Scientific and methodological basic principles for determining design of clay acid treatments applied to wells

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Abstract. A new methodological approach is presented in determining design of current clay acid treatments of wells. The proposed scientific and methodological approach allows differentiating for different groups of objects in the Langepass region to determine certain technological parameters of impact on the bottom hole zone of formations, taking into account the features of geological and physical properties of formations and fluids saturating them. In special cases, it is suggested to use acid retarders for reaction with rock. The authors proposed algorithm for determining wells where the maximum effect can be obtained at a specific time.

1. Introduction

Acid treatment technologies have a long history of application as well stimulation technologies. The development of new approaches to well stimulation and development of new technologies and compositions can transfer them into the category of geological and technical measures (GTM) that will solve problems of developing hard-to-recover oil and gas reserves (TRIZ) associated with complex pore-fractured reservoirs. Salt-acid treatments (SAT) and their modifications (various compositions and technological features) are widely used for production fields [1]. The number of SAT is so large that total additional oil production from the deposit due to SAT and their modifications can be compared with methods of enhanced oil recovery (MUN). Clay acid treatments are also widely used and, if applied appropriately, can take a more important position among well stimulation methods.

Recently, there has been a trend to increase the share of TRIZ in the overall world balance, including in Russia. Significant volumes of TRIZ are confined to low-permeable mud-off terrigenous reservoirs, which have their own features of geological structure. During well operation, the reservoir's filtration and capacity properties (FEC) deteriorate in the bottom hole formation zone (BZF) in comparison with the remote zone. Because of deterioration of FEC in BZF in primary and secondary opening of the reservoir, and after that, during well operation and due to objective physical phenomena [2, 3], here the main consumptions of produced energy takes place, it is used for the movement of fluids in the formation.

Proper well operation implies keeping FEC of BZF close to natural ones; so works are also...
performed to improve filtration and reservoir properties of the bottom hole zone of the formation. Thus, the need to restore and improve FEC arises from the task of maintaining and intensifying hydrocarbon production.

2. Materials and methods
A large number of factors that reduce permeability require an individual approach to the choice of technology and active agent to influence BZF. In order to correctly plan the impact on productive formations and predict its (impact) effectiveness, it is necessary to understand the processes occurring in BZF, and determine possible responses to the impact. For this purpose, there is a methodology for predicting and designing impact, the mandatory element of which is modeling [4, 5].

To justify the choice of oil production intensification method, the authors analysed geological and physical characteristics and current state of operational facilities development of the Langepass group of fields (West Siberian NGP). All objects of the named group are characterized by high compartmentalization of productive layers with high clay content (up to 14 %) and low carbonate content (less than 1%). There are differences in facial conditions and, as a result, differences in mineralogical composition and reservoir properties.

The effectiveness of clay acid treatments (CAT) for terrigenous formations is conventional. In accordance with methodological approach of metotechnology of physical and chemical impact on reservoirs [6], we will conduct impact modeling to predict the efficiency of CAT for conditions of the Langepass group of fields.

To build a mathematical model of distribution of clay acid solution in a porous medium, it is necessary to take into account, first of all, mineral composition of rocks. Presence of minerals and compounds of elements that can form an insoluble sediment during the reaction with clay acid is of great importance. Sandy rock treated with clay acid must have a very low content of carbons and ferruginous compounds. While the high content of clays is not an obstacle to CAT success. Therefore, mineralogical composition of terrigenous oil formation UV1/1 of the Las-Eganskoye field has been studied. The average composition of rocks of this formation is shown in table 1.

| Minerals | Percentage, % |
|----------|---------------|
| Quartz   | 43            |
| Feldspar | 34            |
| Micas    | 6             |
| Clays    | 11            |
| Carbons  | 6             |

3. Results and discussion
Table 1 shows that the formation under consideration contains a large amount (up to 34 %) of feldspar, clay (up to 11 %) and carbons (6 %). In order to increase the flow rates of wells that open UV1/1 formation, it is possible to use treatment of wells with clay acid solution (or mud acid solution – (HF + HCl)).

