EVALUATION OF THE WAVE EFFECT EFFECTIVENESS IN CARBONATE RESERVOIRS WITH HIGH VISCOSITY OIL

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Development of fracture-porous reservoirs can be followed by breakthroughs of water injected into reservoirs through the system of cracks to production wells. This process can reduce the coverage of reservoir by sweeping, which will ultimately lead to a decrease in oil recovery factor. In order to perform a more effective fracture-porous reservoir flooding it is possible to use various methods associated with the injection of gel and sediment-forming agents, the use of wave technologies etc. The paper considers the formation with high-viscosity oil and fracture-porous reservoir. It is observed that water cut increase faster than oil recovery. The authors of the paper propose to use the wave effect associated with the stops of both injection and production wells. Shut-off and shut-in time of each well should be selected based on the parameters of the bottomhole zone. The specific value of the end time of the interaction of blocks and fractures when the pressure changes at the points of the reservoir can be roughly estimated from the beginning of the straight section of the pressure build-up curve in the fracture-porous reservoir. For the selected formation reservoir time of the end of the interaction between fractures and blocks with pressure changes was determined. Various options for implementation were proposed. Process impact modelling was performed using the Tempest More software package. According to the results of the simulation, it can be noted that the wave phenomenon is effective in terms of water cut reduction. Nevertheless, there are losses in oil production with long periods of shut-off of the wells. It should be noted that the time of interaction between fractures and blocks substantially depends on the permeability of the bottomhole zone; the higher the permeability the lower the time. It was also found that a variable frequency wave results in a greater effect.

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Introduction

In the situations involving high number of sand beds, significant variations in stringers’ permeability and presence of a fracture network, the water injected into the formations may burst through certain stringers or a fracture system to the producing wells \[1, 2\]. This process may limit the formation coverage by the development system, ultimately reducing oil recovery ratio \[3-5\]. Such deposit characteristics are most often encountered in carbonate reservoirs. In order to cover the formation with the stimulation, it is possible to use various methods related to the injection of gelling and sediment-forming agents \[6-13\], application of wave technologies \[14-19, etc.] Wave stimulation of the deposits may be achieved with the following methods \[20-23\]:

1) Cyclical flooding by significant change of the water injection rates (reduction or termination of injection) for a certain period of time with further renewal;

2) Change of filtration flows’ direction by redistribution of water injection and fluid drainage across different deposit areas;

3) Focal flooding by additional water injection in the areas with a weak response to the previously deployed flooding system;

4) Forced fluid withdrawal from wells or groups of wells in highly flooded deposit areas, etc.

The above methods are usually used when oil production from a deposit starts declining. A good effect from hydrodynamic stimulation methods is achieved in carbonate reservoirs \[20\] because they are mainly represented by fractured-porous reservoirs. More than a half of oil produced in Perm region is found in carbonate reservoirs \[24\].

There are various methods for determining the optimal time of injection and well shutdown to create a wave of pressure redistribution \[25-29\]. This paper considers the option of comprehensive cyclical stimulation of the production target through both injection and producing wells.

Wave stimulation design

Wave stimulation of deposits is achieved through a wave of pressure redistribution. The speed of formation pressure redistribution will depend to a material extent on its filtration characteristics, which are expressed through the value of the permeability ratio. In Perm region, effective oil-saturated thicknesses usually don’t exceed 10 m, and log-based permeability of more than 60 % of the reservoirs does not exceed 0.1 µm. In such conditions even low-viscosity oil may have a significant impact on the filtration in the formation \[30\]. The information set out in specialized publications \[31-32\] show that the use of comprehensive wave stimulation (on producing and injection wells) causes the flow of oil to the flooded channels, which is directly reflected in the hydrodynamic research results and allows increasing the coverage of a non-homogenous reservoir with the stimulation.

The processing of recovery curves indicates that a detrimental change in the characteristics of the wellbore area (WBA) leads to the slowdown of bottom hole pressure recovery in the shutdown well, which can be explained by the reduction of the area influenced by the well and the slowdown of fluid flow to the wellbore (Fig. 1) \[33\].

![Fig. 1. Pressure recovery in the well 772 of Tournaisian target: 1 – \( k_{WBA} = 0.0197 \mu m^2 \); 2 – \( k_{WBA} = 0.0544 \mu m^2 \)](image)

In case of a change of pressure in the wellbore during the period of positive pressure impulses, the opening of formation fractures increases \[34\] and a fading filtration wave is formed. This wave may be presented as a harmonic fluctuation. With the lapse of time, certain drawdown pressure values will be established at each point of the formation as a result of redistribution of drawdown pressure at each point of the formation. Upon the creation of a pressure wave in several wells, each wave will evoke the exchange of fluids between blocks and fractures proportionate to the drawdown pressure at each given point. Whereas the wave is a harmonic motion, then during one half-period the fluid will flow through the blocks to the fractures and during another – from fractures to the blocks. Upon the creation in wellbores of pressure waves with different correctly selected frequencies, it is possible to create the resultant oscillations with maximum possible drawdown pressures in different points of the formation. The magnitude and frequency of the wave...
shall be selected based on the state of the wellbore areas. In [35] it is shown that with long time intervals the pressures in the blocks and fractures almost align and any cross-flows are terminated. The same paper suggests the determination of the closing time of interaction between blocks and fractures, when the well pressure recovery curve becomes straight in logarithmic coordinates. Based on hydrodynamic modelling in [36], it is noted that the best technological effect from well shutdown and activation in terms of water cut reduction is possible in case of work/downtime ratio of one to three.

