensifying reserves uptake, while the efficiency of production will be low. This result is in good agreement with the results of [2].

Table 1. Rates of oil recovery for development options.

| Option | Orientation of well rows relative to the fault line | Accumulated uptake, thousand m$^3$ | CIN, u.f. | Water cut, u.f. | Change in CIN relative to the base option, u.f. | Oil recovery rate, thousand m$^3$ (month * well) |
|--------|---------------------------------------------------|-----------------------------------|-----------|----------------|-----------------------------------------------|-----------------------------------------------|
| 1      | 2 parallel well rows, the injection well is located in the lower part, the recovery well row is located in the upper part | 275.5 | 1449.7 | 0.306 | 0.836 | 0.000 | 0.030 |
| 2      | 2 parallel well rows, the injection well row is located in the upper part, the recovery well row is located in the lower part | 264.7 | 1449.7 | 0.294 | 0.846 | –0.012 | 0.020 |
| 3      | Well rows are located perpendicularly | 257.1 | 1543.3 | 0.286 | 0.857 | –0.020 | 0.026 |
| 4      | 3 parallel well rows, the recovery well row is located in the upper part, the injection well row is located in the fault | 225.9 | 962.5 | 0.251 | 0.810 | –0.055 | 0.020 |
| 5      | 3 parallel well rows, 2 recovery well rows are located at the edges, the injection well row is located in the fault | 260.9 | 1255.9 | 0.290 | 0.828 | –0.016 | 0.046 |
| 6      | 3 parallel well rows, 2 injection well rows are located along the edges, recovery well rows are located in the fault | 279.2 | 1061.1 | 0.310 | 0.792 | 0.004 | 0.057 |
The table presents final calculation results. To compare the rates of oil recovery for development options with different numbers of wells, a relative parameter equal to the ratio of accumulated oil uptake to the number of months worked and the number of all wells was introduced.

4. Conclusion
The well rows have to be located parallel to the fault line in the reservoirs of high-viscosity oil. The most effective pattern is location of recovery wells in the zone of reservoir decompression, and injection wells - outside the zone of decompression. This option has the highest rates of oil recovery and the highest ORC value. Comparing the extrusion characteristics of the options, it can be emphasized that the sixth option has a smaller value (compared to the first option) of oil recovery for the dry period (lower ORC with a zero water cut coefficient). However, in the water development period it has the highest ORC value with an increasing water cut coefficient.

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