The theory of calculating the main parameters of clay acid treatment (depth of acid solution penetration and increase in productivity of the well after treatment) is given in the paper [7]. The proposed theory considers one-dimensional axisymmetric filtration of acid solution in a porous medium involving chemical reactions. It reviews acid solution injection into a layered formation with hydrodynamically isolated interlayers. The values of desired parameters of treatment are found from the condition of mass balance of reacting components on frontal advance chemical reactions, provided that the process is in equilibrium. The model takes into account: mineral composition of rocks forming the formation, composition of acid solution, stoichiometric coefficients of main reactions of rock
dissolution by acids, structure of the formation (permeability, porosity, thickness of interlayers composing the formation). The obtained value of depth of acid solution penetration has been used to assess relative productivity of the well after treatment.

The authors considered the process of equilibrium dissolution of a porous medium containing soluble minerals with acid solution (a mixture of hydrochloric and hydrofluoric acids). The model ignores the diffusion transfer of components in comparison with convective, gravitational pressure drop at the bottom of the well in comparison with hydrodynamic one.

The system of equations describing the filtration process of a clay acid solution and reaction products obtained as a result of dissolution consists of continuity equations for each component of solution and the equation of motion:

\[
\begin{align*}
\frac{\partial m \cdot \rho_i^0 \cdot c_{HF}}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} \left( r \cdot m \cdot \rho_i^0 \cdot c_{HF} \cdot v \right) &= -K_{f} \cdot J_{f} - K_{cl1} \cdot J_{cl1}; \\
\frac{\partial m \cdot \rho_i^0 \cdot c_{HCL}}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} \left( r \cdot m \cdot \rho_i^0 \cdot c_{HCL} \cdot v \right) &= -K_{c} \cdot J_{c} - K_{cl2} \cdot J_{cl2}; \\
\frac{\partial m \cdot \rho_i^0 \cdot c_{1}}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} \left( r \cdot m \cdot \rho_i^0 \cdot c_{1} \cdot v \right) &= -K_{sf} \cdot J_{f} - K_{cl1} \cdot J_{cl1}; \\
\frac{\partial m \cdot \rho_i^0 \cdot c_{2}}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} \left( r \cdot m \cdot \rho_i^0 \cdot c_{2} \cdot v \right) &= -K_{sc} \cdot J_{c} - \rho \cdot K_{cl2} \cdot J_{cl2}; \\
c_{w} &= 1 - (c_{1} + c_{2} + c_{HCL} + c_{HF}); \\
J_{f} &= -\rho_{H} \frac{\partial \alpha_{f}}{\partial t}; \quad J_{cl1} = -\rho_{cl1} \frac{\partial \alpha_{cl1}}{\partial t}; \quad J_{c} = -\rho_{c} \frac{\partial \alpha_{c}}{\partial t}; \\
J_{cl2} &= -\rho_{cl2} \frac{\partial \alpha_{cl2}}{\partial t}; \quad r_{w} \cdot v \cdot m = \frac{Q}{2\pi \cdot h};
\end{align*}
\]  

where \( m \) is the porosity of the rock; \( \rho_{R,f,cl,c} \) – density of water, rock, rock minerals, respectively; \( c_{HF,HCL,1,2,w} \) – concentration of hydrofluoric, hydrochloric acids, salts obtained as a result of dissolution reaction, water in solution; \( \alpha_{f,cl,c} \) – flow rate of the liquid; \( K_{f,cl1,cl2,l1cl2c,2cl} \) – stoichiometric coefficients of the dissolution reaction; \( J_{f,cl1,cl2} \) – dissolution reaction rate of feldspars, clays with hydrofluoric acid and carbonates and parts of clays with hydrochloric acid; \( \alpha_{f,cl,c,sol} \) – volume content of feldspars, clays, carbonates and parts of clays soluble in hydrochloric acid (\( \alpha = c_{i} \cdot \rho_{R} / \rho_{i} \)); \( r_{w} \) – radius of well; \( Q \) – flow rate; \( h \) – thickness of formation.

It is assumed that the composition of feldspar includes K-feldspar and Na-feldspar. The clays imply kaolinite, smectite, illite, montmorillonite, bentonite. Carbons are represented by calcite and magnesite-dolomite. Stoichiometric coefficients were taken as average for each group of minerals.

