Justification for increasing the performance of hydrochloric acid treatment in wells of fields with carbonate reservoir

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Abstract. The geological and technological parameters, which have a prevailing influence on the success of the treatment, were established on the basis of analysis and synthesis of experience of hydrochloric acid treatments in the conditions of Tournaisian oil deposits of the Volga-Ural oil and gas-bearing province. The algorithms, which allow selecting wells for hydrochloric acid treatment, determining the parameters of treatment taking into account peculiarities of geological structure of formations, time factor, peculiarities of technology of wells and deposits operation, were proposed. The conditions for the most successful implementation of this type of treatment on the bottomhole zone to intensify oil production and reduce the water cut in order to increase the level of profitability of deposits in carbonate reservoirs with hard-to-recover reserves were established.

1. Introduction
Based on the peculiarities of formation structure and technological peculiarities of wells and deposits it is important to select those values of technological parameters during hydrochloric acid treatment on the bottomhole zone that will allow obtaining the maximum profit [1–6].

In order to solve this problem, a geological and field analysis of the treatment on the success and efficiency of hydrochloric acid treatment (HAT) of various geological and technological parameters was carried out in carbonate reservoirs of the Tournaisian formation of the North-West part of Bashkortostan.

The analyzed Tournaisian objects were drilled along both a uniform and non-uniform triangular array with distances ranging from 400 to 600 m between the wells. The central, most productive areas of deposits, where the well density (WD) ranged from 16 to 36 ha/well were the densest well array drilled. Less productive peripheral areas were drilled with single wells in an extremely uneven manner. The density of the well array in the outer oil-bearing circuit varied from 17 to 240 ha/well. The operation mode is elastic water drive, however, in the areas where water injection is not organized as a result of weak hydrodynamic connection of the oil-saturated volume of the formation with the bottom waters, the dissolved gas mode is developed. At the same time, the formation pressure in some areas of deposits decreased to 1–3 MPa.

Fluid is mainly produced from the very beginning of operation by means of rod pumps, the capacity of which is determined by production capabilities of wells. Many wells ensure commingled production of oil from two horizons, thus making it difficult to efficiently control the development.

Water production of extracted products is different. For example, from the very beginning and for quite a long time (up to a drop in formation pressure of 2–5 MPa) most wells produce 10–15 % of water,
indicating that there is no connection to the bottom water, although for some wells the water production is rapidly increasing, indicating the presence of lithological, permeable “windows”, through which water cut cones are formed. Well watering is largely determined by the distance between the bottom holes of the perforation and the surface of the water-oil contact.

As shown by field studies, under the conditions of the accepted density of producing wells array there is no interference between wells during development of deposits in natural modes, which is a consequence of highly developed geological inhomogeneity, low reservoir properties, lens structure of permeable layers.

The rate of oil and fluid extraction, as well as oil recovery in the absence of flooding, are determined by productivity and density of the producing wells array. Depending on these parameters the final oil recovery will be from 1 to 34 % by the end of development.

The analysis of contour flooding carried out in separate areas of deposits shows that along with the increase in the production rate of surrounding production wells there is also lack of oil production growth, i.e. the displacement process takes place only within separate local zones. At the same time, with the increase of distances between production and injection wells (more than 500 m) the efficiency of flooding is significantly reduced.

In order to improve the applied development systems, further drilling of deposits is implied along a uniform triangular and quadrangular array of wells with distances between wells from 300 to 600 m and organization of area (according to five- and seven-point scheme) and focal contour waterflooding by both drilling of new injection wells and transferring the watered production wells on separate areas with favorable geological characteristic. Flooding is not implied in areas with deteriorated reservoir properties due to low efficiency at accepted density of well array.

The following were considered as independent variables: net oil thickness (Hₙ), mean thickness of oil-saturated interlayers (Hᵢ), and their quantity (n), porosity ratio in a well (Mᵢ), share of reservoir rocks in the total formation thickness (Kᵢ), time from the beginning of well operation to the moment of HAT (t), maximum well flow rate before HAT (Qᵢmax), oil flow rate (Qᵢrt), water cut (fᵢ), accumulated oil production (Qᵢs) of a well at the moment of HAT, volume (Vᵢ) and maximum pressure (Pᵢs) of acid injection into the formation. The following efficiency parameters were used as response functions: absolute (Ωₐ) and relative (Ωᵣ) oil yield gain; absolute (Ωₛ) and relative (Ωᵣₛ) water cut reduction; total oil production growth during the effect (Ωₑ); relative increase of well flow index (Ωₑᵢ).

