Modeling of clay acid effects on the bottomhole zone of wells

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Abstract. Typical wells have been identified in the conditions of the Langepass group deposits, according to which modeling of the clay-acid process on the bottom-hole formation zone has been performed. There was a significant increase in the efficiency of operations based on the use of developed models, which allows choosing the most optimal technologies and exposure parameters depending on the properties of the productive formations.

1. Introduction

The last decade has shown an increase in the share of hard-to-recover oil reserves in Russia and around the world [1–5]. Significant volumes of hard-to-recover oil reserves are concentrated in low-permeability clayed terrigenous reservoirs of complex geological structure. In the process of development, there is a deterioration in the reservoir properties of the reservoir in the bottomhole formation zone. The Bottom-hole formation zone is distinguished as part of a formation whose properties may differ from those of the rest of the formation. Due to the deterioration of the reservoir properties of the bottomhole zone during the opening of the formation in the future, as well as due to objective physical phenomena [6, 7], the main share of the energy spent on the movement of oil and gas in the formation is lost.

The main factors that worsen reservoir properties are as follows: swelling of clay cement of reservoir rocks, introducing the smallest mechanical particles into the bottomhole zone during the operation of the well and its repair, rock compaction, and adsorption layers of various compositions on the surface of pores and cracks. The reservoir properties of the bottom-hole formation zone also deteriorate due to the precipitation of salts and a variety of reaction products after chemical reagents are injected. Another reason for deterioration is the collector's water saturation and phase permeability to oil decrease when mineralized water changes to foreign or fresh water. The radius of the bottom-hole zone is from several tens of centimeters to several meters.

An important task in the operation of wells is to maintain reservoir properties of the bottomhole zone in a state as close to the initial one as possible or to improve its characteristics. As a result, there is a need to restore and improve reservoir properties in the bottom-hole formation zone to intensify oil production.
The natural diversity of the mineral composition of the reservoirs, the difference in the structure of the pore space and the variety of factors influencing the reduction in permeability require an individual approach to the selection of an active agent for treating the bottom-hole formation zone [8, 9].

2. Materials and methods
For the basic justification of the choice of the method of intensification of oil production in this paper, we carried out a comparative analysis of the geological and physical characteristics and the current state of development of production facilities of the Langepass group of fields confined to the West Siberian oil and gas field. All of the studied objects are characterized by increased clay content (up to 14%), low carbonate content (less than 1%), and high fragmentation of productive formations. The differences lie in facies conditions and, as a consequence, the difference in mineralogical composition and reservoir properties.

To predict and analyze the effectiveness of the application of enhanced oil recovery methods, simplified models of the studied formations have been developed. We performed the grouping of objects and the selection of polygon objects by known methods. Based on the analysis of averaged geological and statistical sections of productive thicknesses processed by mathematical methods, the main layers and their parameters were identified. The values of these parameters are such that the average values of the permeability of the reservoir model, porosity and productive thickness correspond to the real values of the characteristics of the reservoirs. The properties of the selected interlayers are constant along strike. Parameters of models of polygon objects are summarized in table 1.

Table 1. Models of reservoirs of polygon objects used for mathematical modeling

| Plast, field | Interlayer Number | Thickness, m | Absolute Permeability, mD | Porosity,% |
|-------------|-------------------|--------------|--------------------------|------------|
| IOB1/1, Las Yegansk | 1) | 3 | 14 | 16 |
| | 2) | 1.5 | 5 | 16 |
| | 1) | 4.5 | 302 | 21 |
| BV8, Uryevskoe | 2) | 2.5 | 120 | 21 |
| | 3) | 1.2 | 50 | 21 |
| BV6, Stream | 1) | 4.26 | 463 | 20 |
| | 2) | 5.3 | 180 | 20 |
| AB1/3, South Pokachaevskoe | 1) | 0.54 | 99 | 19 |
| | 2) | 0.95 | 45 | 19 |
| | 3) | 1.4 | 20 | 19 |

3. Results and Discussion
The first object is characterized by low sandiness so that the ratio of the vertical and horizontal components of permeability is 100. The interlayers are assumed to be hydrodynamically coupled, since only in this case the use of cyclic influence has a positive effect. The distribution of oil and water saturation in the reservoir is determined by solving the two-dimensional problem of oil displacement by water to the water cut of the resulting product equal to the average current water cut (72%).

In other accepted models, the interlayers are considered to be hydrodynamically disconnected. The distribution of oil-water saturation is also given by solving the displacement problem to the values of the average current water cut of the product: 88.3%, 97.3% and 55.6% for the second, third and fourth landfill facilities.

The method of stimulation of injection and production wells with clay acid - a composition of hydrochloric and hydrofluoric acids with additives stabilizing against insoluble salts (organic acids) is widely used to treat the bottom-hole zone of wells. The solution acts on rock minerals (carbonates and clays), process fluids and deposits falling into the bottomhole formation zone. Dissolution of deposits
leads to an increase in porosity and permeability of the bottomhole zone. A limitation is the high carbonation of the formation, in which case leaching takes place in the form of “wormholes”.

Surfactant-acid exposure (PCV) is also common. It has a complex effect: it removes hydrocarbon deposits, acts on the skeleton of the formation (mainly clays and carbonates), process fluids and deposits falling into the bottomhole zone of the formation. There are no application restrictions, with the exception of high water cut in production wells.