Initial and boundary conditions for different regions of flow as follows: in the initial moment of time in the formation there is water, concentration of minerals in the rock and porosity is equal to original values; zero lower bound on concentration of acids in solution is equal to original values, the formation contains quartz and carbons, porosity is equal to \( m_{1} = 1 - \frac{r}{R} - \frac{R_{c}}{R} \), for the first boundary in the solution there are salts obtained in the reaction, and the changed amount of hydrochloric acid, in the formation there is quartz, feldspars and part of clay, \( m_{2} = \).
I - \alpha_0 - \alpha_i - (\alpha_{cl} - \alpha_{sol,cl})$, in the second boundary in the solution there are salts obtained by the reactions of dissolution, in the formation – all of the original minerals, the porosity is equal to the original value.  

A hyperbolic system of equations admits availability of discontinuous solutions. The values of unknown parameters at the break obtained from mass balance conditions on the frontal advance of chemical reactions provided that the process is in equilibrium taking into account the initial and boundary conditions are expressed as:

$$r_1^2 = \frac{V_n \cdot J(\pi \cdot h)\rho_i^n \cdot c_{HF}}{m_i \cdot \rho_i^n \cdot c_{HF} + K_f \cdot \rho_i^n \cdot \alpha_f + K_{el} \cdot \rho_i^n (\alpha_{cl} - \alpha_{sol,cl})};$$

$$V_1 = \frac{V_0}{(\pi \cdot h)\rho_i^n (1 - c_{HF})} - r_1^2 (m_i \cdot \rho_i^n (1 - c_{HF}) - K_c \cdot \rho_c^0 \cdot \alpha_c + K_{wcl} \cdot \rho_c^0 \cdot \alpha_c - m_2 \cdot \rho_f^0 - K_{wcl} \cdot \rho_f^0 \cdot \alpha_f - K_{el} \cdot \rho_f^0 \cdot \alpha_f - K_{el} \cdot \rho_f^0 \cdot \alpha_f) \cdot \pi \cdot h;$$

$$c_{HCL} = \frac{r_1^2 (m_1 \cdot \rho_i^0 \cdot c_{HCL} - K_c \cdot \rho_c^0 \cdot \alpha_c) - V_0}{\pi \cdot h \cdot \rho_i^0} + \frac{V_1}{(\pi \cdot h)\rho_i^0};$$

$$r_2^2 = \frac{\rho_i^0 \cdot c_{HCL}}{m_2 \cdot \rho_i^0 \cdot c_{HCL} + K_c \cdot \rho_c^0 \cdot \alpha_c + K_{cl2} \cdot \rho_f^0 \cdot \alpha_{sol,cl}},$$

where $r_1$, $r_2$ is depth of penetration of acid solution (hydrofluoric and hydrochloric, respectively); $V_{0,1}$ – volume of injection initial and after the reaction; $C_{HCL}$ – decrease in the concentration of hydrochloric acid in solution due to water released as a result of the reaction of dissolution of rock minerals with hydrofluoric acid.

Change in the permeability of treated formation zones was calculated according to The Kozeny–Carman law:

$$k(r)/k_0(r) = (m/m_0)^n,$$

where $k(r)$, $k_0(r)$ is formation permeability after and before acid treatment; $n$ is degree indicator ($n = 10$).

Relative productivity of interlayers in the layered formation was calculated according to the formula:

$$Ql/\Delta P = \frac{2\pi \cdot h}{\mu_i \cdot \frac{1}{\pi} \int_{r_i}^{r} \frac{dr}{r \cdot k_i(r)}.$$
The estimated depth of dissipation of contamination through the interlayers for wells under consideration, taking into account the drop in their injection capacity during operation, was: 0.66; 0.339; 0.66; 0.387 and 0.261 m. Radii of acid solution penetration through the interlayers in the analyzed wells, calculated according to the proposed method, are as follows: 0.41; 0.231; 0.582; 0.355 and 0.23 m. Changes in fluid flow after acid treatment of wells were calculated for each interlayer using the generalized Dupuis formula, taking into account zonal heterogeneity of the bottom hole zone of wells (zones of acid leaching and contamination of rock). The distribution of injection capacity of model wells across the interlayers before and after acid treatment is shown in figure 1.

