Improvement of the efficiency of horizontal wells

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Abstract. The research purpose is to identify factors of premature flooding of wells, assess the influence of factors, simulate and compare results obtained with field data. An analysis of the reservoir properties, design and development indicators of horizontal wells showed that only 41% of cases of premature flooding are due to geological causes (heterogeneity of rock permeability). Technological reasons (high specific samplings) occur in 36% of cases, this problem is pronounced in wells where new technologies were implemented – division of the wellbore into sections using water and oil swell packers. In 23% of cases, premature flooding is due to wellbore drilling in the water-saturated zone.

1. Introduction
The accumulated experience of operation of horizontal wells has proven the effectiveness of vertical wells. In some cases, the development of individual fields or their individual sections by horizontal wells is the only possible way. In addition, the role of horizontal wells increases when developing hard-to-recover reserves, including from unconventional reservoirs. In addition to the indisputable advantages, horizontal wells have a number of problems whose solution can improve the efficiency of field development and increase the oil recovery coefficient. One of the key problems is the premature flooding which decreases the technological and economic efficiency of the well.

2. Materials and methods
The fluid inflow to the wellbore, regardless of its design, is proportional to fluid mobility (k/μ), filtration area (S), and formation depression (ΔP). The heterogeneity of any of these parameters leads to heterogeneity of the inflow. Advance production of individual intervals of the reservoir leads to an uneven rise in the oil-water contact, formation of watering cones and premature flooding of the well. Thus, to determine causes of flooding, it is necessary to determine the effect of fluid mobility (k/μ), a filtration area (S) and formation depression (ΔP) on the efficiency of horizontal wells.
3. Results and discussion

**Influence of inflow heterogeneity on the efficiency of horizontal wells:**

- **fluid mobility**

  The fluid mobility parameter \( k/\mu \) represents the ratio of rock permeability to fluid viscosity. Variability of permeability of reservoir rocks along the wellbore is the most common cause of heterogeneity of inflow during the development of traditional oil reserves.

  From the intervals with the highest permeability, fluid sampling is more intensive (Figure 1, A), which leads to flooding of these wells. Viscosity of the fluid mixture decreases, which leads to an increase in its mobility and heterogeneity of the inflow. After a water breakthrough, the productivity of the local inflow interval can fully ensure the depression and block the intervals of oil inflow (Figure 1, B).

  In case of development of unconventional reserves, such as super-viscous oil (UHV), the second component of fluid mobility - its viscosity - comes first. Since the viscosity of oil depends on temperature, during the development of the SHF by the method of steam gravity drainage (PGD), heterogeneity of the inflow can be caused by uneven distribution of the coolant along the horizontal trunk.

![Figure 1. The schematic profile of the inflow along the horizontal wellbore with productive intervals of different permeabilities (before and after the water breakthrough)](image)

- **Filtration area**

  The filtration area is characterized by the length of the production interval - perforated formation thickness \( h \) for vertical wells or the length of the production interval \( l \) for horizontal wells. The unevenness of the inflow can be caused by the design of the well in case of sampling of productive intervals by packers or the use of filters.

  Thus, wells with different lengths of operating intervals (equal fluid flow rates, horizontal wellbore lengths, the same FES) will differ in inflow uniformity. When the entire trunk is operating (Figure 2, A), uniform drainage of stocks occurs. In case of individual intervals (Figure 2, B), leading production and premature flooding occur.
• *Reservoir depression*  
  Reservoir depression (ΔP). Heterogeneity of depression along the horizontal wellbore can be caused either by the opening of hydrodynamically unrelated formations with different levels of reservoir pressure, or by a change in the bottomhole pressure along the wellbore due to the heel-toe effect, which consists in the loss of friction pressure from the heel to the toe of the well and manifested as significant lengths of horizontal boreholes and high flow rates (Figure 3).

*The mechanism of influence of inflow heterogeneity on the efficiency of horizontal wells*

To determine the mechanism of influence of heterogeneity of the inflow on the efficiency of horizontal wells, the methods of numerical simulation were used. Heterogeneity of the inflow was described by two parameters: the ratio of the total length of working intervals and the total length of the horizontal wellbore, which characterizes the degree of involvement of reserves in the development or coverage of the formation by drainage. The ratio is calculated by formula:

\[ l^* = \frac{\sum_{i=1}^{n} l_i}{L} \times 100, \]  

where \( l^* \) – share of working intervals, %; \( l_i \) – working interval length, m; \( L \) – total length of the drilled horizontal shaft.