Geological and technological parameters, which have the greatest influence on HAT efficiency, were identified using the Wald’s sequential procedure. Information value was determined by Kulbak’s criterion.

The Wald’s method of sequential diagnostic procedure is based on the Bayes formula, which is written as follows:

\[ D_A < \frac{P(X_i^j/A)}{P(X_i^j/B)} \cdot \frac{P(X_i^{2j}/A)}{P(X_i^{2j}/B)} \cdots \frac{P(X_i^{nj}/A)}{P(X_i^{nj}/B)} < D_B, \]

where \( D_A, D_B \) – threshold values determined on the basis of a priori level of errors of assignment of an object of one class to another, or on the graph of distribution of sums of diagnostic coefficients;

\( (P(X_i^j/A))/(P(X_i^j/B)) \) – diagnostic coefficient (recognition coefficient) – ratio of frequency detected at i interval of j characteristic of class A to the frequency of the same range and characteristic, but in class B.

Diagnostic coefficient \( D(x_i^j) \) for i interval of j characteristic change is calculated by the following formula:

\[ D(x_i^j) = 10 \cdot \lg[P(x_i^j/A)/P(x_i^j/B)], \]

and the information value \( J(x_i^j) \) – by Kulbak’s formula:
\[ J(\mathbf{x}_j^*)=D(\mathbf{x}_j^*) \cdot 0.5[P(\mathbf{x}_j^*/A) – P(\mathbf{x}_j^*/B)]. \]

Informative were the features, the information value of which, according to Kulbak’s formula, is more than 0.5.

Such a large number of efficiency criteria and the use of different amounts of information is caused by the need to solve the task at different stages of development and in conditions of limited information about deposits (due to insufficient volume of field studies, due to organizational and financial reasons), as well as by changes in the tactics and strategy of the enterprise in market conditions. This will make it possible to respond flexibly to changes in internal and external operating conditions [7-12].

2. Results

The analysis of well distribution depending on the change of informative geological and technological parameters, where the incremental oil rate served the efficiency criterion, showed that the success significantly increases for wells with worse reservoir properties and greater geological heterogeneity. At \(H_m < 4.2 \text{ m}, n > 3, M_F < 13.3 \text{ %, } K_G < 0.66 \text{ unit fractions, the success is more than 50 %}. \) Low reservoir properties and increased geological inhomogeneity cause weak formation development in the well drainage zone and cause the reserve of oil production on one side and presence of significant filtration resistances in the bottomhole zone of the formation on the other side.

The fact that it is desirable to treatment the wells, which service life is less than 160 months and with accumulated oil production less than 24 thousand tons, indicates the need for oil production reserve. At the same time, the probability increases across wells with higher \(Q_{f_{max}}\). This fact is caused by the clogging of the bottomhole zone due to the precipitation of resins, asphaltenes and paraffins as a result of intensive oil production, and a significant reduction in formation pressure in the drainage zone.

An important point in HAT is the determination of the volumes of acid injected into the formation. These volumes depend on geological features of the formation at the site of its drilling by a well and technological features of wells and deposits. The use of significant dependencies resulted in inequalities in the determination of acid injection volumes and injection pressures:

\[ V_K > 0.71 \; H_s; \]
\[ V_K > 1.49 \; H_m; \]
\[ V_K > 0.059 \; Q_{H1}; \]
\[ V_K > 0.175 \; f_s; \]
\[ V_K > 4.4 \cdot 10^{-4} \; Q_{max}; \]
\[ P_{max} < 0.98 \; V_K. \]

Inequalities make it possible to diagnose the required volume of acid according to the maximum value of the parameter.