### Table 2. Formation models of typical objects used for mathematical modeling

| Formation, field            | Interlayer | Thickness, m | Absolute permeability μm² | Porosity, % |
|----------------------------|------------|--------------|---------------------------|-------------|
| YuV 1/1, Las-Yeganskoye    | 1          | 3            | 0.014                     | 16          |
|                            | 2          | 1.5          | 0.005                     | 16          |
| AV1/3, Yuzhno-Pokachevskoe | 1          | 0.54         | 0.099                     | 19          |
|                            | 2          | 0.95         | 0.045                     | 19          |
|                            | 3          | 1.4          | 0.020                     | 19          |

### Table 3. Data on structure and injection capacity of wells, selected for clay acid treatment

| Formation | Permeability of the interlayer, mD | Interlayer thickness, m | Maximum well flow rate for the entire operation time Qmax, t / day | Current well flow rate Q, t / day |
|-----------|-----------------------------------|-------------------------|----------------------------------------------------------|-----------------------------|
| UV 1/1    | 0.014                             | 3.0                     | 40                                                       | 8                           |
|           | 0.005                             | 1.5                     |                                                          |                             |
| AV1 / 3   | 0.099                             | 0.54                    |                                                          |                             |
|           | 0.045                             | 0.95                    | 120                                                      | 80                          |
|           | 0.02                              | 1.4                     |                                                          |                             |

The purpose of acid treatment of productive formation, as noted above, is to clean the colmataged filtration channels, create new channels and expand existing ones by dissolving the rock matrix.

The process of creating new channels in reservoirs during acid treatment can be regulated by increasing the injection rate and reducing the diffusion rate (time required for acid to reach the rock surface). In domestic and foreign practice, various methods are used to reduce diffusion rate. The basis for such methods are compositions containing special chemicals that cause the diffusion process to slow down acid frontal advance, these reagents are called "retarders". Simultaneously with slowing down process when using such compositions, also a deviation takes place. The "delayed" composition retains its ability to dissolve rock and can be pushed further into the formation, so there is deepening and deviation of acid frontal advance. The effect of such deviations increases the coefficient of formation coverage with treatment and increases acid treatment efficiency.

The acid application with an acid moderator (ZSK-1M) reduces the rate of dissolution of rock in the water-saturated part of reservoir formations, and simultaneously increases the rate and efficiency of dissolution of hydrocarbon-saturated interlayers. The active reagent ZSK-1M makes it possible to hydrophobize the surface of the pore-crack area of the productive formation. The developed technology using a complex selective action reagent (CSAR) based on an acid moderator (ZSK-1M) has the properties described above of deflecting acid frontal advance and slowing down the rate of its reaction with rock. Successful tests of the technology were carried out [10-12], they showed the prospects of its application in various geological and physical conditions.
The technology makes it possible to intensify the following categories of wells:
- wells that exploit terrigenous and carbonate formations with poor reservoir properties;
- wells characterized by a weak reaction to repeated acid treatments.
Features of "CSAR" impact are as follows:
- reduces the rate and degree of dissolution in watered part of reservoir (about 3 times);
- increases the rate and degree of dissolution of oil-saturated reservoir (1.5 times);
- the composition has a low viscosity (up to 2 MPa·s);
- does not form stable emulsions;
- the composition has a reduced corrosion activity (0.293 g / m²·hour).
The treated facilities are:
- wells that exploit terrigenous formations with low reservoir properties;
- wells characterized by a weak reaction to repeated acid treatments;
- reagent "CSAR " – for wells with a water content of no more than 40%;
- solution "ZSK-1" in a solvent for wells with a water content of more than 40 %.
To increase the treatment efficiency, "CSAR " reagent can be used for static or hydrodynamic baths in the well in combination with wave action or implosion action. It is possible to use "CSAR" technology with an additional flow-deflecting or water-insulating gel screen.

**Figure 1.** Diagrams of distribution of injection capacity on interlayers before and after acid treatment of model wells of formations: a) group I, b) group II
4. Conclusion
1) For a specific well-formation system, impact modeling and design should be performed.
2) Effective use of CAT in terrigenous formations is possible in various geological and technological conditions, if the criteria for impact applicability are met and correct design for the impact is performed.
3) To increase the efficiency of the process of secondary acid treatments, it is possible to use composite acid solutions of selective action.

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