Methods for increasing the efficiency of hydrochloric-acid treatments of wells

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Abstract. The authors generalize the experience of conducting hydrochloric-acid treatments in the wells of high-viscosity oil deposits with hard-to-recover reserves in carbonate reservoirs. Intervals of changes in the values of geological and technological parameters with the efficiency of hydrochloric-acid treatment over 50% have been estimated. The impact parameters have been determined in various geological-field conditions. The causes of catastrophic water cut of wells as a result of impact have been established.

1. Introduction

Increasing the efficiency of impact on the bottom-hole zone of wells using hydrochloric-acid solutions is one of the factors of effective development of oil deposits in carbonate reservoirs. To solve this problem, it is necessary to provide a geological and technological justification for the selection of wells and technological parameters of impact in specific geological conditions of deposits [1–8].

A significant number of technologies proposed to date for stimulating the bottomhole zone using hydrochloric acid indicates a wide variety of productive formations in terms of bedding conditions, geological-physical and physicochemical properties of reservoir rocks and fluids saturating them, differences in the development technology, which must be taken into account when impacting to increase its effectiveness.

The experience of carrying out hydrochloric acid treatments (HAT), highlighted in the literature by various researchers, shows that in different geological and field conditions, this method of influencing the bottomhole formation zone has different efficiency and its value is determined by the influence of a wide variety of factors, among which the main ones are:

- type of HAT (foam acid, thermoacid, regular HAT, etc.);
- technological parameters of HAT (acid volume, injection pressure, acid concentration, etc.);
- geological features of formations (porosity, permeability, fracturing, etc.);
- technological performance of wells and deposits (current reservoir pressure, water cut, frequency of HAT, etc.).

The effectiveness of treatments is assessed in different ways: by the change in the productivity and flow rate of wells before and after the treatment; by the relative increase in flow rate; by the total additional oil production; by the change in inflow profiles; by success rate (the ratio of the number of
effective operations to the total number of treatments). At the same time, along with the intensification of oil production, in some cases there is also a change in oil recovery. For example, under the conditions of the Yablonevskoye field, when developing it in the mode of dissolved gas, the radius of the zone of the carbonate formation, which was actively affected by hydrochloric acid, which increased the natural pore permeability, did not exceed several tens of meters. Active hydrochloric acid penetrates much deeper into the formation along some of the largest fractures. Vertical layer-by-layer macrocracks have a small specific surface area, and therefore concentrated acid moves along them at high speed over long distances, commensurate with the distance between the wells. Along the way, it corrodes fracture taper points and thereby increases fracture permeability. In this case, the speed of movement of the acid can reach several hundred meters per day. Calculations showed that oil recovery due to fracturing and acid treatments increased 1.62 times.

At the same time, during waterflooding of productive formations, unsystematic hydrochloric acid treatments may lead to a decrease in waterflooding and a decrease in oil recovery. For example, in the conditions of carbonate deposits of the Kuibyshev region, when acid is pumped under pressure, productive formation thickness decreases by 21 - 75%.

There have been cases where the injected acid appears in the production of adjacent production wells. As a result of deep penetration of acid into natural fractures of a carbonate reservoir and a multiple increase in the permeability of narrow fractured intervals, the heterogeneity of the carbonate reservoir in permeability may increase and the coverage of the pore volume of the reservoir by displacement due to the predominant movement of water along the fractures may decrease. This is the negative effect of haphazard acid treatments on the porous-fractured carbonate reservoir. A decrease in the reservoir sweep efficiency is also noted in the fields of Tatarstan, Udmurtia, and the Perm region. After the wells are commissioned from drilling, the sweep coefficient in thickness does not exceed 0.3; after the first HAT, it rises to 0.5; after the second HAT, it decreases again to 0.3; and after the third and fourth HATs, it does not exceed 0.2.

On the other hand, in low-permeability carbonate reservoirs (less than 100·10^{-3} \, \mu m^2) with a large specific surface, hydrochloric acid is neutralized directly at the wellbore walls, and only the products of its interaction with acid penetrate deep into the formation, which also reduces the efficiency of treatments with an increase in their frequency. Moreover, in this case, the depth of penetration of the active acid into the formation does not exceed several meters.

In this regard, in order to increase the effectiveness of the impact and eliminate the adverse consequences of hydrochloric acid treatments on the oil recovery process, various varieties of them have been proposed and used.

2. Materials and methods
The geological-field analysis of impact of different geological and technological parameters on the efficiency of conducting usual and pressurized hydrochloric-acid treatments has been carried out using the deposits of high-viscosity oil in carbonate reservoirs of the Turnaisian stage of the North-Western part of Bashkortostan.

The parameters are as follows: effective oil-saturated thickness \( N_e \), average thickness of oil-saturated interlayers \( N_p \) and their number \( n \); coefficient of layer's porosity \( M_p \) in the well; share of reservoir rocks in the total thickness of the layer \( K_p \); time period from the beginning of operation of wells to the hydrochloric-acid treatment \( t \); maximum oil flowrate in the well before conducting the treatment \( Q_{n_{max}} \); flow rate \( Q_n \); water cut \( f_1 \); cumulative oil production \( Q_{cum} \) at the time of hydrochloric-acid treatment; volume \( V_k \) and maximum pressure \( P_{max} \) of pumping acid into the layer.