Oil-bearing reservoirs of the YV 1/1 layer of the Las Yeganskoye field were considered. This layer contains a large amount (up to 34%) of field spars, clay (up to 11%) and carbonates (6%). In order to increase the flow rate of wells that open up the YV 1/1 layer, you can use well treatment with a clay acid solution.

The main chemical reactions of the interaction of acids with rock minerals are described by the following schemes:

\[ \text{SiO}_2 + 6\text{HF} \rightarrow 2\text{H}^+ + \text{SiF}_6^{2-} + 2\text{H}_2\text{O}; \]
\[ \text{KAlSi}_3\text{O}_8 + 20\text{HF} \rightarrow \text{K}^+ + 4\text{H}^+ + 3\text{AlF}_3^{2-} + 3\text{SiF}_6^{2-} + 8\text{H}_2\text{O}; \]
\[ \text{NaAlSi}_3\text{O}_8 + 20\text{HF} \rightarrow \text{Na}^+ + 4\text{H}^+ + 3\text{AlF}_3^{2-} + 3\text{SiF}_6^{2-} + 8\text{H}_2\text{O}; \]
\[ \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 + 16\text{HF} \rightarrow 2\text{H}^+ + 2\text{AlF}_4^- + 2\text{SiF}_6^{2-} + 9\text{H}_2\text{O}; \]
\[ \text{KAl}_3\text{Si}_4(\text{OH})_6 + 24\text{HF} \rightarrow 3\text{K}^+ + 2\text{H}^+ + 3\text{AlF}_6^- + 3\text{SiF}_6^{2-} + 12\text{H}_2\text{O}; \]
\[ \text{CaCO}_3 + \text{H}^+ \rightarrow \text{Ca}^{2+} + \text{HCO}_3^- . \]

The article presents the theory of calculating the main parameters of clay-acid treatment (the depth of penetration of the acid solution and the increase in well productivity after treatment) [10]. It studies one-dimensional axisymmetric filtration of an acid solution in a porous medium in the presence of chemical reactions. The injection of an acid solution into a layered reservoir with hydrodynamically isolated interlayers is also under study. The values of the desired processing parameters are found from the condition of the mass balance of reacting components on the fronts of chemical reactions, subject to the equilibrium of the process. The model takes into account: the mineral composition of the rocks forming the formation, the composition of the acid solution, stoichiometric coefficients of the main reactions of dissolution of the rock with acids, the structure of the formation (permeability, porosity, thickness of the layers that make up the formation). The obtained value of the penetration depth of the acid solution was used to assess the relative productivity of the well after treatment.

To assess the effectiveness of the impact, a model well with a geological and statistical section, based on the data in tables 1 and 2, and the composition of the rocks were considered.

**Table 2.** Data on the structure and injectivity of wells selected for clay processing

| Plast | Permeability interlayers, mD | Interlayer power, m | The maximum well production rate for the entire operation period, t / day | Well production rate, Q, t / day |
|-------|-------------------------------|---------------------|------------------------------------------------|-------------------------|
| IOB1/1 | 0.014 | 3 | 40 | 8 |
| | 0.005 | 1.5 | | |
| | 0.099 | 0.54 | | |
| | 0.045 | 0.95 | 120 | 80 |
| AB1/3 | 0.02 | 1.4 | | |


The main criteria for selecting wells for treatment are the following: a drop in fluid consumption during operation by more than a factor of two, low flow rates for liquid at this time (for injection wells below 200 m$^3$/day, for producers below 40 m$^3$/day), low reservoir heterogeneity in terms of power (dissection coefficient of the order of 3). According to the data on the decrease in well flow rates, the size of the bottomhole contamination zone was estimated.

To calculate the efficiency of acid treatments of selected wells, the following composition of the main reagent of the working solution was adopted: 1% HF + 7% HCl. The concentration of acids in the solution was selected based on the requirements to minimize corrosion of the treated wells. The volume of injection of the acid solution was selected depending on the productive capacity of the formation: from the calculation of 20 m$^3$ of solution per meter of power.

The forecast of the efficiency of processing a well model is as follows. The total volume of the recommended injection of the acid solution is 225 m$^3$ and 144.5 m$^3$ for the facilities. Depending on the conductivity of the layers, the indicated volumes are distributed over the section of the layers according to the numbers of the layers as follows: 205.14, 19.9 and 80.7, 45.5 and 18.26 m$^3$. The estimated depths of penetration of contamination through the interlayers, for the considered wells, taking into account the drop in their injectivity during operation, are as follows: 0.66, 0.339, 0.66,
Changes in fluid flow after acid treatment of the bottom-hole formation zone were calculated for each layer using the generalized Dupuis formula taking into account the zonal inhomogeneity of the bottom-hole zone of the wells (leach zones Bani acid rock and dirt). The distribution of injectivity of model wells across the interlayers before and after acid treatment is shown in the figure.

4. Conclusion
Thus, we simulated the process of acid exposure on the bottom-hole formation zone in order to intensify the influx of oil and gas and made a forecast of efficiency. Such modeling should be carried out when planning the impact on the bottom-hole formation zone and predicting the technological effect, which is an indispensable element of the recovery technology and increasing well productivity and oil recovery.

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