![Figure 2. The schematic inflow profile along the horizontal wellbore with idle intervals](image)

![Figure 3. Estimated inflow profile along the horizontal wellbore of high extent with heel-toe effects](image)
Specific fluid samplings along the horizontal wellbore are an indicator of the load on a reservoir section exposed by the horizontal wellbore. The physical meaning of the influence of this parameter on well operation can be described using the following example. The total well production rate of about 100 m$^3$/day can be ensured both by the interval of the productive formation 100 m long and by the interval of 10 m. In the first case, products from one part of the formation will be selected with specific samplings of 1 m$^3$/day · m, and in the second case - 10 m$^3$/day. Higher selection rates will lead to premature flooding.

Specific samplings are calculated by formula:

$$q_i^{sp} = F_i \frac{Q}{l_i},$$

where $q_i^{sp}$ – specific selection of the interval, m$^3$/day · m; $Q$ – total well production, m$^3$ / day; $l_i$ – interval length, m; $F_i$ – share of withdrawals from a single interval in the total well flow rate, % (based on the value of permeability of the interval).

The mathematical model was based on the following principles:
- the length of the horizontal wellbore is divided into intervals in terms of absolute permeability;
- each interval corresponds to the volume of drained reserves, determined during empirical modeling;
- the total fluid flow rate is equal to the sum of specific samplings for each interval;
- the share of samplings of each interval is calculated based on its length, phase permeability and depression;
- the water cut of each interval is a function of the initial oil and water saturation, phase permeability and accumulated oil and water samplings from this interval;
- the water cut is calculated as the weighted average water cut of the intervals according to the amount of samplings.

The model was adapted according to actual data on the operation of horizontal wells No. XXXX, YYYY, ZZZZ.

The analysis of geological data, as well as the results of geophysical and hydrodynamic studies showed that reservoir layers of the beaver horizon of the field have high permeability to ensure high productivity of all intervals of the horizontal wellbore.

The specific fluid samplings depend on the permeability of this section. Given this fact, as well as the design of the well, the distributions of specific samplings for wellbore No. XXXX, YYYY, ZZZZ were built. (figures 4, 6, 8). The simulation result is the calculated dynamics of the water cut of the wells presented in Figures 5, 7, 9.

**Well No XXXX**

With a fluid flow rate of about 50 m$^3$/day and a total length of working intervals of 40 m, the average specific fluid samplings were 1.25 m$^3$/day for one meter of the filter portion of the shank (Figure 4).
Figure 4. Distribution of specific samplings for well No. XXXX

Such a load on production intervals led to an early breakthrough of water in almost all intervals and complete watering of the well in the first year of operation (Figure 5).

Figure 5. Actual and estimated dynamics of water cut in well No.XXXX

Well No YYYYY
With a fluid flow rate of about 45 m$^3$/day and a total length of working intervals of about 115 m, the average specific fluid samplings were 0.39 m$^3$/day for one meter of the filter portion of the shank (Figure 6).
Figure 6. Distribution of specific samplings along well No. YYYY

For these geological conditions, such rates of sampling were the result of high rates of well watering (60% per year). A breakthrough of water occurred in individual highly permeable intervals of the horizontal trunk (Figure 7).

Figure 7. Actual and estimated dynamics of water cut in well No. YYYY

Well No ZZZZ

For well No. ZZZZ with a total fluid flow rate of about 40 m³ / day and a total length of working intervals of about 190 m, the average specific fluid samplings were 0.21 m³ / day for one meter of the filter portion of the liner (Figure 8).
According to the actual data on the water cut and simulation results (Figure 9), the current value of specific samplings allows maintaining the rate of water cut at 10-12% per year.

4. Conclusion

Thus, there is a direct relationship between the specific rates of sampling and the rate of watering. Obviously, the nature of this dependence is different for different fields depending on geological and technological characteristics. Thus, the reason for the flooding of horizontal wells XXXX and YYYY is high specific rates of sampling under the incomplete involvement of the reservoir.

The calculations showed that a similar pattern is observed in wells developing formations with a high degree of heterogeneity of reservoir properties. The rate of irrigation of products is a multiple of the specific rate of selection at the most permeable intervals. This reaffirms that another reason for
premature flooding of the SGA products is the advance sampling of reserves at the most permeable intervals due to the uneven flow of fluid along the horizontal wellbore.

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