Taking into account the above, we are going to evaluate the possibility of using short-term well shutdowns to create filtration wells and improve the effectiveness of deposit development on Tournaisian carbonate target with highly viscous oil in Perm region (Fig. 2).

Key deposit parameters are set out in Table 1. The target is characterized by lower values of permeability, low gas content of formation oil, high oil density and high number of sand beds.

### Table 1

| Geological and physical parameters of Tournaisian formation |
|-------------------------------------------------------------|
| Beryozovskoye oilfield                                     |
| Average net oil thickness, m                               | 5.3 |
| Porosity, %                                                | 15  |
| Permeability according to logging, μm²                     | 0.035 |
| Sand content ratio, unit fractions                         | 0.38 |
| Average number of permeable intervals, unit fractions      | 3.56 |
| Oil viscosity in reservoir conditions, mPa·s               | 87.08 |
| Oil density in reservoir conditions, tonnes/m³             | 0.914 |
| Bubble point pressure, MPa                                | 8.9  |
| Gas content, m³/tonne                                      | 6.6  |
| Water viscosity in reservoir conditions, mPa·s              | 1.44 |
| Water density in reservoir conditions, tonnes/m³           | 1.179 |

The water cut of producing wells in the deposit section varies from 26 to 98 %, while oil output varies in the range of 1.1-8.1 tonnes/day.

The closing time of interaction between blocks and fractures ($T_c$) in case of a change of pressure in formation points may be roughly indicated by the start of the flat part of the pressure recovery curve of a fractured-porous reservoir (Fig. 3).

The following time values ($T_c$) were obtained for the wells located in the area: 747 – 95 hrs; 750 – 119 hrs; 905 – 46 hrs; 909 – 132 hrs; 912 – 83 hrs; 913 – 25 hrs; 926 – 105 hrs; 941 – 63 hrs.
Table 2

Results of hydrodynamic modelling of wave stimulation during the first year

| Option | Time of well work/downtime, hrs | Accumulated fluid production, thousands of m³ | Accumulated oil production, thousands of tons | Water cut, % |
|--------|--------------------------------|-----------------------------------------------|---------------------------------------------|-------------|
| Basic  | Wells operation in the current mode | 426.72                                        | 162.839                                     | 0.83        |
| 1      | 25/25*                          | 430.833                                       | 163.798                                     | 0.80        |
| 2      | 25/25                           | 430.343                                       | 163.435                                     | 0.80        |
| 3      | 84/84                           | 430.253                                       | 163.268                                     | 0.80        |
| 4      | 132/132                         | 424.172                                       | 162.413                                     | 0.83        |
| 5      | Individual $T_C$               | 430.451                                       | 163.663                                     | 0.81        |

Note: * – only injection wells.

Hydrodynamic modelling of wave stimulation

The software complex Tempest More has modelled the following options for creating a filtration wave: option 1 – periodic operation of only injection wells of the area; options 2-4 – setting the same operation and downtime mode for all the wells in the area at a constant level (option 2 – minimal time (25 hrs); option 3 – average time (84 hrs); option 4 – maximum time (132 hrs), option 5 – setting an individual operation and downtime mode for each well ($T_C$).

The results of hydrodynamic modelling are set out in Table 2.

The modelling has shown that practically all the options involve the growth of accumulated oil production as compared to the basic value, at the same time stagnation and slight reduction of water cut is observed. A negative technological effect was achieved as a result of long shutdown of producing and injection wells. The highest technological effect was observed only in case of periodic operation of only injection wells (cyclical water cut according to option 1) (Fig. 4).

The total oil output of the wells in the area as at the end of the first year of the modelling period amounted to 13.8 m³/day in the basic option, and in other options – to 31-35 m³/day; this means that the effect from cyclical stimulation even during a year will yield a lengthy positive impulse for the deposit development. In case of comprehensive stimulation the highest effect is achieved by different frequency operation of the wells, when the time of well operation and shutdown is selected individually based on the wellbore areas’ parameters.

Studies [37-40] conclude that in case of comprehensive wave motion the effectiveness of the technology declines with time with same frequency. In connection with the evaluation of modelling results it should be noted that the rate of incremental oil production slows down and, therefore, it is necessary to correct the motion parameters in order to maintain high technological indicators.

Conclusions

The provided materials allow drawing the following conclusions:

1. Wave technologies may be an effective method of enhancing the metrics of oil deposits development.

2. When planning comprehensive stimulation (on the producing and injection wells), it is necessary to choose the operation and downtime of each well based on their wellbore areas’ characteristics.

3. It is necessary to change the operation and downtime of the wells to support high technological metrics of wave motion.
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