The selection of geological and technological parameters that have the greatest impact on the effectiveness of hydrochloric-acid treatment has been carried out using a sequential Wald procedure. Informational value has been determined according to the Kulbak criterion.
3. Results and Discussion

Distribution of wells depending on changes in the values of informative geological and technological parameters with the effectiveness criterion being represented with an increase in oil flowrate, shows that the efficiency rate increases significantly for wells with worse reservoir properties and greater geological heterogeneity. At $N_r < 4.2$, $n > 3$, $M_k < 13.3\%$, $K_p < 0.66$, the efficiency makes more than 50%. Low reservoir properties and increased geological heterogeneity cause weak layer development in the drainage zone of the well and condition the presence of a reserve of oil production, on the one hand, and the presence of significant filtration resistances in the bottom-hole zone of the reservoir, on the other hand.

The need for a reserve of oil production is conditioned by the fact that it is advisable to impact on the wells with a service life of less than 160 months and with accumulated oil production of less than 24.6 thousand tons. At the same time, the probability increases for wells with a higher $Q_{max}$ value. This fact is explained by the clogging of the bottom-hole zone due to the deposition of resins, asphaltene and paraffins as a result of intensive oil production and a significant decrease in layer pressure in the drainage zone.

Determining the volume of acid injected into the layer is an important point in conducting the hydrochloric-acid treatment [9-14]. The volume depends on the geological features of the layer at the site of its opening in the well and the technological features of wells and deposits. The use of relevant dependencies allows us to obtain inequalities for determining the volume of injected acid and injection pressures: $V_1 > 0.71 \, N_e; \, V_4 > 1.49 \, N_p; \, V_5 > 0.059 \, Q_{oil}; \, V_6 > 0.175 \, f_1; \, V_7 > 4.4 \times 10^{-4} \, Q_{cum}; \, P_{max} < 0.98 \, V_k$.

Inequalities (1) allow diagnosing the required volume of acid by the maximum value of the parameter.

However, the results obtained are probabilistic. To get an unambiguous answer to the question about efficiency, the values of total diagnostic coefficients (TDCs) have been calculated, and the interval with the proved positive effect have been estimated. This interval changes from 8.9 to 66.8.

The use of TDC distributions allows changing the technological parameters of the impact and transferring wells from zones with a negative effect and zones of uncertainty to zones with a positive effect.

The distribution of wells depending on changes in the values of informative geological and technological parameters with the efficiency criterion being represented with a decrease in the water cut of the extracted products, shows that at $N_c > 11.5$; $N_p > 4.3$; $n < 3$; $K_p < 0.73$; $M_k < 13\%$, the efficiency rate of the impact makes more than 50%. It is advisable that the values of technological parameters are as follows: $t < 118$ months; $Q_{incl} < 17.8$ thousand tons; $Q_{max} < 349$ t/month; $Q_{n1} > 77$ t/month; $V_k < 7.5$ m$^3$; $P_{naa} < 7.6$ MPa.

The obtained inequalities also allow us to diagnose the efficiency of treatment operations at a qualitative level, both within the analyzed fields and similar ones in terms of geological and field characteristics, by searching wells for appropriate informative features, as well as to approximate the impact parameters. However, these results, as well as in the case when the efficiency criterion is represented with an increase in oil flowrate, allow assessing only probable impact and cannot give a clear-cut answer. The TDC values have been calculated to resolve this issue. It has been revealed that the TDC change from 14.4 to 40.9 provides for unambiguously positive efficiency of hydrochloric-acid treatment.

Comparison of research results for both variants shows that a significant number of wells in the first variant make part of the group with positive effect, while the second variant represents the group with negative effect, and vice versa, i.e. the higher the oil flowrate, the higher the water cut.

Comparison of the intervals of changes in the values of relevant parameters with the efficiency of hydrochloric-acid treatment over 50% indicates the presence of common intervals in both variants. The values of these intervals are shown in Table 1.

It is the total intervals that explain the fact that some wells are characterized by a decrease in the water cut of oil products after exerting the impact, along with an increase in oil flowrate.
Table 1. Intervals of changes in the values of relevant geological and technological parameters with the efficiency of hydrochloric-acid treatment over 50%

| Interval by variants | Total interval for variants 1 and 2 |
|----------------------|------------------------------------|
|                      |                                    |
| $N_e > 7.7$          | $N_e > 11.5$                       |
| $M_e < 13.3$         | $M_e < 13.0$                       |
| $K_e < 0.66$         | $K_e < 0.76$                       |
| $t < 160$            | $t < 118$                          |
| $Q_{\text{max}} > 180$ | $Q_{\text{max}} < 349$           |
| $Q_{n1} < 125$       | $Q_{n1} > 77$                      |
| $Q_{\text{cum}} < 24.6$ | $Q_{\text{cum}} < 17.8$        |
| 7.5 < $P_{\text{max}} < 9.0$ | 7.6 < $P_{\text{max}} < 9.0$     |

Besides, simultaneous increase in oil flowrate and water cut can be explained by the absence of common intervals for certain parameters (Table 2).

Table 2. Intervals of changes in the values of geological and technological parameters with the efficiency of hydrochloric-acid treatment over 50%

| Interval by variants |                                    |
|----------------------|------------------------------------|
| $N_p < 4.6$          | $N_p > 4.2$                        |
| $n > 3$              | $n < 3$                            |
| $V_e > 7.8$          | $V_e < 7.5$                        |
| $V_e/N_e > 0.71$     | $V_e/N_e < 0.65$                   |
| $V_e > 0.71N_e$      | $V_e < 0.65N_e$                    |

4. Conclusion

Thus, the obtained results provide for the geological and technological justification of increasing the efficiency of hydrochloric-acid treatment of wells for high-viscosity oil deposits in the carbonate reservoirs of the Turnaisian stage.

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