However, the results are probabilistic. In order to be able to answer the question of success unambiguously, the values of total diagnostic coefficients (TDC) were calculated and intervals, in which the effect is unambiguously positive, were established. This interval varies from 8.9 to 66.8.

By changing the process parameters of the treatment the use of TDC distributions allows transferring wells from zones with the negative effect and zones of uncertainty to the zone with the positive effect.

The distribution of wells depending on the change in the values of informative geological and technological parameters, where the efficiency criterion was the reduction of the water cut, showed that at \(H > 11.5 \text{ m}, H_l > 4.3 \text{ m}, n < 3, K_f < 0.73 \text{ unit fractions, the success of the treatment is more than 50 %.}\)

It is desirable that the process parameters be as follows: \(t < 118 \text{ months, } Q_{max} < 17.8 \text{ th. t, } Q_{f_{max}} < 349 \text{ t/mon., } Q_{H1} > 77 \text{ t/mon., } V_K < 7.5 \text{ m}^3, P_{max} < 7.6 \text{ MPa.}\)

The obtained inequalities also make it possible to diagnose the success of treatments at a qualitative level both within the analyzed fields and close to them according to geological and field characteristics by sampling of wells according to the corresponding informative features, as well as to approximately estimate the treatment parameters. However, these results, as in the case where the efficiency criterion was the increase in oil yield, only allow assessing the probability of effective treatment and cannot give
a clear answer. Thus, the TDC values were calculated. It was established that if TDC changes from 14.4 to 40.9, the success of HAT is definitely positive.

The comparison of results of the study for both versions showed that a significant number of wells in the first version were in the group for which a positive effect was obtained, and in the second version – in the group for which no effect was obtained, and vice versa, i.e. often with an increase in oil production there is also an increase in water cut.

The comparison of intervals of change of significant parameters, in which the success of the treatment is more than 50%, in both variants indicated the presence of common intervals. The values of these intervals are shown in Table 1.

It is the general intervals that explain the fact that in some wells after exposure, along with the increase in oil production, there was a decrease in the water cut of the produced product.

### Table 1. Intervals of change of significant geological and technological parameters, in which the success of HAT is more than 50%

| Interval by variants | Common interval for variants 1 and 2 |
|---------------------|-------------------------------------|
| $H_3 > 7.7$         | $H_3 > 11.5$                        |
| $M_r < 13.3$        | $M_r < 13.0$                        |
| $K_{it} < 0.66$     | $K_{it} < 0.79$                     |
| $t < 160$           | $t < 118$                           |
| $Q_{H_{max}} > 180$ | $Q_{H_{max}} < 349$                 |
| $Q_{H1} < 125$      | $Q_{H1} > 77$                       |
| $Q_{\text{max}} < 24.6$ | $Q_{\text{max}} < 17.8$         |
| 7.5 < $P_{\text{max}}$ < 9.0 | 7.6 < $P_{\text{max}}$ < 9.0 |

Besides, the simultaneous increase in oil production and well water cut is caused by the absence of common intervals for individual parameters (Table 2).

### Table 2. Intervals of change of geological-technological parameters, in which the success of HAT is more than 50%

| Intervals by variants |
|-----------------------|
| 1                     | 2                     |
| $H_{it} < 4.6$        | $H_{it} > 4.2$        |
| $n > 3$               | $n < 3$               |
| $V_k < 7.8$           | $V_k < 7.5$           |
| $V_k / H_3 > 0.71$    | $V_k / H_3 < 0.65$    |
| $V_k > 0.71 H_3$      | $V_k < 0.65 H_3$      |

The absence of a common interval of change in volumes and specific volumes of injected acid shall be particularly noted. The results show that in pursuit of additional oil production it is possible to obtain a significant increase of the water cut.

### 3. Conclusion

The studies made it possible to conclude the following:

- geological and technological parameters, which have a prevailing influence on the process of treatment on the carbonate reservoir of the bottomhole formation zone, are identified;
- a set of algorithms is proposed, allowing selecting wells for bottomhole formation zone treatment, technological parameters of operations in different geological conditions;
- the limits of the most successful hydrochloric acid exposure are established to increase the profitability of development of carbonate oil deposits with hard-to-recover reserves.
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